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ECO-ARCHITECTURE III

Harmonisation Between Architecture and Nature

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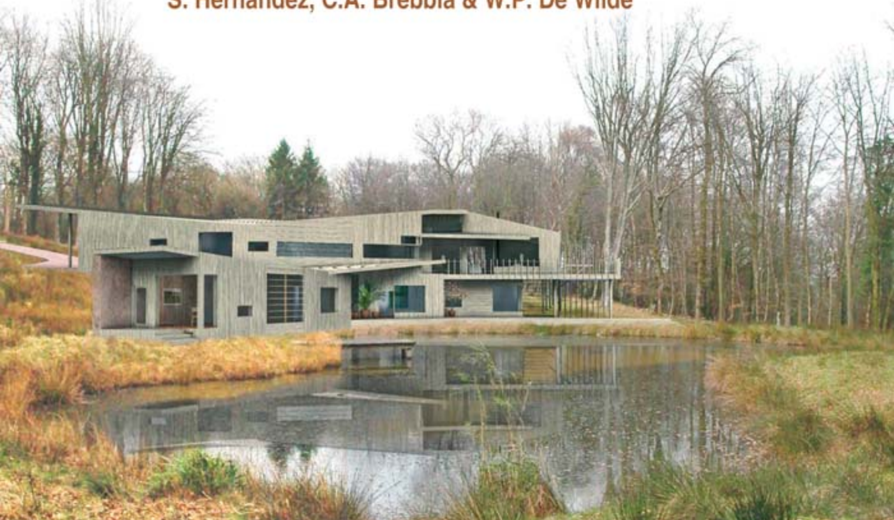
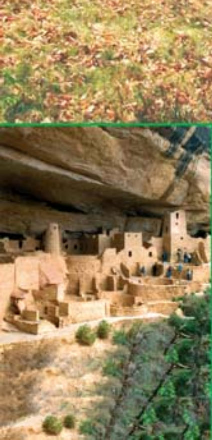
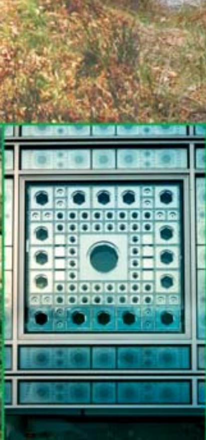
S. Hernández, C.A. Brebbia & W.P. De Wilde







Eco-Architecture III

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Eco-Architecture III

Harmonisation between Architecture and Nature

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Preface

This book contains most of the papers presented at the Eco-Architecture 2010 conference, which was the third edition of the International Conference on Harmonisation between Architecture and Nature. Previous editions were held in the New Forest, UK (2006) and the Algarve, Portugal (2008) and demonstrated the importance of a forum like this to discuss the characteristics and challenges of such architectural vision.

Eco-Architecture implies a new approach to the design process intended to harmonise its products with nature. This involves ideas such as minimum use of energy at each stage of the building process, taking into account the amount required during the extraction and transportation of materials, their fabrication, assembly, building erection, maintenance and eventual future recycling.

Another important issue is the adaptation of the architectural design to the natural environment, learning from nature and long time honoured samples of traditional constructions.

Presentations in the conference were related to topics like building technologies, design by passive systems, design with nature, ecological and cultural sensitivity, life cycle assessment, quantifying sustainability in architecture, resources and rehabilitation, and issues from education, research and practice. Case studies from different places around the world were also presented.

Eco-architecture is very multidisciplinary by definition, attracting, in addition to architects, many other professionals. In that regard the conference participants, in addition to architects, were engineers, planners, psychologist, sociologists and economists, providing an opportunity to share information and ideas with their colleagues from different regions around the world.

The Editors would like to express their gratitude to all authors for their contributions. They are also indebted to the members of the International Scientific Advisory Committee of Eco-Architecture 2010 who reviewed most of the manuscripts efficiently and timely, thus ensuring their quality.

The Editors
A Coruña, 2010

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Section 1
Design with nature

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Assessing a carbon neutral building approach

M. Bendewald & J. Brew
Rocky Mountain Institute (RMI), USA

Abstract

"*One of nature's most critical cycles is the continual exchange of carbon dioxide and oxygen among plants and animals. This "recycling service" is provided by nature free of charge. But today carbon dioxide is building up in the atmosphere, due in part to combustion of fossil fuels. In effect, the capacity of the natural system to recycle carbon dioxide has been exceeded, just as overfishing can exceed the capacity of a fishery to replenish stocks. But what is especially important to realize is that there is no known alternative to nature's carbon cycle service*". – Natural Capitalism (1999)

At Rocky Mountain Institute we have been developing ways to evaluate our built environment with regard to carrying capacity. Green Footstep™, a free online tool, is an outcome of these efforts.

The Green Footstep calculator is a building assessment tool using ecologically based assessment criteria. Most existing tools and assessment systems measure performance relative to a baseline case of "standard performance." Generally this equates to a code-compliant building and green performance is measured as a percentage reduction in a particular area, such as water or energy use. As a result, green buildings are rewarded for causing less environmental damage than typical buildings. However, these relative, rather than absolute, performance evaluations rarely make the connection to actual environmental impacts.

The Green Footstep tool brings forth building site ecology and ecological limits into the domain of building stakeholders and addresses the ecological challenges of our time.

Keywords: carbon, footprint, assessment tool, ecological limits, carrying capacity, building, design targets.

1 Measuring sustainability

One way to measure progress toward an absolute measure of sustainability is with the ecological concepts of carrying capacity and ecosystem services. Carrying capacity refers to the maximum population of humans or animals that an environment can support without damaging that environment. When a population exceeds carrying capacity, this over-exploitation of resources and excessive waste generation places stress on the various ecological systems and they slowly begin to collapse. This phenomenon is known as “overshoot.”

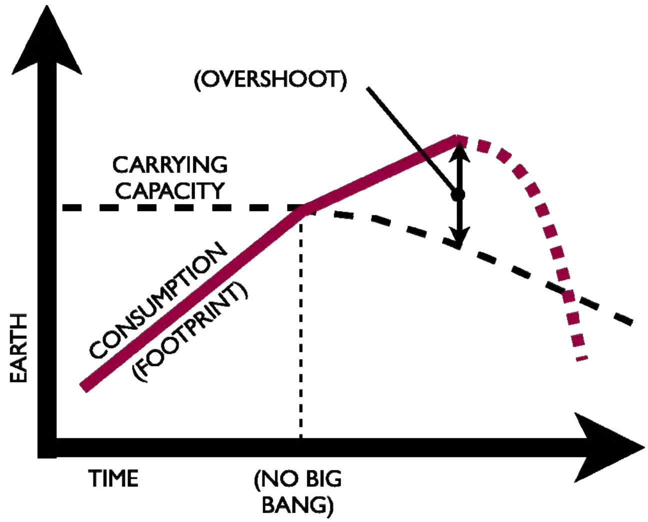

Figure 1: Concept of ecological “overshoot” Wackernagel and Rees [1].

Of particular concern with ecological overshoot of carrying capacity is the eventual decay of ecosystem services. These services can be seen as forming a life-support system, as they provide functions such as climate regulation, nutrient cycling, water purification, and food and fiber growth. Ecosystem services are immeasurably valuable and cannot be replaced. In 2005, the Ecosystem Millennium Assessment, formed by the United Nations, attempted to define ecosystem services in terms of human well-being. Figure 2 illustrates their results. Services ranging from the mundane (e.g., food growth) to the esoteric (e.g., spiritual services) each contribute to elements of well being, such as Security and Health.

In order to make an assessment of a building project with regard to carrying capacity, we need to determine the amount of ecosystem services we have to use. This estimate would provide us with a better sense of how we need to build our environment in order to live within the ecological limits of the earth.

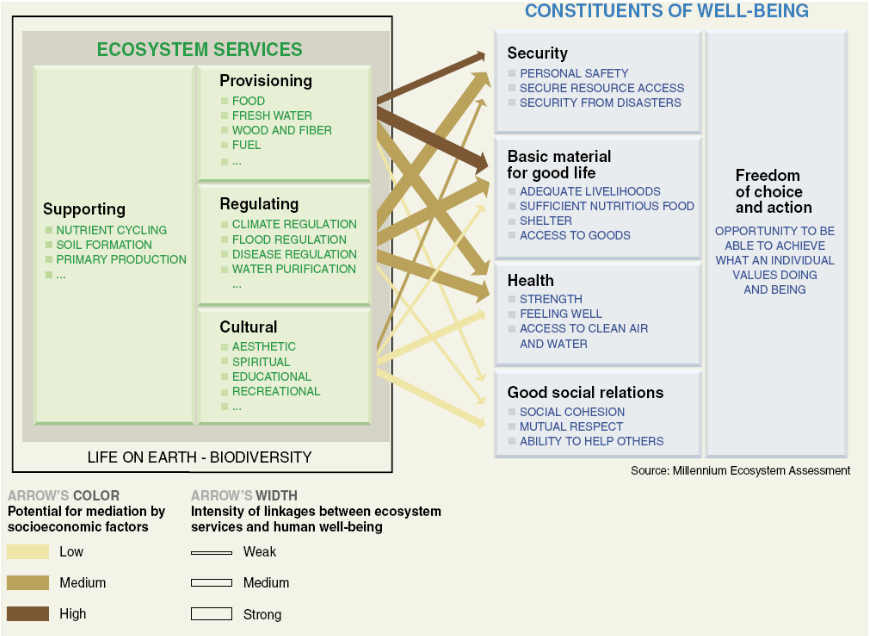

Figure 2: Millennium ecosystem assessment [2].

2 Carbon and buildings

While it can be difficult to assess ecosystems services, one of the most important is also relatively easy to measure: the global carbon cycle. Carbon is an abundant naturally occurring element. It can combine easily with other elements and is an integral part of the basic processes of life. Through the global carbon cycle, carbon is constantly moving between the atmosphere and the earth. There is a certain rate at which vegetative life, the ocean, and other carbon sinks remove (or sequester) carbon dioxide from the air. If this sequestration is at a lesser rate than global carbon dioxide emissions, carbon dioxide begins to accumulate in the atmosphere and creates the greenhouse effect. Since the Industrial Revolution we have been systematically adding carbon dioxide and other greenhouse gasses (GHG) into the atmosphere through the burning of fossil fuels, clearing of forests, and other activities. The increased level of GHG in the atmosphere is due to these excessive emissions, which is exceeding the ecological carrying capacity with regard to the service of carbon and other nutrient cycling. After three centuries of overshoot, we are now beginning to see the degradation of our ecosystem service of climate regulation, and the effects of global warming. These effects and potential effects have been revealed by a variety of researchers, including the Nobel Laureate Intergovernmental Panel on Climate Change (IPCC) formed by the United Nations. The IPCC has provided evidence that in order to avoid dangerous interference of the Earth’s climate, globally we need to decrease our greenhouse gas emissions by 50 percent by 2050 from 1990 levels. This would limit the global average surface temperature to a rise of no more than 2 degrees (Celsius) above pre-industrial levels, which corresponds to the highest temperature recorded from any earlier interglacial (warm) period in the Earth's history.

The IPCC recommendation is for all types of anthropogenic GHG emissions. It identifies all the major emissions sources, which can be organized into three main categories, Figure 3. Emissions from "agriculture and waste" are a by-product of synthetic nitrogen fertilizer application, gasses produced from animal stock digestive processes and others. "Biomass decay" emissions result from clearing forests for agriculture, decay of drained soils and other land use change, and other sources. Emissions from "fossil fuel use" result from burning coal, oil, and natural gas. All of these sources contribute to an imbalance in the global carbon cycle, such that more carbon is flowing into the atmosphere than to the earth.

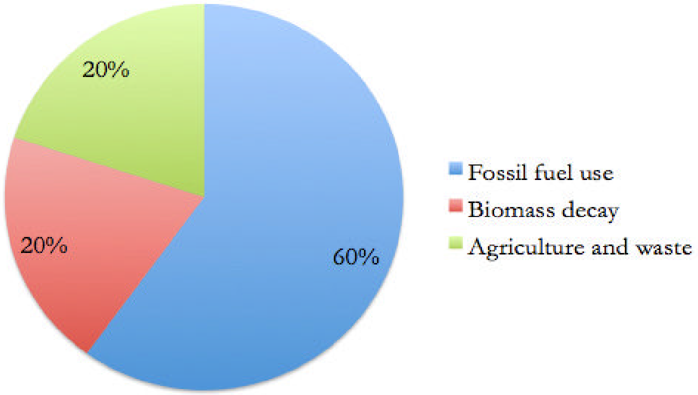

Figure 3: Current mix (rounded to nearest 10%) of global GHG emissions by source [3].

An imbalance in the carbon cycle can be quantified using the parts-per-million (ppm) metric. This metric describes the concentration of greenhouse gasses in the atmosphere. The IPCC recommendation for emissions reduction is meant to stabilize the concentration of GHGs at 450 ppm. The IPCC recommendation to reduce emissions 50 percent by 2050 provides a timeline for global emissions reduction. This recommendation has provided and continues to provide guidance for nations setting emissions reduction goals, however, when we envision a goal based on staying within the limits of carrying capacity, the ultimate reduction is likely greater. Such a goal would require us to completely eliminate anthropogenic GHG emissions. In effect, this would create a situation of net zero carbon flow from the earth to the atmosphere, thus returning balance to the global carbon cycle.

A societal goal of net zero carbon provides a unique opportunity for building sustainability assessment. It allows us to set a goal that is not relative to other buildings, unlike all existing carbon emissions goals, but to an estimate of sustainability itself. A building project with net zero carbon flow is what we call "Carbon Neutrality."

2.1 Calculating carbon neutrality

Calculating carbon neutrality involves an estimate of net carbon flow each year as a result of the construction of the new building, over the course of the building lifetime. We recognize that there are two ways that carbon flows on a net annual basis: either from the earth to the atmosphere, such as through the burning of ancient vegetation (i.e., fossil fuels), or vice versa, such as through the restoration of a forest. There are two major steps involved with calculating net annual carbon flow. The first is to draw a boundary of analysis around the building and estimate the emissions from the various sources. This boundary of analysis will likely not capture everything that should be captured, so we are underestimating our GHG emissions. With regard to the classifications of the GHG Protocol, the Green Footstep tool accounts for emissions classified as Scope 1 (direct emissions), Scope 2 (indirect emissions associated with purchased electricity, heat or steam), and Scope 3 (all other emissions, including embodied emissions). The specific emissions accounted for within each Scope category are explained below. The second major step has to do with offsetting emissions. Emissions can be offset with on-site renewable energy and investment in off-site carbon emissions reductions (or "off-site carbon investments"). More on offsetting emissions can be found in a subsequent section.

There are at least four major GHG emissions sources arising from building developments. The first is regarding the development of the site. The second is the embodied emissions from construction, retrofits, and demolition. The third is the operation of the building. The fourth aspect is the transportation to and from the building. The Green Footstep calculator currently accounts for, at least in part, the first three of these four aspects. We anticipate that subsequent versions of the calculator will account for the transportation aspect, which takes on a special dimension with developments such as Smart Garage and Plug-In Hybrid Electric Vehicles. These four aspects are described in successive sections.

2.2 Site development and net site carbon storage

Accounting for the carbon emissions as a result of development of the site requires comparing the native carbon storage of the site to the storage after the site is developed. Site development typically results in a net positive carbon flow from the earth to the atmosphere. This phenomenon is perhaps most well known in the context of forest depletion and other land use change. For instance, forests in Africa are becoming smaller due to increased consumption of wood for cooking. Carbon intensive rain forests in South America are being converted to less intensive farmland. Using the same method developed by the IPCC to account for this depletion in carbon storage, we can calculate the emissions associated with land development for buildings and urban sprawl [4].

In order to understand this concept of carbon storage, it is best that we reach out to the discipline of chemistry. The main idea is that each molecule in a plant contains a certain number of carbon (C) atoms. Carbon makes up roughly half the dry mass of vegetation. Ecologists have already gathered data to estimate the total weight of vegetation per hectare for different ecosystems. They have shown that the mass of vegetation ebbs and flows with each season in some ecosystems, with the greatest mass toward the end of the growing season, as you might expect. In the case of deciduous trees, for instance, significant loss of mass occurs with the loss of leaves for the winter season.

This mass returns during the spring and summer seasons, and the cycle continues. There is a concurrent cycle of dying and sprouting of trees and other plants. Over the course of several generations of trees and other vegetation, we know how much carbon is typically stored per acre of the ecosystem. If we think back to a time when there were no buildings, the native vegetation on those sites stored a certain amount of carbon. By simply removing that vegetation to make room for buildings and pavement, we are decreasing the ability of the earth to sequester and store carbon.

Studies of carbon storage specific to land types have already been gathered by the IPCC for a variety of forests and grassland. This data is preliminary and will likely be updated as more studies are made. For instance, current data only accounts for above ground biomass. In some ecosystems, up to 80 percent of total biomass is located below ground. Building professionals will need to reach out to the field of ecology to stay up to date as to the amount of carbon emitted due to site development.

2.3 Embodied emissions

In addition to accounting for the development of the site, we need to account for the so-called embodied carbon emissions as a result of the construction, retrofit and demolition of the building. (The Green Footstep tool currently does not account for the retrofit and demolition of the building.) About eight percent of all energy consumed in the U.S. falls into this category. Using a method known as Life Cycle Assessment (LCA) we can trace back all the energy used and the resulting carbon emissions from the extraction of raw materials, materials processing, assembly or demolition of materials on the construction site, and the transportation involved throughout this series of events. These emissions can be minimized by using recycled and salvaged materials, achieving the same design objectives using fewer materials, and purchasing local materials to reduce transportation.

For projects in the United States, emissions intensity for different space types was derived using an Economic Input Output LCA approach. Results from the Athena Institutes' EcoCalculator can be input to estimate an overall reduction from average. An explanation of this method can be found in a forthcoming study and is available from Rocky Mountain Institute upon request.

2.4 Operation emissions

The emissions as a result of building operation can be divided into two major areas. One is the provision of thermal comfort, indoor air quality and lighting. This area typically represents the greatest portion of carbon flow as a result of a building throughout its lifetime. The second area is the provision of fresh water, the handling of waste (including wastewater) generated by building occupants and refrigeration leak. While the second area is a significant source of emissions, the current version of Green Footstep does not estimate these for users. These emissions can be reduced through efficient water fixtures, on-site water treatment (such as the EcoMachine or Living Machine) use of low Global Warming Potential refrigeration fluid, and a recycling system and composting.

The emissions from area one, defined above, are measured for each type of energy required to provide those services. Whether the fuel is district steam, natural gas, electricity, or another, you can estimate the emissions using standard emissions coefficients available from the U.S. Environmental Protection Agency or other sources. Designers can minimize this source of emissions with a climate responsive building design that incorporates a variety of strategies for a very high level of energy efficiency. In RMI's experience, the best and most cost-effective way to handle this is, in the following order: define the end-use service first, not the amount of equipment required; reduce loads through passive design; use efficient systems and equipment to meet these loads; turn down or switch off equipment when not required (controls) and continuously monitor and verify performance.

It is important to acknowledge the fact that the rate of GHG emissions associated with use of electricity will likely decrease with time. The Green Footstep tool currently does not account for this decrease. A subsequent version of the tool will include this aspect.

2.5 Transportation emissions

The transportation of people to and from a building is influenced by a number of factors, including number of parking spaces and distance to mass transit stops. Perhaps the greatest effect a building designer can have on transportation is by providing a limited number of car parking spaces, bike racks, a shower room for those who bike, and plug-in stations for an emerging fleet of Plug-in Hybrid Electric Vehicles. The current version of Green Footstep does not account for this aspect of emissions. We expect to incorporate this into a future version.

3 Strategies to offset emissions

In addition to accounting for the emissions of a building project, including the effects of a an energy efficient design, the Green Footstep calculator reveals two main ways in which building stakeholders can offset these emissions. One is on-site renewable energy, which prevents the use of off-site energy that is typically and in large part, at least currently, fossil fuel based. The second is investment in off-site carbon emissions reductions, or off-site carbon investments.

3.1 On-site renewable energy

On-site renewable energy can take the form of electricity or thermal energy. Typically, photovoltaic panels and wind turbines are integrated into the building design to produce a portion or all of the electricity required by the building without sacrificing, and sometimes augmenting, the architecture. Solar thermal panels and geothermal heat pumps can provide thermal energy in a cost-effective, efficient way. There are a variety of building integrated renewable energy products on the market for any building size and type.

The Green Footstep calculator balances the would-be emissions of required energy with the “offset” emissions by the on-site renewable energy. The emissions coefficients for each incoming energy and on-site energy can be found on the “Operation” table of the calculator.

The emissions coefficient of on-site renewable electricity equals that of off-site electricity, such that if the building uses 30 MWh of electricity each year and produces the same amount of electricity, the net emissions is zero. Regarding thermal energy, the rate of emissions offset is equivalent to the emissions rate of the fuel it is replacing. For instance, if the auxiliary fuel for hot water heating is natural gas, the solar thermal application should offset the emissions required for this energy load at the same emissions intensity of natural gas. The user specifies this auxiliary fuel.

3.2 Off-site carbon investments

Off-site carbon investments can be organized into two categories: off-site renewable energy investments and carbon offsets.

Off-site renewable energy. There are a couple of ways of purchasing carbon-free electricity to meet a building’s needs. Individuals or organizations could buy renewable energy directly from their utility if available. Alternatively, stakeholders could buy Renewable Energy Credits, or RECs, which represent all of the environmental attributes of renewable generation. This means that the environmental benefits of purchasing RECs are equivalent to the environmental impacts of purchasing renewable energy directly. Purchasers can maximize the impact of their RECs by ensuring that they are supporting renewable energy that would not have been installed otherwise. You can accomplish this by purchasing certified RECs from states where electric utilities are already required to buy renewable power. RECs generated in such states are in addition to any renewables that would have been installed anyway for economic reasons or for regulatory compliance. One source of such RECs (and of additional information on RECs and offsets) is Village Green Energy.

Carbon offsets. A carbon offset is a real, verifiable, permanent reduction of GHG emissions that occurs above and beyond expected or required reductions. In recent years a carbon offset market has emerged internationally. Through the market, individuals and organizations can purchase credits that negate a portion or all of their GHG emissions. Types of carbon offset credits vary widely. Specifically, there are many different kinds of projects that can reduce carbon concentrations in the atmosphere. These could include projects promoting additional efficiency measures or use of renewables, or they could include capturing methane, or planting trees for instance. While individuals and organizations may have particular preferences about the type and location of the offsets they purchase, they should always select quality offsets. This means that offsets should be real –i.e., they are actual reductions in total GHGs emitted globally and are not, for instance, just displacement of emissions from one place to another. The offsets should also be clearly calculated, tracked and verified. They should be reductions that are guaranteed to be permanent. Finally, offsets should also represent reductions that occur in addition to what would have happened in the absence of the offset purchase – i.e. reductions were not implemented for regulatory reasons nor did they occur simply as a result of an economic downturn for instance.

There are some certifications and third parties that can help individuals and organizations identify quality offsets. One such resource is Environmental Defense's Carbon Offset List where the organization publishes projects they have pre-screened and approved.

3.3 Selecting offset strategies

The Green Footstep calculator does not make a blanket recommendation that one emissions offset strategy is better than another. On a case-by-case basis, developers and building owners should evaluate both on-site and off-site strategies within a financial model based on Life Cycle Cost Analysis (i.e., the evaluation of capital and operating costs to calculate net present value or internal rate of return of alternate sets of building design options). Other forms of value that should be considered but are more difficult to quantify include added building resale value, value of building energy autonomy, and value to community for investment in renewable energy.

4 Ecological accounting

The idea of a net zero carbon flow over the course of a building lifetime is analogous to financial planning. Owners of buildings own much more than just buildings. In a way they also "own" and should be responsible for the carbon that would have been stored on the site in its native, natural form. We can estimate this value using data from the IPCC. The Green Footstep calculator defines this value as the carrying capacity limit of the building site. In order to stay within carrying capacity, the cumulative emissions over the course of the building lifetime need to reach or exceed this carbon storage value.

Carbon storage can be considered a form of natural capital. When a building is first constructed, this capital is "spent" through site disturbance. Embodied emissions of construction also represent the spending of carbon storage capital. These emissions can be 5 times or more (typically much more) than the amount of carbon originally stored on site. Likewise, any carbon emissions during the course of building operation contribute to the “carbon debt.” After the lifetime of the building, these operation emissions can be 5-15 times that of the embodied emissions.

In this paradigm of building assessment, the operation of a building can either drive the building further into debt or, by reducing and offsetting carbon emissions, the debt can be paid back. As soon as the debt is repaid, the building development has reached carbon neutrality. Figure 4 below illustrates this concept, which we also call an “ecological mortgage.” The green (top, horizontal) dashed line represent the net site carbon storage in its native state. Below this line represents a net flow of GHGs into the atmosphere. Above the line represents a net flow from the atmosphere to the earth. The red (downward sloping, bottom) line represents standard performing buildings. They incur an initial debt from site development and building construction. Then they begin to operate and go into greater carbon debt. There are major retrofit projects that occur along the way as well (denoted in the chart), which contributes to the debt. The orange (horizontal, stepped) line is a net zero carbon emissions building during operation. However, as shown in the chart, it remains in carbon debt due

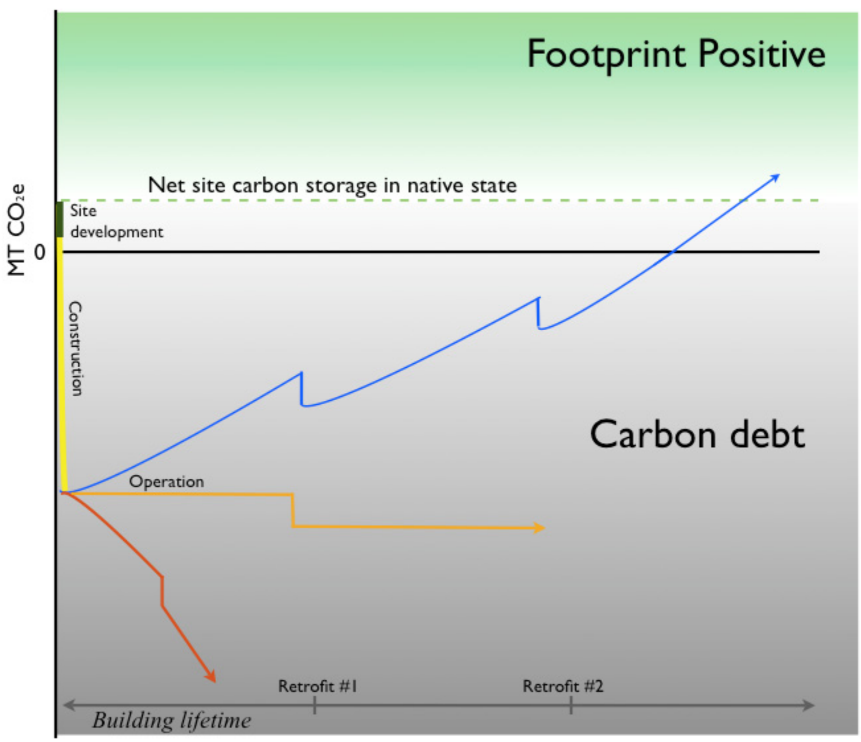

Figure 4: Illustration of ecological mortgage concept.

represents a building that, through energy efficiency and the offset of carbon, has surpassed carbon neutrality and is “Footprint Positive.” This is the ideal form of assessment for which we have designed Green Footstep. The current version of the tool does not account for the illustrated retrofits.

The “ecological mortgage” concept can be directly related to a global target of no more than 450 ppm of GHGs in the atmosphere. The cumulative emissions by the end of building lifetime – which is an output of the Green Footstep tool – is the amount by which the building has contributed to an increase in global GHG concentration. So, in effect, Figure 3 above can be restated in the following way “A typical building (red line) continually contributes to a higher global concentration of GHGs in the atmosphere. A regenerative building (blue line) reaches above the “Line of neutral contribution to global ppm” to contribute to the decrease of global GHG ppm.

Addressing the atmospheric carbon associated with buildings is critical to reducing the impacts of global climate change. The calculations associated with this issue are not complicated, but are typically not done. Green Footstep provides an accurate, comprehensive and easy to use tool that allows decisions to be made during the design process to encourage the development of high performance, very-low carbon designs. Broad use of tools such as Green Footstep may assist in the development of high performance buildings appropriate for an ecologically constrained world.

References

[1] Wackernagel, Mathis & Rees, William, *Our Ecological Footprint*, New Society Press, 1996

[2] Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Synthesis*, Island Press, Washington, DC, pp vi, 2005

[3] Barker T., I. Bashmakov, L. Bernstein, J. E. Bogner, P. R. Bosch, R. Dave, O. R. Davidson, B. S. Fisher, S. Gupta, K. Halsnaes, G.J. Heij, S. Kahn Ribeiro, S. Kobayashi, M. D. Levine, D. L. Martino, O. Masera, B. Metz, L. A. Meyer, G.-J. Nabuurs, A. Najam, N. Nakicenovic, H. -H. Rogner, J. Roy, J. Sathaye, R. Schock, P. Shukla, R. E. H. Sims, P. Smith, D. A. Tirpak, D. Urge-Vorsatz, D. Zhou, 2007: Technical Summary. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[4] Keith Paustian (USA), N.H. Ravindranath (India), and Andre van Amstel (Netherlands), Michael Gytarsky (Russian Federation), Werner A. Kurz (Canada), Stephen Ogle (USA), Gary Richards, (Australia), and Zoltan Somogyi (European Commission/Hungary), *2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use*, 2006

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Ambiguous boundaries: a Japanese way of designing with nature

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Abstract

Building and nature are two elements that traditional Japanese architecture regards as one. The effects of a building on the surrounding environment, its orientation, and the integration of nature creates a space of ambiguity, a space in constant harmony, as well as a space that can fully adapt to changing environments. After retiring, Kobori Enshu, a Japanese tea master, designed his personal residence in 1643, in which he created the Bosen tea room. For this space he created a unique type of hanging paper screen, able to adapt to different uses and conditions around the year. Through this study, the important characteristics of such a screen have been analyzed. Although the main use of this screen is as a shading device, it can become an entrance, a picture frame for the exterior, control exterior views, and be a source of ambient illumination. Such a screen is able to create a direct link between exterior and interior, harmonizing both areas. The paper also highlights the strengths and possible applications of such a screen in contemporary architecture, especially in cities where the lack of space has resulted in windows with no views. The application in the Japanese housing market will also be studied, showing current trends and the evolution of the screen into contemporary architecture. Finally, improvements to current screens will be discussed, in order to make them more adaptable to changing urban space.
Keywords: Japanese traditional architecture, shading devices, building and nature, paper screen, urban space.

1 Introduction

Through my research I have been able to visit over one hundred traditional temples, shrines, tea houses, and farm houses in Japan. From this, I have been

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able to study different aspects of traditional Japanese design, one of which is the creation of views. In each space, especial attention is given to the placement of openings, and more important the creation of boundaries. These boundaries are able to capture views and framed them like a painting on the wall. During a period of five years of visiting traditional spaces, it became clear that many of the spaces repeat the same process on framing views. It was not until visiting Koho-an Temple that a found a unique way of adding boundaries to a scene. This time it was not just a frame, but a paper screen with multiple uses. In order to further understand Japanese traditional architecture, one important point to keep in mind is the importance given to interior and exterior space. Both are seen as one, an ambiguous space created by blurred boundaries. The application of such a paper screen would be especially beneficial in areas where space is limited. In Tokyo the lack of space is a big factor, resulting in most windows facing nowhere. In this case the understanding and creation of boundaries would improve the creation of urban spaces. In contemporary Japanese architecture paper screens have continue to evolved, in some cases still keeping the essence of the original, and are still greatly used in the housing industry.

2 Koho-an Temple and the Bosen tea room

In 1643, Kobori Enshu, a Japanese tea master designed his personal residence, eventually becoming Koho-an Temple after his death in 1647, Kanji [1]. Here he was able to apply all his personal design ideas and experience, resulting in the Bosen tea room, fig. 2. Before retiring he was in charge of constructing castles, gardens, and other building, many of which still remain, Naoko and Mari [2]. While growing up, Enshu lived near Lake Biwa, the largest fresh water lake in Japan, so upon retiring he decided to bring the memory of his childhood to the Bosen tea room. The name Bosen is made up of two Japanese characters, first, Bo, meaning to forget, and second, sen, which refers to a fishing rod. When put together the meaning can change depending on the person, a belief rooted in zen philosophy, where every person may interpret things in their own way. So one translation of Bosen can be, once you catch a fish you will forget about the tool you used to catch it. This referring to the point that one should forget about the possessions of the world and focus on life. If seen this way, the name Bosen fits the tea room perfectly, which is meant to relate to Lake Biwa. But this name is open to interpretation, it has also been translated as "*Forgetting about the Net*", meaning, "*When the fish is caught one needs no net*", Gisei and Kinzo [3]. Although the name Bosen refers to the tea room, in reality it is meant to describe the paper screen. As a whole, the design and layout of the tea room is quite common, only the design and position of the paper screen is unique. This screen is the main element which makes it possible to view the tea room in relation to Lake Biwa. Finally in order to fully enjoy the view, Enshu gave himself the best seat in the space, positioned at the back of the room. From this point, the view towards the garden in fully appreciated. As a whole, one important theme in the design of the tea room is the idea of being near water. For this reason the space can be described as a tea room floating on a lake. In order to enhance this experience Kobori Enshu incorporated many hints relating to water in the design of the space. First, from his seating position, which is the area where the tea master prepares tea, he is able to view a small wooden railing near the screen, as a reminder of being on a boat, fig. 1. Second, the design of the garden is meant to represent different views of Lake Biwa, depending on the location of the person. Next, the garden is organized so that one can see vast open areas of plain dirt, surrounded by islands of moss, the dirt representing water. Finally, and most important, is the creation of water ripples on the ceiling of the tea room. By precisely positioning a wash basin in front of the tea room, at certain times of the year water is reflected from the wash basin into the tea room, giving the impression of being near water. Although not many people have seen this, since the temple is highly guarded, and visits are very rare. While talking to the temple monk and other researchers, they mentioned that they have seen water ripples on the tea rooms ceiling during summer, Kanji [4]. I order to confirm what they told me, I created a detailed 3d model of the tea room, making it possible to simulate any time and season. With this, I was able confirm that the only time water ripples can be seen on the ceiling is during summer, when the sun is positioned perpendicular to the tea room, fig. 1. During other seasons, water ripples are also visible, but are limited to the area in front of the tea room, never making it to the interior ceiling.

2.1 A unique shading device with multiple functions

Aside from its main use as a shading device, the paper screen has several functions in the space. These ranging from an entrance, as a picture frame for

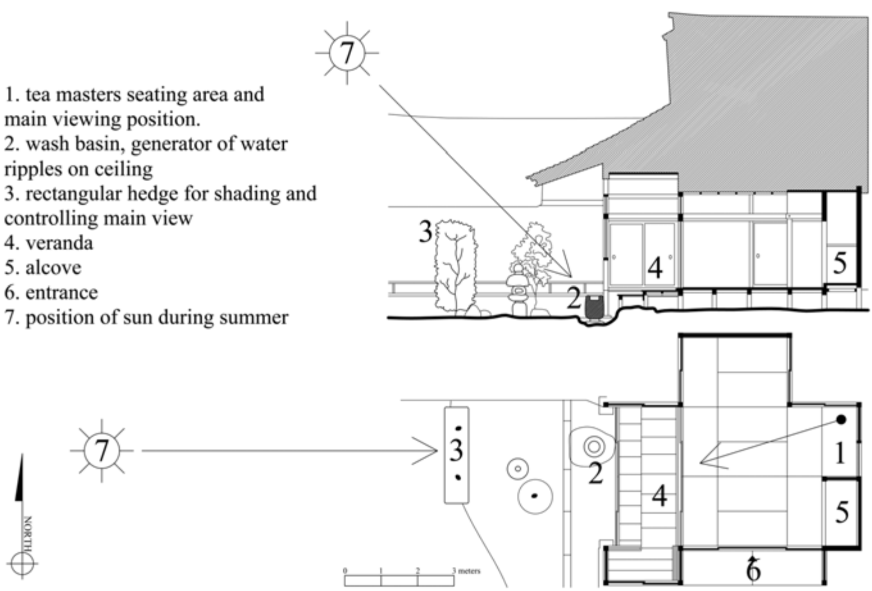

Figure 1: Plan and section of the Bosen tea room.

the garden, controlling exterior views, and providing ambient illumination to the tea room.

2.1.1 Paper screen as a shading device

Due to the west orientation of the Bosen tea room, direct sunlight becomes a constant factor in the interior space. During any season sunlight will reach the deepest areas of the space, fig. 2. Also, during the evening hours, sunlight may cover as much as half of the floor space with direct light. Although the paper screen works as a shading device, it does not completely provide shade, but instead it filters sunlight into a more diluted light. The screen also works best when combined with other layers of shading, during summer for instance, a bamboo screen will be added in front of the paper screen, providing a second layer of shade. If the interior paper sliding doors are closed, it would yet again provide another layer, further diluting the light. But still, light only continues to be filtered and redistribute to all parts of the space. Traditional Japanese spaces are meant to be places of mystery, where special attention is given to the play of light and shadow, spaces of ambiguity where boundaries are lost. If direct light is allowed to pierce the tea room, it will create strong divisions between dark and light, but if light is filtered, the space can become one.

Figure 2: Simulation of the Bosen tea room through an 8mm fisheye lens.

2.1.2 Paper screen as an entrance

Depending on the use of the tea room, the entrance might change from one through the temple or one through the garden. For the residents of Koho-an temple as well as the tea master, most of the time they will enter through a set of paper sliding doors on the side of the tea room, fig 1. But in the case of tea ceremony, guests will enter through the garden. This entrance known as *nijiriguchi*, which literally mean to crawl in Japanese, is represented by the paper screen. Normally this type of entrance has a height of 65 centimetres and a width of 60 centimetres, forcing every person to crawl as they enter. Also, upon entering the space every person will have the same status, in the case of samurai, the size of the entrance will forced them to remove their swords, relinquishing their position while in the tea room. In the Bosen room, the paper screen becomes the entrance, even though the width has changed to four meters, the height has remained the same, fig. 3.

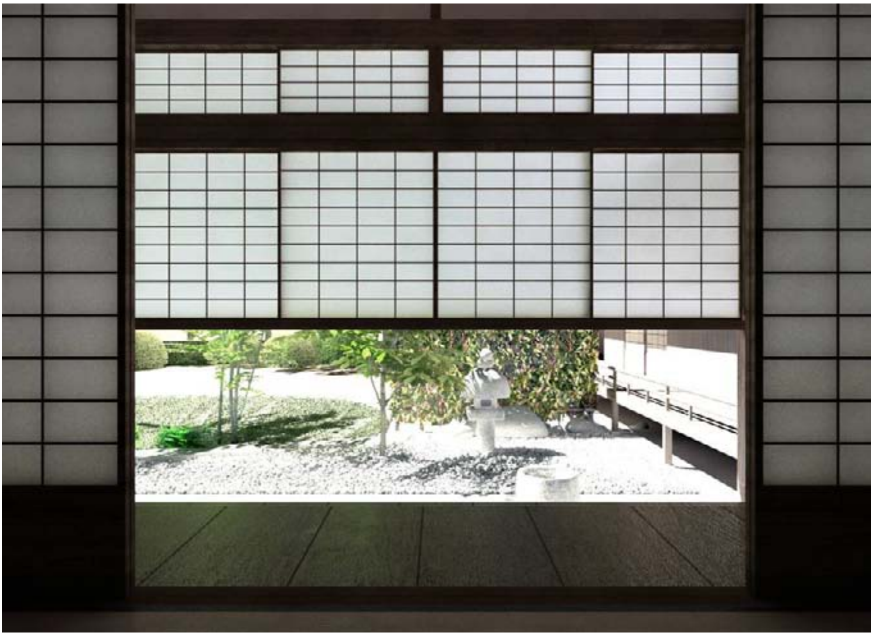

Figure 3: Simulation of the garden view through the paper screen shading.

2.1.3 Paper screen as a picture frame

In traditional Japanese architecture the idea of framing a landscape as a painting is very important, especially in tea houses, where one can drink tea while enjoying the scenery. By adding boundaries to the garden the tea master can capture a perfect natural painting, constantly changing during the year. The frame also helps to reinforce the connection between interior and exterior by establishing a direct link to the outside.

2.1.4 Paper screen as generator of space

While the placement of the paper screen creates a framed view of the garden, it also makes the view incomplete. In Zen philosophy the idea of leaving things incomplete is very important, by doing this each person can fill in the gaps in his mind, making the space more personal, Kobori [5]. In the Bosen room, the screen obscures the actual size of the exterior, while at the same time hiding any hints of the surrounding scenery. Aside from this, a large rectangular hedge outside the veranda further obscures more of the scenery. What is left is a controlled view of the garden, starting from the tea masters seating area the eye moves through the room, first focusing on a small railing next to the veranda, giving the first clue of being on a boat. Next, the eye moves to the garden, which is made up of various islands of moss, surrounded by a sea of red dirt. Last, the idea of being on a lake is given by the water ripples created by the wash basin. Finally, the area obscured by the paper screen becomes a blank sheet of paper, left to each person to combine the hints and generate a view of what might lie behind the screen.

2.1.5 Paper screen as ambient illumination

Another important feature of the paper screen is that it serves to enhance the light conditions of the tea room. Due to the large area of paper, as light passes through the screen it transforms the paper into a natural lamp, distributing ambient illumination to the entire space. During the summer months when direct light is very strong, the screen works as a shading device. But, in winter, the screen becomes a source of illumination, as it collects exterior light.

3 A building designed for summer

In the 14th century Japanese writer Kenko Yoshida once said "*when you build a house*, *build it for summer*", expressing the main characteristics of Japanese a house, Quotidiana [6]. Among the four seasons in Japan, summer is one of the most extreme ones, for this reasons traditional houses are build to escape the heat and humidity of summer. In Japanese, paper screens are known as shoji, which refers to a partition able to divide a space, JAANUS [7]. The variety of papers screens is also immense, ranging from different shapes, sizes, materials, designs, as well as placement on the wall. On its own a paper screen in only a piece of paper glued to a wood frame, offering little protection from heat or cold, in order to be effective it needs to work with other components in the space. In summer, the exterior and inner screens can be removed, allowing air to cross the building. Air circulation is then enhanced by the flexibility of moveable screens, which provide control of air flow. Furthermore, the air flow entering the building is then cooled by the garden, through the evaporation of moisture in the vegetation. The building is also raised off the ground, allowing more air to travel under the floor. As the interior floor is made of tightly woven straw, it allows air to travel through it, dispersing heat to the outside. Finally, the building is designed with deep eaves to block the intense sunlight of summer.

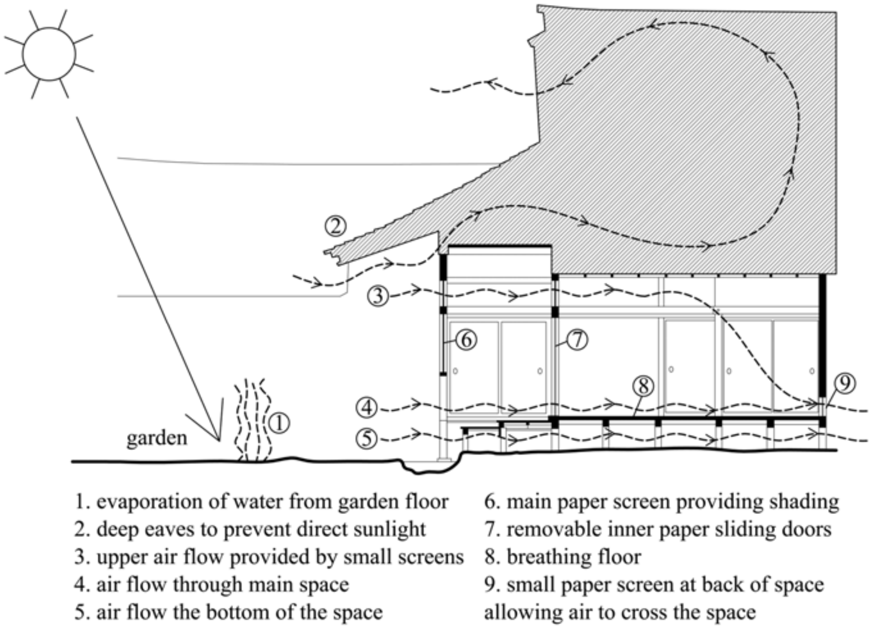

Figure 4: Air flow and components used to cool the building during summer.

4 Development of shading devices in contemporary Japanese housing market

Even with the Western and European influence on the Japanese housing market, all manufacturers still provide traditional style homes, fig. 5. Although some houses are being designed completely in a contemporary Japanese style, in most cases only one room will have a traditional influence. These spaces are usually limited to living rooms, tea rooms and bedrooms, but most of the time it will be a tea room, this being the space with the deepest traditional values to Japanese people. While researching traditional spaces, I also visited many housing manufacturers in Japan, each time looking at the influence of traditional design in their spaces. Overall, a general pattern can be seen in the style of screens used, a style similar to the Bosen tea room. Due to the close proximity of new constructions, exterior views are limited, making it important to focus on small gardens near the windows. For this reason, the traditional ideas of obscuring the top view and opening the bottom has become very practical. Paper also continues to be widely used in new construction, especially in screens located in the interior of the home; the paper also adds another value of tradition with its texture. In the case of screens near the exterior, they no longer offer the main protection from the environment; instead relying on the protection provided by double and triple glazed glass doors and windows. But still, the applications remain useful in contemporary architecture by enhancing the insulation qualities of existing doors and windows in the home through layering, fig. 6.

Figure 5: Contemporary screens in Japanese housing market.

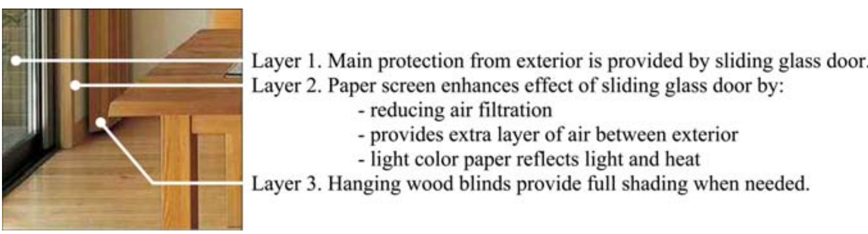

Figure 6: Application of paper screens in Japanese housing market, [10].

4.1 Improved energy consumption through reflective shading

Although the design and original applications of paper screens have changed, the way in which they work continues to be the same. One paper screen will provide little protection, but in layers its efficiency improves. The paper material has also been improved, or replaced by cloth, opaque glass, or even polycarbonate, providing better insulation and reflective qualities while maintaining a traditional feel. Some screen manufacturers like the Japanese company Akagi, have also introduced a lace screen as an alternative for typical paper screens, providing increase visibility from the interior, while still maintaining privacy if viewed from the outside, Akagi [8]. Since most of the housing market in Japan is dedicated to building Westernized homes, the application of traditional screens is similar to blinds, varying in colour, material, and size, depending on personal taste. A recent study in Canada by the Institute for Research in Construction, recently found that the used of reflective shades can greatly improve energy consumption of a house. For their experiment they compare two identical homes in summer, one with reflective shading and another with typical Venetian blinds. During a period of three weeks the electric energy for cooling was measured, upon completion their results showed that the daily energy consumption by air conditioning and fan units in the house with reflective shades went down an average of 13%. During sunny days the use of reflective shades also reduced the hourly electricity demand by up to 45%. Furthermore they concluded that during a 21 day period, between 11am to 5pm, there was a 19% reduction in energy consumption, reducing the strain on air conditioning units, and most important reducing the price of electricity for the end-user, Galasiu et al. [9]. By using a similar material as the reflective screen, Japanese manufactures are able to maintain the feel of a traditional screen, while providing extra visibility and illumination to the space, all while improving energy efficiency.

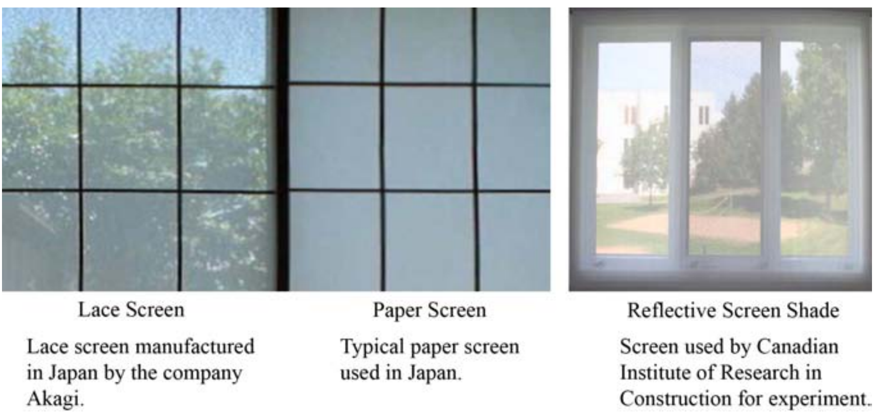

Figure 7: Comparison of Japanese screens to reflective screen shade used in energy performance experiment, [8, 9].

5 A Japanese screen for urban space

As seen by the Japanese housing market, a tendency exists to use screens which focus attention to the ground. Unlike the Bosen tea room, which has a fixed screen, providing no protection from the environment, other traditional screens have similar characteristics while providing more protection. A combination of these two would go further in improving the adaptability and applications of traditional screens for urban space. One such screen is known in Japanese as *Yukimi Shoji*, Yukimi meaning to view snow, and Shoji, a sort of partition, meaning a screen for viewing snow. Even though the name refers to snow, it can be used to enjoy any season, autumn leaves, rain droplets, or the green of summer. The design of this screen is basically a sliding door, but the bottom area can slide vertically to reveal a view or provide ventilation.

In looking at the traditional use of paper screens in Japan, such devices are mostly limited to small rooms. If the screen was to be used in a large area, the

Figure 8: General design of a snow viewing paper screen.

effect would disappear, light would vanish in the space, the view would become lost and the connection between interior and exterior would be lost. A person needs to be close to the screen to fully appreciate the limits of the space, and to feel part of it. This being said, the influence of traditional screens would be beneficial on the creation of new screens better suited for small urban spaces.

5.1 Obscuring unwanted urban views

The general design of a snow viewing screen is already widely used in contemporary Japanese architecture. However, generally it is only used to bring attention to the ground. So if we create a screen able to adapt to a changing environment, given us the freedom to select views, it would have a greater use in urban space. Urban space is full of unwanted views, blank walls, parking lots, mechanical equipment, but in some cases natural views exists among these obstructions. This is when the freedom to control a view would become important. A snow viewing screen is already able to work as a sliding door and window, so by changing the top to also work as a window, it would increase the filtering capabilities of the screen. Depending on the exterior, the screen could adapt to improve the view, or to provide a changing view depending on the season.

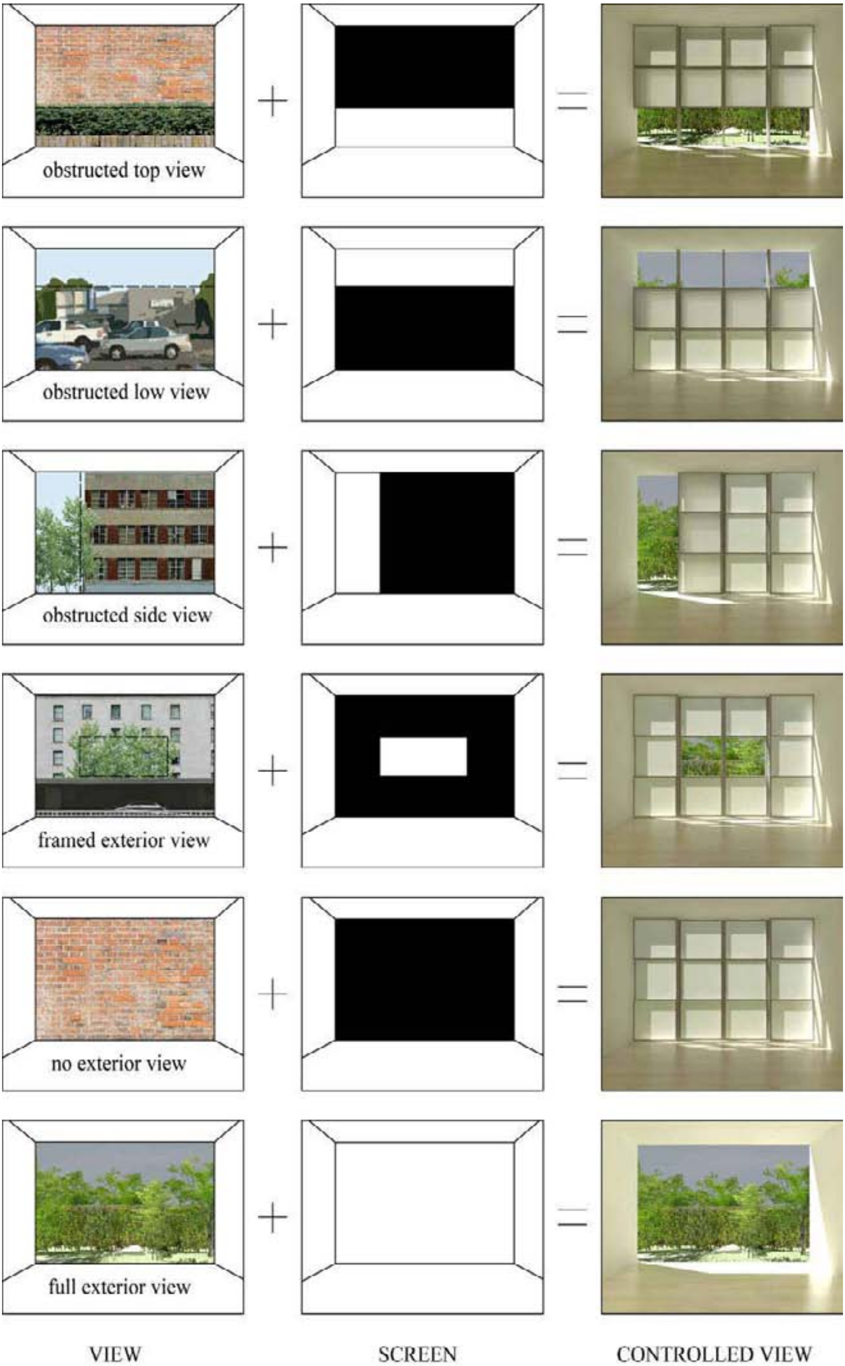

Figure 9: Flexibility of a contemporary Japanese screen in urban space.

6 Conclusion

As a result of researching hundreds of traditional Japanese spaces, it made it possible to study different shading devices, and so, finding one with beneficial applications to urban living. In all aspects of Japanese architecture, paper screens are deeply rooted in the creation of space, given freedom to the creation of views, as well as enhancing the connection between interior and exterior. Although the design and types of paper screens is extensive, most of them share similar characteristics, which are to improve air circulation, provide natural illumination, and flexibility in the creation of interior space. But, among all the different styles, this research made it possible to determine a unique shading screen at the Bosen tea room of Koho-an Temple. The characteristics of such a screen have proven helpful in controlling views where none exists, and so becoming a popular screen style in the Japanese housing market. The lack of space in cities like Tokyo has also added to the popularity of it, in enhancing green areas which are very small due to expensive land prices. A step forward would be to improve the flexibility of the design, making the screen more useful in urban space. By creating a system of panels which can move from side to side or up and down, it would improve the control of unwanted views, while still maintaining the essence of traditional design. Overall, providing an opportunity to escape the hectic life of the city and at the same time creating a space based on tranquillity.

References

[1] Kanji, N., *Kobori Enshu: A Tea Master's Harmonic Brilliance,* Kyoto Tsushinsha Press: Kyoto, pp. 54-65, 2009.

[2] Naoko, O., Mari, M., Discovering the Beauty of Traditional Kyoto. *Casa Brutus,* Takefumi Ishiwatari: Tokyo, pp. 66, 67, 2007.

[3] Gisei, T., Kinzo, H., *Invitation to Japanese Gardens,* Mitsumura Suiko Shoin: Kyoto, pp. 60-63, 1960

[4] Kanji, N., Personal communication, 24 November 2009, President of Nomura Landscape Laboratory, Nagoya, Japan.

[5] Kobori, T., Personal communication, 27 November 2008, Head Monk of Koho-an Temple, Kyoto, Japan.

[6] Quotidiana, Yoshida Kenko Selections, www.essays.quotidiana.org/kenko/selections

[7] JAANUS, www.aisf.or.jp/~jaanus/

[8] Akagi, www.lacesyoji.co.jp

[9] Galasiu, A.D., Laouadi, A., Armstrong, M., Swinton, M.C. & Szadkowski, F., Field summer performance of interior reflective screen. *The 11th International Building Performance Simulation Association (IBPSA),* Scotland, pp.1-10, 2009

[10] Sekisui House, www.sekisuihouse.co.jp

Homeostasis and perpetual change

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Abstract

Historically, we have built to overpower nature with minimal concern for environmental impact. The Solar Energy Efficient Dwelling: SEEDpod prototype is intended to respond to and advantageously interact with the forces of nature and the unique characteristics of each project site. These include the **sun** – utilized to create electricity, heat water/air and provide day lighting; **water** – harvested for domestic needs and irrigation of edible plants and landscaping; and **air** – used for ventilation and maintaining a healthy environment. The SEEDpod provides a tool for engagement with specific microclimates and the natural environment of its location.

The arid Sonoran Desert, with limited vegetation, water resources and cloud cover has a climate characterized by a year round average diurnal temperature swing of 26°F. This variable condition enables the SEEDpod to employ an environmental control strategy in which the building envelope and surrounding vegetation form a "selective filter" that dynamically interacts with the surroundings.

Establishing a homeostatic relationship becomes the premise upon which we can begin to improve the design quality, efficiency and environmental responsiveness of residential construction. Balance is achieved in this energy efficient solar prototype by dynamically interacting with energy inputs and outputs in service of climatic stability. Air exchange, humidity and thermal control, interior and exterior lighting conditions and natural resource management are integral components that are continuously engaged in order to achieve a healthy, energy-efficient, and sustainably-built environment.
Keywords: ecological architecture, regional adaptation, performance based design, desert architecture, energy efficiency, materials research, thermal mass.

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1 Introduction

The challenge for the SEEDpod and the focus of this research is to provide an effective architecture/engineering solution to rising energy costs that balances passive and active building systems. A remedial engagement with the local environment provides further direction and clear inspiration for our performance-based design process. The resulting architecture sensibly integrates anticipatory strategies and multi-disciplinary design principles in order to provide a high quality of life for the inhabitants.

Figure 1: SEEDpod water wall and photovoltaic array [2].

"A thing is right..." Aldo Leopold wrote in his Sand County Almanac, "when it tends to preserve the beauty, integrity and stability" of the biotic community. Bio-cultural stability in the context of the built environment can be both dynamic and sustainable. Leopold then described the condition of homeostasis, as the maintained equilibrium in environments of perpetual change. This balanced condition is the premise that inspired our prototype dwelling and provided direction to the design and development process as we uncovered our solution for an efficient solar powered environmentally responsive dwelling [1].

2 Methodology

Research, testing and construction for the SEEDpod prototype desert dwelling was initiated and completed at the University of Arizona: College of Architecture and Landscape Architecture (CALA). During the two-year span of this project, the team integrated the expertise of numerous collaborators from Agriculture, Materials Science Engineering, Civil Engineering, Eller College of Management, Electrical and Computer Engineering, Optical Science, and Mechanical Engineering. Structural and systems engineering consulting was provided by Buro Happold: Los Angeles.

Four design studios including both graduate and undergraduate students in the School of Architecture were dedicated to research/analysis, project development, prototyping, and detailing. Construction took place in our materials laboratory over a period of twelve weeks, utilizing the assistance of master craftsman for direction, but completed almost entirely by students. The process began with an analysis of natural systems and adaptation strategies of both flora and fauna within the Sonoran Desert environment. Simple kinetic models were constructed based on this initial research, and a more complex building program/strategy began to take form in the subsequent studios.

Several building components were earmarked for their clear potential as interdisciplinary research projects. The structural system, thermal storage water wall, and self-regulating shade system became the design problems that were rigorously prototyped in our materials laboratory and became integral components of the final composition. Each of these components has applicability beyond the SEEDpod prototype, and the student design teams are in the technology transfer and patent review process. Comprehensive site testing is the next step in our evaluation sequence.

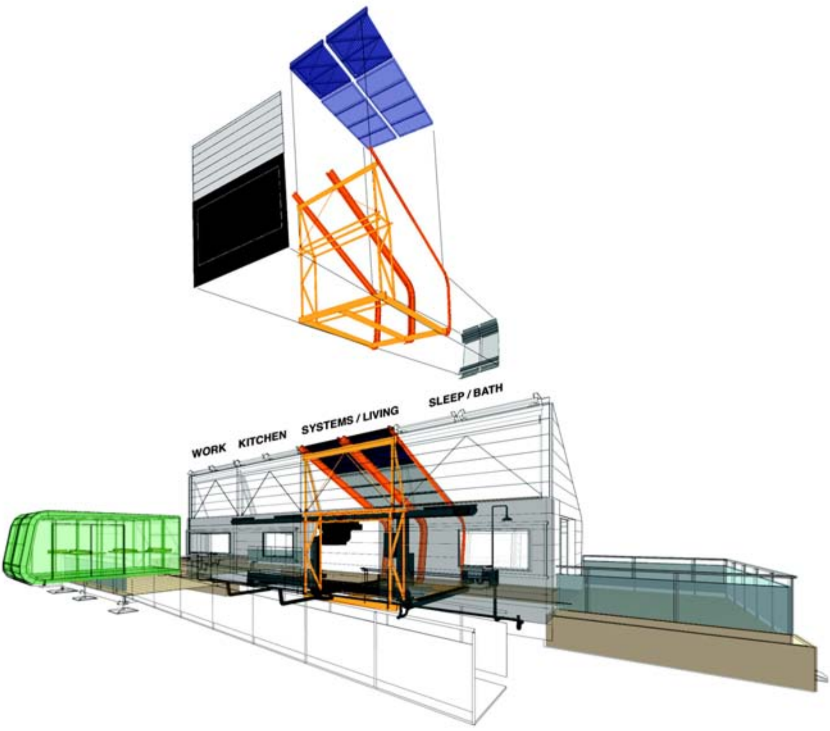

Figure 2: Exploded perspective illustration [3].

3 Components

3.1 Core/adaptable space

The SEEDpod consists of four modules with identical structural rib frames. Each module contains a utility core that provides the essential living components: kitchen, bathroom, workspace and systems (mechanical and electrical). The resultant continuous core frees the remaining floor plan for adaptable and flexible living space.

The essential living unit is composed of four modules with 800 square feet of interior space and an adjacent greenhouse. This one bedroom option contains a work area, kitchen/dining facilities, a systems module with associated living area, and a bathroom core with adjacent sleeping space. The modules are assembled end to end and the resultant continuous utility core amply serves the adjacent flexible, open-plan living space. Unit assembly proceeds along a logical path:

1. After the foundation rail system is installed and levelled. The first prefabricated module, with roof assembly in the compact shipping position, is hoisted into place and aligned on the rails
2. Module 2 is placed on the rails and the roof of module 1 is pivoted into position and fixed at the correct solar angle by securing the north clerestory frame to the top of the core module.
3. The sequence is repeated with the placement of modules 3 and 4.
4. After the roof is secured at module 4, the final foundation rails are installed and covered with the west and east exterior porous decking system.
5. The on-site installation of SEEDpod is completed by the addition of entry ramps, guardrails, landscape materials, water-harvesting elements, and the greenhouse.

The interior face of the core is wrapped continuously with a dense, waterproof composite material (Richlite) made of recyclable paper fibres from FSC-certified sources treated with resin, and pressed into rigid sheets. The exterior core and wall panels are clad with a zinc rain screen, which offers protection from the elements and an opportunity for cooling via air movement in the gap between the water-proofing membrane and the exterior cladding. The zinc material was chosen for its abundance, recyclability, and lasting performance qualities. Zinc is a highly malleable material allowing for the custom fabrication of the skin system in our materials laboratory.

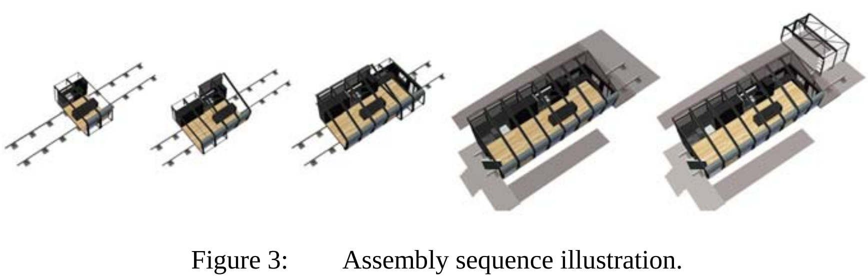

Figure 3: Assembly sequence illustration.

3.2 Systems

The exterior envelope is designed as a “selective filter” that can be operated to advantageously interact with the incident forces of nature and its climatic context. The majority of the optimally sloped (depending on location) south-facing roof is covered with a 9kW bifacial photovoltaic solar array that produces ample electricity for the entire dwelling.

The south-facing roof array produces grid tied electricity for dwelling functions and powers the entire environmental control system. The bifacial array allows the underside of each panel to absorb reflected light in the plenum space above the building’s white waterproofing membrane, significantly increasing electrical generation. Potential for ventilation and exhaust of hot air through the roof plenum will increase the collection efficiency of the photovoltaic panels. Additionally, above the core, a portion of the roof is dedicated to a highly efficient evacuated cylinder hot water assembly.

The building systems are designed in response to varying seasonal conditions and large diurnal temperature swings that exist in hot arid environments such as the Sonoran Desert. The mechanical systems of the SEEDpod incorporate a set of active and passive systems. The primary passive system utilizes “Stack Effect Ventilation.” Cool air is supplied at the base, near the pivot point of the house, and as the air warms it is allowed to flow out the peak of the clearstory through a set of operable windows.

The active heating and cooling strategy involves a series of ductless heat pump and air conditioning units. This compact system includes a condensing unit and three heat pumps. During the cooling cycle, the exterior condensing unit

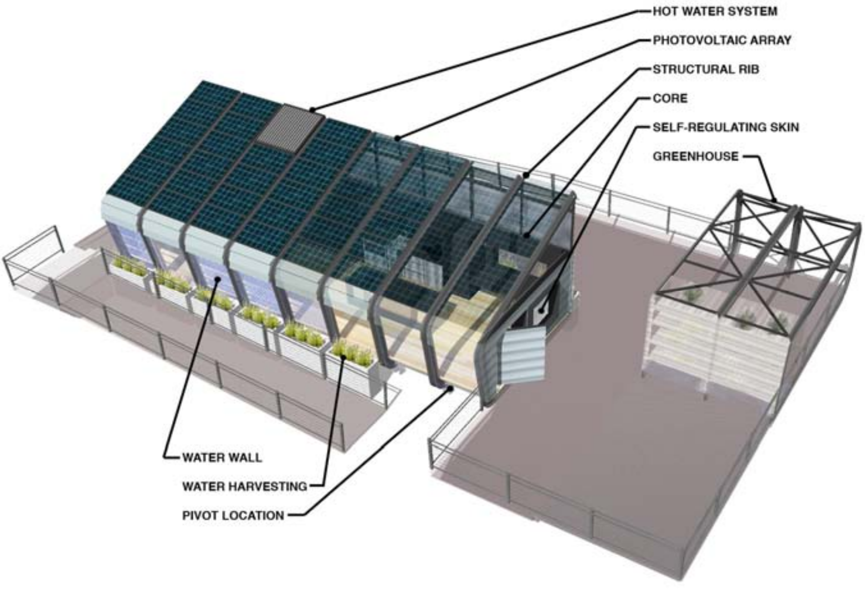

Figure 4: Systems illustration.

cools refrigerant and delivers it to fans incorporated in the indoor heat pumps. The heat pumps then supply cool air to the house. When heating is required the system works in reverse.

In Tucson, Arizona and other hot arid locations with low humidity and high diurnal temperature swings, the system can be frequently operated in a "vent only" mode or in off-position with full utilization of natural ventilation. Several control conditions were modelled by Buro Happold Consulting Engineers and will provide baseline information for on-site testing in the next phase of project development.

Summer - Day:
During daylight hours in a hot arid climate, the interior can be cooled by evaporation using low energy fans. Air is evacuated through the roof plenum reducing the cooling load on the space below and resultant air turbulence cools the solar panels above. Additionally, cool water introduced into the water wall tanks will absorb heat and reduce the cooling load.

Summer - Night:
During low humidity nights, cooling can be provided solely by cross ventilation entering through the lower opening in the southern wall. This can be supplemented with mechanical systems during extreme heat or high humidity.

Winter - Day:
During winter days, air warmed by the roof plenum can be drawn into the interiors during the day. Water wall collects and stores heat from the sun.

Winter - Night:
During the night, the heat collected in the south wall will be allowed to radiate into the space in order to supplement heating supplied by the mechanical system.

3.3 Structural rib system

Close collaboration with Buro Happold: Los Angeles allowed the team to benefit from digital form finding operations and optimization in the fabrication process. SEEDpod's structural system is made by laser cutting high-recycled content sheet steel, which is bent and folded to create a multifunctional form [4]. The deep structural profile allows for air movement in a plenum space that maximizes the efficiency of the photovoltaic array by cooling the underside of the panels, attached directly to the structure. The "V" shaped profile of the ribs facilitates drainage for water harvesting and expedites module-to-module connectivity.

The bent sheet steel structural ribs employ a system of tabbing for quality control purposes during the forming process. A series of strategic folds transforms a flat sheet of steel into a structurally optimized series of cantilevered ribs. These ribs are constructed with an integrated hinge located at the bottom of the southern wall. The resultant pivot action allows the team to change the angle of the roof and provide precise angle positioning in order to accommodate solar angles of incidence for any location. It can be adjusted during initial construction to any geographic location in relation to the optimal solar angle.

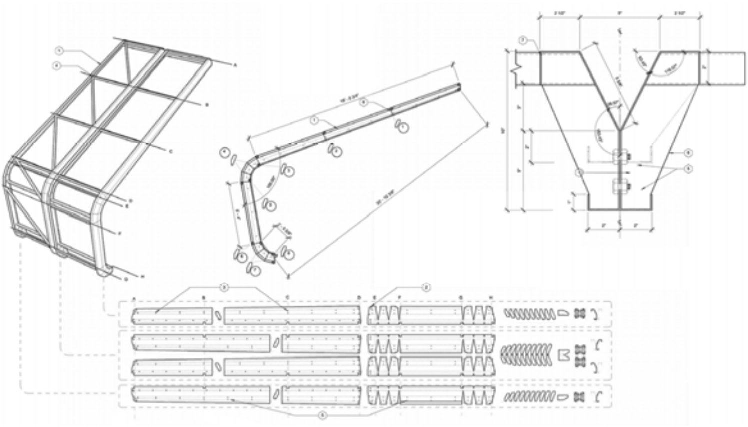

Figure 5: Structural rib construction drawing.

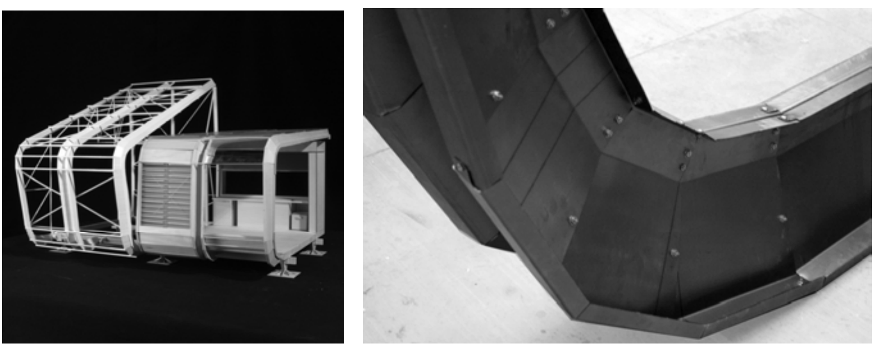

Figure 6: Structural rib model and joint prototype.

For ease of transport, the roof of the SEEDpod is lowered to rest on the top of the core module. Using a forklift or crane, rotating about a pin at the bottom of its south wall, it is raised to the optimum solar angle. It is then affixed in place by swinging in and connecting a triangular support frame at the north clerestory to the top of the SEEDpod core. The installation of insulated glazing at the clerestory completes the exterior weather-proofing system.

3.4 Water wall

The south wall consists of an insulated glass panel and a vacuum formed “water wall” made from recyclable PETE (polyethylene terephthalate) plastic sheets separated by a vented air space [5]. After arriving on site, the empty plastic tanks will be charged with a water-based solution drawn into the tanks via vacuum action. The water wall will absorb and hold the sun’s heat during the day and then radiate toward the interior at night. Exterior shades will be closed to hold the heat in the space. In addition to winter heating, water cooled by taking advantage of the large diurnal temperature swing could be introduced into the tanks at night in the summer to absorb heat from the ambient air in the space the next day. An aesthetic benefit of the water wall is a constantly changing translucent pattern of daylight filtered and refracted through the undulating geometry of the tanks. At night, interior light gently illuminates the water and provides privacy for the occupants.

Between the exterior envelope and the internal water wall is a gap, allowing for air movement, which provides the ability to warm or cool air as it passes along the water wall. During the summer, the tanks will be filled with cool water, and shaded on the exterior side to resist the heat and keep the interior cool. In contrast, the tanks will be charged with warm water in the winter. The water, which has three times the thermal mass capacity of concrete or brick will absorb the sun's heat during the day and re-radiate it to the interior at night.

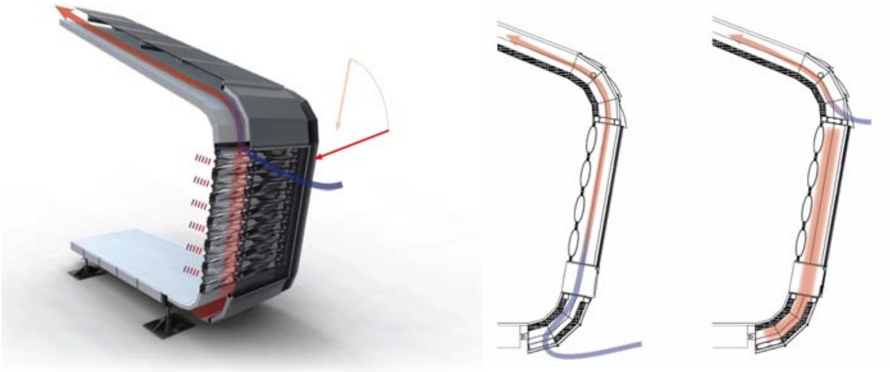

Figure 7: Water wall and air plenum illustrations.

Figure 8: SEEDpod interior with water wall and bath/system/kitchen core elements.

The ability to adjust the temperature of the water within the tanks makes the water wall a desirable element in a variety of climates. Further control is provided by the ability to open or close the south water wall and roof plenums separately, allowing them to be vented independently or together.

3.5 Self-regulating skin system

When the SEEDpod is placed on a desert location in Tucson, integrated site improvement components can be combined to create a benevolent micro-climate for the building and outdoor activity spaces. Ideally, this will be done in a way that preserves the natural equilibrium of the fragile desert ecology.

Landscape and hardscape will vary by location in order to soften the edges of the linear profile and allow the SEEDpod to integrate logically into specific ecosystems. The landscape area on the southern side of the dwelling becomes an important component of the water-harvesting system. Performance-based integrated vegetation will lead to increased building/site stability by passively utilizing the natural processes of evapotranspiration as an evaporative air conditioner and carbon dioxide filter. The greenhouse module is utilized for the growth of edible plants and performs a biofiltration function— the oxygenation, filtration and humidification of interior air.

Figure 9: SEEDpod self-regulating skin prototype.

Incorporated into the east wall assembly is a test panel for the self-regulating shade system, which opens and closes in response to changing thermal conditions and light levels. The self-regulated system prototype investigates elastic structures and materials in terms of mechanical and physical properties for the design of a bistable (capacitor) mechanism which is programmed to deform an aperture, complying with variable thermal loads and light, in order to provide shade and thermal comfort regulation between an exterior and interior space [6]. These systems would most benefit the dwelling on the east and west facades, where the thermal load is higher.

Figure 10: SEEDpod entry, greenhouse, waterwall.

With direct exposure to sunlight, the glazing assembly experiences a “miosis” function, or the constriction of light, based on thermal expansion properties of smart materials and programmatic structural arrangement. With no direct exposure to sunlight, the assembly experiences a “mydriasis” or dilation function, allowing for indirect light to penetrate into interior spaces based on the orientation and materials ability to recoil with lack of heat input.

4 Conclusion

The SEEDpod envelope is designed to selectively filter and interact with its local climatic context. It consists of a series of skin systems that protect the interior condition from varying environmental factors. These are the photovoltaic roof array, the south water wall, and the north, east and west wall assemblies, which have insulated panels and screened glazing systems. Within these walls, operable windows and doors can be positioned to facilitate cross ventilation. The primary objective of the SEEDpod is to provide a compact, highly efficient core dwelling that can advantageously interact with surrounding spaces and natural forces. The intention is to literally grow liveable interior and exterior spaces.

It has been the experience of the authors/architects that, in working with the residents of passive solar homes and observing interactions with their dwellings in response to natural climatic cycles, residents continually developed strategies to improve the dwelling’s energy use efficiency. Similarly, it is our belief that living in the SEEDpod will give its inhabitants a homeostatic vessel, with which they can engage the local ecosystem and become more energy efficient, but also be able to understand and identify opportunities for advantageous interactions with sun, shade, air, water, and cultural and ecological systems within which they live.

Recognizing this, the next steps in the Seedpod’s continuing development are to place it in a desert environment with a resident group, cultivate a landscape that utilizes native vegetation to create benevolent micro-environments surrounding the dwelling, and to monitor their experiences and the relative performance contribution of each of its elements or systems in response to changing environmental conditions over time. It is our goal that in this process the residents will be stimulated to steward preservation of the beauty, integrity and stability of the biome within which they dwell.

References

[1] Research, prototyping, and construction of the Solar Energy Efficient Dwelling was based on work initially proposed for the UASD grant proposal submitted to the United States Department of Energy: completed by Larry Medlin, Joseph Simmons, Dale Clifford, and Jason Vollen, 2007.
[2] All photography by Adam Strauss (undergraduate CALA student).
[3] Work completed by CALA students and faculty under direction of SEEDpod Principal Investigators Larry Medlin and Christopher Domin. Typical attribution at all illustrations and photographs.
[4] Principal Investigators Larry Medlin and Christopher Domin worked with Anton Toth (undergraduate CALA student) and Tom Reiner at Buro Happold: Los Angeles on the development, prototyping, and integration of the structural rib system into the SEEDpod prototype dwelling.
[5] Principal Investigators Larry Medlin and Christopher Domin worked with Eddie Hall (undergraduate student at CALA) an his capstone/thesis committee: Christopher Domin, Alvaro Malo, Beth Weinstein on the development, prototyping, and integration of the thermal water wall into the SEEDpod prototype dwelling.
[6] Principal Investigators Larry Medlin and Christopher Domin worked with Brent Vander Werf (graduate student at CALA) and his thesis committee: Alvaro Malo, Larry Medlin, Nancy Odegaard on the development, prototyping, and integration of the self-regulating skin system into the SEEDpod prototype dwelling.

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Fractal geometry: a tool for adaptability and 'evolutionability'

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Abstract

Buildings must be able to adapt and adjust to change in order to achieve a sustainable architecture, reduce waste and keep harmony with nature. Adaptability advocates the design and organization of the built environment according to different scales and levels (layering). With this in mind, the fractal theory seems to be an interesting approach to explore architectural adaptability. It allows us to conceptualize spatial organization as a multi-scale pattern. Fractals are everywhere in natural forms. They facilitate the creation of coherent, organic and complex structures, which fit harmoniously in the natural environment and interact with it. Fractals emerge in evolution due to the natural need for efficiency and optimization. Fractals are used in different fields including architecture and urbanism. Nevertheless, most of the publications deal with urban planning (city or neighborhood levels) or with aesthetic (detail level) but little about spatial and functional configuration of buildings (architectural level). Our research focuses on the latter; it aims to highlight contributions of fractals to adaptability and evolutionability of buildings by implementing fractal geometry as an architectural ordering of the built environment.

Keywords: architectural adaptability, evolutionability, fractal geometry, sustainability, spatial and functional configuration.

1 Introduction

Buildings and their surroundings are, and should be, considered as complex systems by their need to be diverse, dynamic, adaptive and evolutionary. These abilities enable them to meet change through time and sustain while paying attention to the environmental and socio-economical issues as well as future

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uncertainty. Buildings are also complex by the fact that they are made up with multiple connected components organized and interacting according to a layering process. Considering these characteristics, fractal theory constitutes a valuable tool to explore architectural adaptability and 'evolutionability'.

In order to avoid any eventual terminology confusion, it might be more appropriate to give a definition for 'adaptability and 'evolutionability' as used in this paper:

Adaptability understands the built-in capacity to adapt and adjust to change by meeting different uses and allowing various spatial and functional configurations without significant disruption (Kronenburg [1]).

'Evolutionability' is the built-in ability to evolve through time according to different scales and levels. It allows upgrading the building's systems and their interrelation in order to improve their organization and functioning and preserving the coherence of the whole.

2 What is fractal

We do not intend through this section to provide an in-depth definition of the fractals, since it has been exposed widely in books and papers, but to simply introduce the paper's subject by setting out some aspects that characterise the fractal geometry.

The interest to fractals dates back to the late 19th and the early 20th century, when many mathematicians such as Helge von Koch, Waclaw Sierpinski, Bertrand Russell, Georg Cantor, Felix Klein, etc. were investigating some iterated functions. However, the term 'Fractal' was not known until 1975, when it was coined by Benoît Mandelbrot from the Latin word 'fractus' which means 'irregular or fragmented' (Mandelbrot [2]).

Later, the fractal geometry was defined by Bovill [3] as "the study of mathematical shapes that display a cascade of never-ending, self-similar, meandering detail as one observes them more closely". On this basis, the fractal geometry is characterized by many aspects from which we will enumerate the following for further development, with regard of their implementation in architectural adaptability and 'evolutionability'.

2.1 Self-similarity and form hierarchy

"A fractal is a shape made of parts similar to the whole in some way" (Feder [4]). A fractal object is similar to a part of itself which is also fractal. This similarity is present at every scale; the small parts resemble to the bigger parts, which resemble in their turns to the whole, Fig. 1. This is obtained by the continuous repetition of a pattern according to a recursive or iterative process (algorithm).

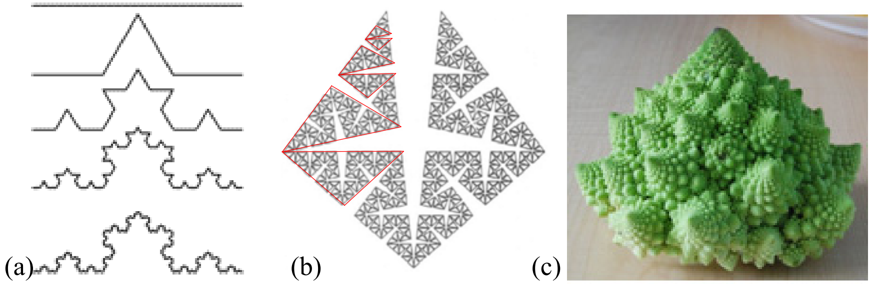


Figure 1: Examples of self-similarity in fractal forms: (a) the von Koch curve, (b) another version of the von Koch curve, (c) a cauliflower.

2.2 Irregularity, meandering and roughness

Unlike Euclidian forms which have no textural depth, a fractal object is 'non-smooth', it is rough, irregular and fragmented, and as the magnification of examination is increased, more of the roughness and meandering are revealed, Fig. 2.

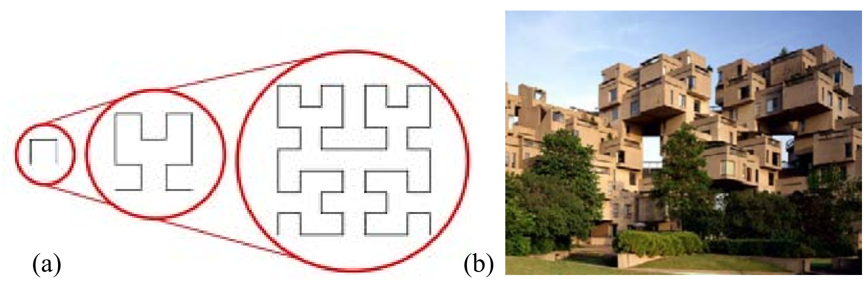


Figure 2: Example of irregularity, meandering and roughness in fractal forms: (a) the Hilbert curve, (b) the Moshe Safdie building (from: www.msafdie.com, ©Tim Hursley, reproduced with his kind permission).

2.3 Fractional dimension

The fractional dimension of an object is strictly bigger than its Euclidian dimension, which is whole (zero for a single point, one for a line or a curve, two for a plan and three for a volume). Complex systems are better described using a fractional dimension (a decimal dimension between two whole numbers). So, while a curved line has a dimension of one in Euclidian geometry, it will have a dimension between one and two in fractal geometry, depending on how much space it takes up as it twists and weaves. The more the fractal curves to fill every corner and area of a plane, the closer it tends to lose its property of one dimension to approach two dimensions; likely, the more, it folds to fill and pack a bounded volume, the closer it approaches three dimensions, Fig. 3. The space filling property allows to an infinite length and surface to fit in a relatively small volume.

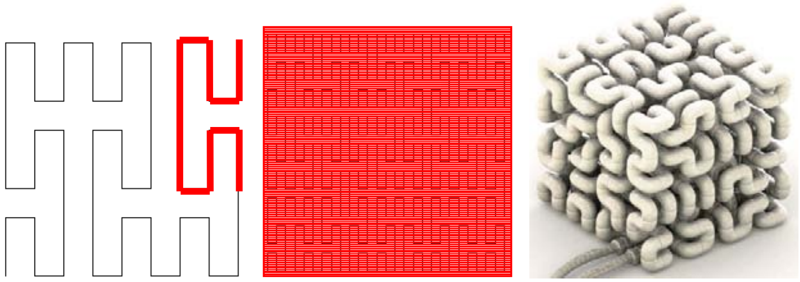


Figure 3: Fractal dimension – example of the Peano curve.

3 Fractals as a tool for adaptability and 'evolutionability'

Fractals are omnipresent in natural forms, and they are widely used in different fields, including architecture and urbanism; the main reason may be their coherence, efficiency and optimisation (Mandelbrot [5]). However, the most of researches, in relation with our field, focus merely on urban planning (city or neighbourhood levels) or on aesthetic (detail level) but little on spatial and functional configuration of the building (architectural level). This paper aims to explore the latter aspect by explaining how an understanding of the fractal geometry, and its implementation on the architectural configuration and ordering of spaces, might guarantee the building's adaptability and 'evolutionability'.

3.1 Multi-scales and hierarchical evolution

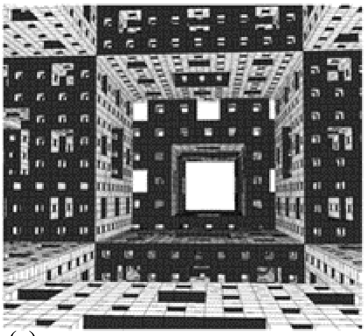
The fractal structures develop step-by-step, according to an incremental, and hierarchical organic growth, rather than at once like it is in massif structures. Each level is related to at least one level above and one below, according to a control relationship based on dominance/ dependency equation: the upper level controls and dominates the change of the lower level, it determines the context, entails constraints and draws limits; as for the lower level, it encourages and fit to change, depending on the upper level. This organizing process operates continually without affecting the whole; it achieves both change and stability, thus, it ensures coherence, durability and sustainability (O'Neill *et al.* [6]).

Likely, a building which evolves progressively through multiple layers and different scales by renewing its individual cells, allows to meet future needs and adapt to change, while remaining coherent with the socio-cultural and economical conditions (Habraken [7]). Thus, each entity can be transformed, upgraded and regenerated with a minimum of disturbance. In contrast, a building which is totally 'finished' and 'perfect' to its delivery, is considered 'completed', once built, and it is difficult to transform and to adapt and therefore, it becomes obsolete a few years later.

3.2 Space optimization

The fractal geometry gives a feeling of spaciousness (Crompton [8]) because it helps to increase density and optimize space without expanding the topological dimension. The Menger Sponge is an example of how fractal geometry can be used advantageously in the optimization of space and its utilization. The Menger Sponge (whose the area tends to infinity) is a structure that develops from outside to inside, by hollowing out the initial volume to create empty spaces. That allows one to multiply spaces, and provides a good way to set up hierarchy of volumes, while preserving the same exterior appearance of the initial volume. The multiplication of subspaces, alcoves, pockets, recesses, mezzanines as well as variations in heights and sizes allow to benefit of each millimetre of the space and to multiply the activities places. Thus, the space becomes complex, rich in activities places because, according to Crompton [8], the complexity of a space depends on how much varied activities is able to house.

The Menger Sponge also helps to fix landmarks which allow one to structure and configure the space, own it and adapt it (group together different spaces; separate and divide them; rearrange them, etc.). The Menger Sponge concept has been applied by the architect Steven Holl in some of his projects like the 'Sarphatistraat' office building in Amsterdam, Fig. 4.



(a)

(b)

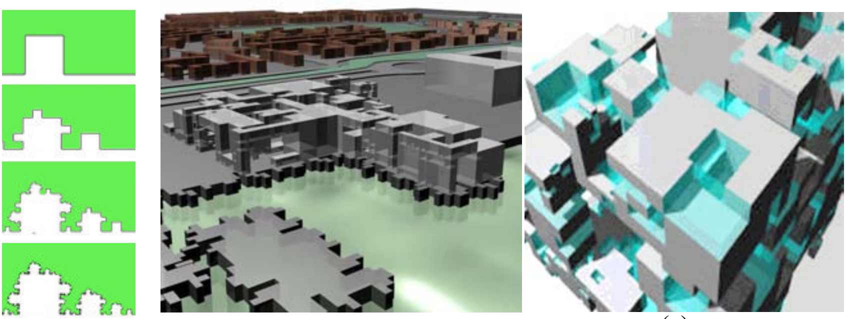
(c)

Figure 4: Space optimization according to 'Menger Sponge': (a) the 'Menger Sponge', (from Crompton [8], ©Andrew Crompton, reproduced with his kind permission), (b) and (c) the Sarphatistraat office building (from: www.stevenholl.com, ©Paul Warchol, reproduced with the kind permission of Paul Warchol Photography Inc).

3.3 Increase of permeability and accessibility

Fractal forms, compared to Euclidian smooth ones, are known by their infinite perimeter and external surface, which helps to maximize performance of the exchange surfaces. On this basis, the vegetal species develop their forms in such a manner to increase considerably their external contact area in order to facilitate exchange functions, like photosynthesis process, cellular respiration and absorption from roots (Salingaros and Padrón [9]).

By analogy, a building designed on the basis of the fractal geometry, spreads out its external skin to be interlaced with the natural and built surrounding environment and to optimize their connection. These enable the building and its different parts to breathe, and interact as well as to be better ventilated and lit, etc. Furthermore, fractal geometry allows one to enhance physical and visual accessibility and permeability while preserving a strong relationship with the centre of the built mass (Coates [10]) and keeping a harmonious relationship with the immediate environment, Fig. 5. That improves adaptability of the spaces because it makes their configuration, reconfiguration, subdivision and restructuring easier by preserving a good indoor quality, minimizing energy use and construction waste; which lies within the scope of High Quality Environmental standards (HQE).



(a) (b) (c)

Figure 5: The use of fractal geometry to enhance permeability and accessibility, (b) and (c) from http://uelceca.net/research/other/fractarch2004arielsmall.pdf and http://www.generativeart.com/on/cic/ga2001_PDF/coates.pdf, ©CECA, reproduced with the kind permission of Paul Coates, the author).

3.4 Multi-centres evolution

In general, the fractal structures evolve according to ordered centres which ensure the hierarchical distribution of flows and allow the creation of several poles of life and animation. This configuration helps also to guide and direct any future extension or densification, in order to avoid anarchy and consequently to preserve the coherence and the integrity of the whole, Fig. 6.

This configuration around centers allows subdividing the space into distinct entities when necessary, preserving each one its own centre (animation, access, lighting, ventilation, view, greenery, services, etc), and thus, preserving the building's architectural quality, its ambiance and its integrity, Fig. 7.

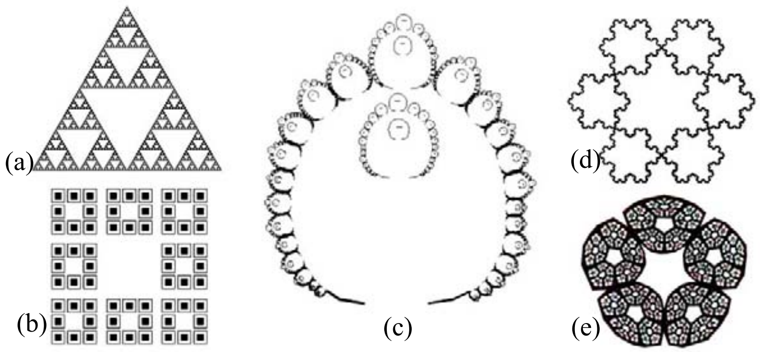


Figure 6: A multi-centres evolution for a coherent whole and ordered extension, (a) the Sierpinski triangle, (b) a Sierpinski carpet, (c) the Ba-Ila African settlement (from: Eglash, R., *African Fractals*: Modem Computing and Indigenous Design, Rutgers University Press: New Jersey, p.27, 1999, ©Ron Eglash, reproduced with his kind permission), (d) a Koch snowflake, (e) simulation of a natural fractal form.

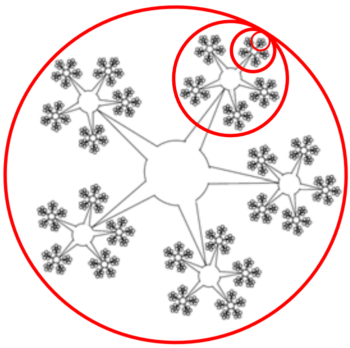


Figure 7: Multi-centres evolution: possibility of many subsets distinction.

3.5 Diverse, dynamic and complex modularity

Modularity is essential to architectural adaptability because it allows essentially saving time and money, but also it facilitates updating, upgrading and maintaining the building, as well as introducing new technologies and suiting aesthetic tendencies. However, the identical repetition of a module with the same scale creates monotony and uniformity. Façades based on empty rectangular panels repeated without respect of the building hierarchical scales, i.e. housing schemes and 'HLM' of the 20th century, create a disconnection from the environment, and act negatively on human perception (Salingaros [11]). In the same way, an overloaded design and tightly spaced scales may scramble the façade coherence and destroy the scales hierarchy.

The fractal geometry constitutes a good alternative; it helps to create different configurations based on the same module by developing it on various scales, and to introduce a visual balance between the different systems of the façade from the largest scale to the smallest one. Consequently, the fractal geometry helps to create mixed, dynamic and personalized façades (Salingaros [11]).

In order to come up with a coherent façade, the hierarchical subdivision of the architectural scales must be clearly defined, and the small units should be coordinated with the large ones. Basing on empirical researches of Christopher Alexander (Salingaros [12]) proposes a specific ratio for the consecutive scales in the hierarchy, given approximately by the constant $e \approx 2.7$. This constant constitutes the base of natural logarithms and arises in the most successful and psychologically comfortable buildings.

4 Conclusion

Fractals have significantly influenced current scientific thinking. Architecture also benefits from the use of this tool in the way it helps architects and designers to express complexity. Within this context, the present paper sets out an attempt to implement fractal geometry in architectural adaptability and 'evolutionability' by looking to the building as a complex structure made up with different layers and multiple connected components. The study has shown that the fractal geometry contributes significantly to a positive and progressive transformation of the building, to the optimization of its spaces and their use, as well as to the increase of permeability and accessibility which lead to a better connexion with the immediate environment in addition to a better indoor quality and energy optimization. Furthermore, the fractal geometry allows to design the building according to hierarchically ordered centres which ensure a rational distribution of flows and a constant human and environmental ambiance and services supply - even when the spaces around are reconfigured or restructured- preserving thus coherence and integrity of the building. Finally, using fractal patterns may help to avoid monotony and uniformity of façades by creating personalised and dynamic façades with a visual balance between its different components.

References

[1] Kronenburg, R., *Flexible: Architecture that Responds to Change*, Laurence King Publishing Ltd: Great Britain, p.115, 2007.

[2] Mandelbrot, B.B., *Les Objets Fractals, Forme, Hasard et Dimension*, Champs Flammarion: France, p.5, 1999.
[3] Bovill, C., *The Fractal Geometry in Architecture and Design*, Birkhäuser: Boston: France, p.3, 1996.
[4] Feder, J., *Fractals*, Plenum Press: New York, London, p.11, 1988
[5] Mandelbrot, B.B., *The Fractal Geometry of Nature*, W.H.Freeman & Co Ltd: USA, 1982.
[6] O'Neill, R.V., Deangelis, D.L, Waide, J.B. & Allen, G.E., *A Hierarchical Concept of Ecosystems*, Princeton University Press: Princeton, pp.98-90, 1986.
[7] Habraken, N.J., *The Structure of the Ordinary, Form and Control in the Built Environment*, The MIT Press: Cambridge, p.7, 1998.
[8] Crompton, A., The fractal nature of everyday environment. *Environment and Planning B: Planning and Design*, **28(2)**, Pion Ltd: London, pp. 243 – 254, 2001.
[9] Salingaros, N.A. & Padrón, V., Ecology and the fractal mind in the new architecture: a conversation, http://zeta.math.utsa.edu/~yxk833 /Ecology.html
[10] Coates, P.S., "Current Work at CECA: Fractal Composition in Architecture", http://uelceca.net/research/other/fractarch2004 arielsmall.pdf, 2004
[11] Salingaros, N.A., *A Theory of Architecture*, ISI Distributed Titles: Delaware, pp. 159-160, 2007.
[12] Salingaros, N.A., Hierarchical cooperation in architecture and the mathematical necessity for ornament. *Journal of Architectural and Planning Research,* **17(3)**, Locke Science Publishing Company, Inc: Chicago, pp. 221-235, 2000

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An open system model of ecological architecture

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Abstract

This paper presents a model of open systems evolution as a paradigm for ecological design in architecture. Based on evolutionary thermodynamics and complex systems science, the model of open systems evolution is constituted by the mechanisms of the adaptation of open systems to the host environment via natural gradients, the self-organization of open systems so as to optimize resource distributions according to the maximum entropy principle, the generation of diversity and the production of minimal entropy in the host environment. According to this model, the authors propose a conceptual framework for ecological architecture that describes the ecological interactions of buildings with the natural environment in open thermodynamic terms, and actively engages the end-users in buildings into the micro-climate control. In the manner of open systems evolution, these multiple interactions evolve to optimize the environmental performance of buildings, resulting in a sustainable symbiosis of architecture and nature.
Keywords: open systems evolution, ecological architecture, intelligent design.

1 Introduction

Induced by human activities, including industrial development and production, urbanisation and agriculture over the last two centuries, global warming and climate change are recognised as an entropic consequence of environmental depletion (Ingersoll [7]; Moore [13]). The environmental crisis has been and will continue to be a serious threat to basic social well-being and global stability, presenting the world with a major dilemma and challenge of achieving

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sustainable development in the 21st century. On such a background, a conceptual systems theory framework for sustainable development is described in this paper.

Crisis is often a prelude to the emergence of new theories, and philosophical thinking is a powerful device to unlock riddles in any field (Kuhn [11]). The environmental crisis caused by industrial development raises the urgent need to explore a new theoretical framework for development. Based on the theory of evolutionary thermodynamics (Prigogine [15]) and complex systems science (Kauffman [9], [5]), in this paper the authors generalise the mechanisms of open systems evolution and introduce a new paradigm for ecological architecture and sustainable design in the built environment.

2 Open system evolution

In thermodynamics an open system refers to a system that is able to make use of available resources from the host environment for its evolution, driven by naturally arising pressure, density, temperature gradients etc, between the system and the host environment. At the macroscopic level, an open system evolves from an initial chaotic state to a non-equilibrium state or a steady state when order emerges in the open system, which is indicated by a zero entropy rate and a minimal value of entropy. Subsequently the open system will maintain this stable interrelation with its host environment. In other words the open system is compatible with the constraints of the host environment.

At the microscopic level an open system exhibits a mechanism of self-organisation during its evolutionary phase whereby an organised structure gradually emerges such that the distribution of resources in the system is optimized according to the maximum entropy principle. Corresponding to this microscopic level self-organisation, at the macroscopic level there is reduction in entropy transfer by the open system to its host environment. This final state, composed of the emergence of a highly ordered structure for an optimal distribution of input resources in the system and the minimised entropy produced by the system, is identified as the emergence of order in the open system.

In abstract terms, the evolution of an open system can be thought of as the open system adapting to the host environment spontaneously due to natural gradients. During the evolution, indicated by entropy, the system is aware of its on-going performance, aware of its negative impact upon the host environment. The system adapts to the host environment by self-organising a highly organised internal structure for resource distribution aimed at minimising entropy thus optimising the system’s interrelation with the host environment. These desirable consequences, i.e. the ordered structure, minimised entropy and stable interactions, are identified as the order of the open system after evolution.

To interpret the black-box description of open systems evolution, we assume, it is the internal structure being self-organised by the open system which reduces the rate of entropy towards zero and minimises the value of entropy at the arrival of a stable state. In other words, we assume that the entropy jointly produced by the inputs from the host environment at the macroscopic level and by the self-organisation of the open system at the microscopic level fully describes self-organisation of an open system during the evolution towards an ordered state. The following section specifies the mechanism of self-organisation in more detail.

2.1 Mechanisms of self-organisation

At the local level in response to the global evolution of an open system, self-organisation without central power (Prokopenko et al. [17]) is a primary mechanism to process the evolution dynamics within the system in response to stimuli from the host environment, e.g. inputs of energy, matter and information. The term, self-organisation, has deep roots in biological science, related to the origin of life (Kauffman [10]), e.g. chemical bonding at molecular level. It is related to resource allocation within a system, resulting in an increase in complexity (Adami [1]; Prokopenko et al. [17]).

During the evolution of an open system, after entering into the system across the boundary, the input resources will be released within the system in an evolutionary manner that finishes in a non-equilibrium state of the open system when entropy is minimised. Starting from the release of the input resources, the open system self-organises itself in the following steps:

i) A structure is self-generated internally by the system after the release of the input resources, which function to control, channel and distribute the resources, and also constrain and limit the distribution;
ii) As a direct result of the structure generation, the input resource are distributed by the structure within the system, and constrained by and subjected to the structure;
iii) Most of the input resources are effectively distributed within the system for useful work by the structure, but some of them are limited and constrained; thus it requires further development of the structure in order to support the ongoing effective release and distribution of resources in the open system;
iv) Gradually, the release and distribution of input resources shape a complex topology emerging in the open system.

In brief, a structure is spontaneously generated by the open system after inputs flowing into the open system are released. It is used for a possibly broadest distribution of inputs resources within the open system. In turn, it produces a complex topology of resource distribution in the system.

Over this complex process of self-organisation, entropy is inevitably transferred from the open system to the host environment. The change of the rate of entropy and the value of entropy, e.g. the reduction or the increase of entropy, indicate the on-going process of self-organisation at the microscopic level in response to the on-going process of evolution of the open system at the macroscopic level. The value of entropy is finally stabilized at a minimal value that indicates the completion of the evolution phase and the emergence of order in the open system. The repetitions of generations of structure for the effective distribution of resources are processed in the direction of reducing the rate of entropy towards zero and minimising the value of entropy till completion of the evolution.

In summary, the black-box dynamics of self-organisation are composed of the self-generation of structure in the direction of an optimisation of the distribution of inputs resources at a microscopic level. When the evolution of the open system at the macroscopic level is completed, which is indicated by the minimised entropy, complexity and diversity emerge in the system, i.e. a complex topology of resource distribution. Such a complex process of an open system is generalized as the mechanism of self-organisation.

2.2 Mechanisms of evolution

The mechanism of self-organisation of an open system at the microscopic level to complete the evolution of the system at the macroscopic level suggests an evolutionary mechanism for optimising resource distribution in a system with minimal negative impact, i.e. entropy produced by an open system to the host environment. Three distinctive transitional phases occur during the evolution of an open system (Prigogine [15]), as shown in Figure 1. Far from the equilibrium state of the system and near the equilibrium state of the system, when the system is growing from being uneven and frustrated with its host environment, and finally a non-equilibrium state of the system when the system is growing so as to be compatible with the host environment.

In the end, the system may gain autonomy from its host environment. If there are some new gradients between the system and the host environment, the open system may start another new round of evolution to develop its complexity. One of economists (Dmitry [3]) argues that it takes 50 years for the global economic system to self-organise and settle-down in a new stable state that lasts only 20 years. This is a good example of an open system evolving from a chaotic state to an ordered state.

During evolution, it is the uncertainty, entropy of a system, which drives the successive evolution of the open system from the far from equilibrium state to the final ordered state, in a feedback-control loop. From this perspective, entropy, or the uncertainty in a system, is the attractor of evolutionary dynamics, without which the evolution and self-organisation cannot take place. When we have an entropic environmental crisis caused by industrial development, it indicates the need for further evolution to minimise entropy as much as possible, for example, by making full use of available resources, e.g. solar, wind, geothermal and some other renewable sources, to replace the use of fossil fuel and to minimise the negative impact, supported by innovative technologies. As physicist Fredrik Keffer argued in 1960 (Rogers [18]), "the early industrial revolution involved energy, but the automatic factory of the future is an entropy revolution. The future belongs to those who can control entropy."

Over the voyage of open systems evolution, there are two arrows of time. The first arrow of time is the irreversible production of entropy by the open system towards the host environment, which is macroscopically observable (Prigogine [16]). The second arrow of time is the emergence of self-organising structure towards an ordered state of the open system at the microscopic level. This results in the complexity and diversity in the open system. In the case of the earth which

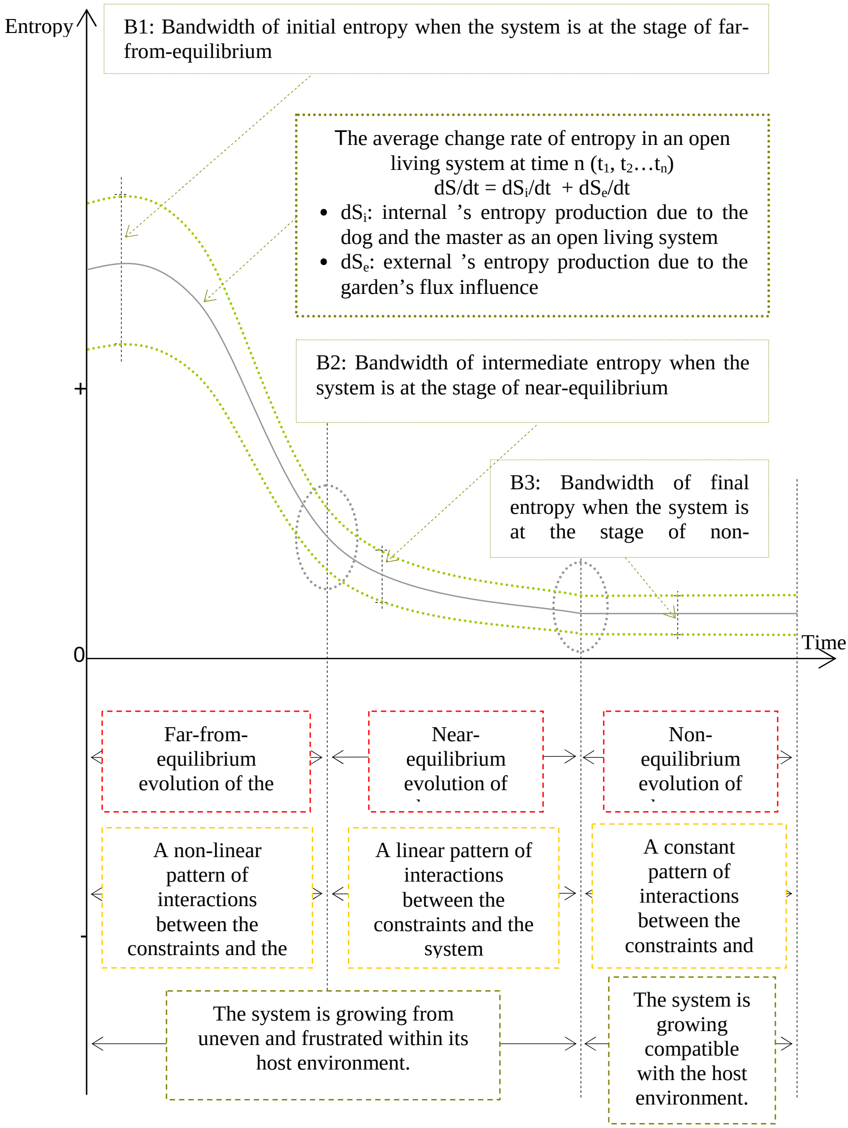

Figure 1: Three transitional phases of an open system evolution.

thermodynamically exchanges energy, e.g. solar energy, with the universe as the host environment, entropy increases irreversibly into the universe; in the meantime, life on the earth is growing to high levels of organisation, complexity and diversity through a steady growth of structure (Davies [4]).

As argued in the previous section, the change of the rate of entropy and the value of entropy indicate an on-going process of evolution. Over the evolution, the production of entropy from the open system into the host environment continues accumulating, although it is minimised when evolution completes. This interpretation of open systems evolution is consistent with the classical statement of the Second Law of Thermodynamics which states that the irreversibility of entropy produced by the system, e.g. closed or open systems, into the host environment during a thermodynamic exchange, results in a heat death of the host environment, e.g. the universe as a host environment to the earth as an open system. The difference between an open system and a closed system is the possibility of open systems producing less and less entropy into the host environment due to the continuous inputs supported by the host environment for the successive evolution of the system. However, a closed system does not have the chance of continuous energy and matter input into the system, to reduce the value of entropy produced to the host environment.

In summary, it is by the structure self-generated by the open system in response to the stimulation of input resources from the host environment that an open system is able to complete evolution and realise a compatible interrelation between the system and the host environment. During the dynamic process of self-organisation, the system's performance is dynamically changing as displayed in Figure 1, where the bandwidth and the amplitude of the value of entropy is actually determined by the present structure in the system and the state of the surroundings i.e. the host environment. A desirable structure is a structure which can maximise the distribution of all available resources in the system, committed to all components within the system for minimal entropy. The authors assume this distribution is in accord with the maximum entropy principle as the optimal resource distribution companied with minimised entropy to complete the evolution of the open system. In other words, the more entropy, which is uncertainty of information in a probability sense, the more diversity will be generated by the system. The consequence of self-organisation, i.e. the emergence of complexity and diversity in the system, reinforces the vitality of the system, e.g. increasing the possibility of the further evolution of the system due to the existence of gradients between the agents of the system. This complexity and diversity thus facilitate an efficient transfer of the system from the past to the future, which can be identified as an alterative paradigm for sustainable development and human survival on earth.

3 Open system evolution in ecological architecture

The paradigm of open systems evolution is a guiding principle in Nature that seems specifically designed for sustainability. Learning from Nature, several implications of open system evolutions in architecture are generalised as follows.

3.1 A model of open thermodynamic systems for ecological architecture

As stated previous, the basic meaning of entropy in thermodynamics theory refers to unavailable and wasted energy during the thermodynamic transformation in a closed system, a dysfunction of the system. Some extensional meanings of entropy in the real world include chaos, disorder, poverty, frustration, irreversibility (Prigogine [16]), uncertainty (Shannon [19]) in information science. In contrast, order refers to all the desirable properties, including organisation, intelligence, efficiency, beauty, humanity, and so on. In particular, 'humanity' has been used as a slogan by many politicians to campaign for order in the world. Accordingly, applied to architecture, the authors argue that entropy refers to all the negative environmental impacts of buildings over their life-cycles, and order refers to the optimal environmental performance of buildings, e.g. positive ecological impacts.

A model of evolutionary architecture was initially suggested by Frazer (Frazer [6]) for an alternative to ecological sustainability, which exhibits the metabolism of buildings in such a way that architecture enjoys a thermodynamically open relationship with the environment in both a metabolic and a socio-economic sense. It will maintain its stability with the environment by negative feedback interactions and promote evolution in its employment of positive feedback. It will conserve information while using the processes of autopoiesis, autocatalysis and emergent behaviour to generate new forms and structures. It will be involved with re-adjusting points of disjuncture in the socio-economic system by operation of positive feedback. It is not a static picture of being, but a dynamic picture of becoming and unfolding, a direct analogy with a description of the natural world.

The authors take this model of open systems further and argue the implication of an open systems model lies in an evolutionary mechanism of open systems for the optimisation of energy and resources consumption in buildings over their life-cycles, to improve the environmental performance of buildings in the context of the natural environment. By efficiently using energy and material fluxes available in the natural environment, it is possible to realise an ecological sustainability, i.e. minimised negative environmental impact towards an ecological compatibility between building systems and their natural ecosystems. The implications of open systems evolution are further specified below.

3.2 Sustainability through evolutionary optimization

'Intelligent design' was anticipated by Darwinism. The exquisite, complex structure in nature could have evolved by accumulated random mutations and by natural selection. With the framework of open systems evolution, intelligence means the system able to adapt to the host environment and to use inputs for evolution, aware of its on-going performance and its impact upon the host environment, able to self-organise a highly ordered structure for resource distribution in order to optimise its performance with minimal negative impact, and consequently to generate a compatible interrelation with its host environment, thus achieving long term ecological sustainability.

Within this framework, the concept of sustainability is generalised to attain a balanced ecological interrelation between the system and its natural environment through an evolutionary process. Sustainable design as an alternative design standard in the coming decade is necessary not only to design for energy and resource efficiency, and pollution reduction, but also to design with full responsibility to all the imperatives in a social-economic-environmental context, and to design with an awareness of impact in that context, i.e. the natural environment, human beings etc.

In summary, sustainable design should be treated as intelligent design. Hence, the questions raised from the framework of open systems evolution to architecture design are:

i) What is the aim of design? Design for optimal performance of a system, such as a building. The optimisation can be defined as a desirable property in each particular context, e.g. optimised environmental performance in the context of the natural ecosystem;
ii) Which evolutionary phase best describes a system of buildings, the chaotic stage of dynamic evolution or the ordered stage of stable non-equilibrium?
iii) What is the performance of a system of buildings and/or cities? Suppose the performance of the system is determined by the structure and the context, i.e. the system's performance at a macroscopic level is determined by the internal self-organised structure of the system at the microscopic level, and the state in the particular context.
iv) How can we evaluate the performance of the system? Indicated by some referential entropy.
v) Does the system need further evolution? Is the system fully evolved, under-evolved, or un-evolved in the direction of reducing the entropy of the system, i.e. the dysfunction of environmental performance;
vi) Which system and structure are more adaptive and viable for achieving desirable long term ecologically sustainability performance of a building? and
vii) How can we achieve optimisation of system performance using the mechanisms of open systems evolution?

A recent example involving the application of intelligent mechanisms for optimisation is the Taipei Performing Arts Centre, designed by Kokkugai in 2008. Swarm intelligence (Leach [12]) is the emergent properties of this swarm intelligence system, a population composed of a large number of smaller discrete elements, e.g. colonies of ants, flocks of birds, networks of neurons or even the global economy. It displays a bottom-up collective intelligence, generating an active networked topology in which agents self-organise in reforming their topology enabling a gradient interaction between explicit design and emergent processes. The creation of a fresh and highly innovative vocabulary of architectural forms is generated by the algorithmic potential of the computer, including the adaptive, parametric behaviour of distributive systems mutating across a filed condition.

In order to optimize the performance of a building, it is necessary to establish a relevant internal structure that responds to the desirable external performance. For example, by organising a topological structure of energy and resource consumption in response to the optimal environmental performance of a building over its life-cycle, a range of minimised negative environmental impacts can be achieved. This topological structure does not necessarily mean a hierarchical one, but some other alternative forms, e.g. democratic, as suggested by complex systems science. It is highly self-organised with the aim of minimising entropy, i.e. negative environmental impact of buildings to the natural environment, to realise ecologically sustainable compatibility of buildings with the natural environment.

In summary, the second implication of open systems evolution to architecture is as an intelligent mechanism for ecological design towards an optimisation of sustainability.

3.3 A holistic scheme for systematic sustainability in ecological architecture

Based on the mechanism of self-organization of open systems evolution, the authors propose a holistic scheme for sustainable design with the intelligent mechanism of open systems evolution, as shown in Figure 2. This embraces not only buildings, and the natural environment, but also brings an active participation of the end-users of buildings. In this model, an interactive design scheme for system sustainability is integrated into a holistic information environment, which is open to the participation of end users, concerning the environmental impacts of design and development, a positive engagement of man, nature and buildings all aligned towards sustainability. In other words, through the medium of buildings as man-made intervention into nature, an ecologically positive relationship of man and nature can be achieved.

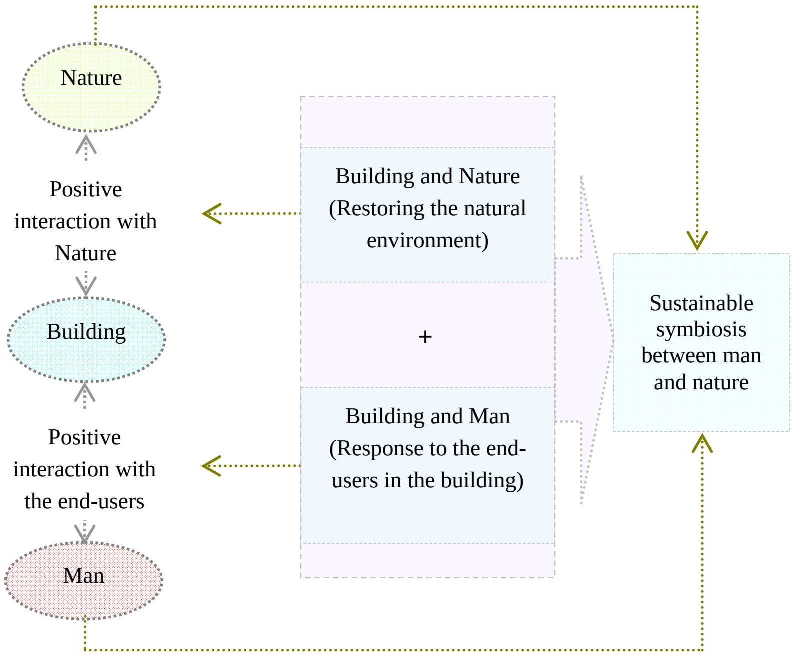

Figure 2: A holistic design scheme for system sustainability in architecture.

The quest for environmental values in architecture and for a harmonious balance between man and the natural surroundings is not new. In China, “the harmony between the heaven and the human” or “man and nature in one” (Jin [8]) was originally argued by Zhuang-zi, and later developed by Dong Zhong-shu in the Han Dynasty, 200-300 B.C., when the fundamental cultural personality of China were established. In modern times, Jin Yue-lin generalised it as the philosophical foundation of Chinese civilisation over thousands of years. It reflects the agricultural civilization, when tangible knowledge was not fully enough developed to strengthen people with the idea of conquering nature. On the contrary, the ideological dependence on the natural environment was well developed, and provided people with the idea of nature being more powerful than man. Ironically, in our current industrial age, this human dependence on nature is still developing. It implies, compared to the greatness of Nature, how powerless human beings are after more than two hundred years’ aggressive and desperate hunting, fighting, and exploiting in the industrial pattern.

4 Ecological design from concept to creation

Based on the arguments above, the authors articulate sustainable design at the abstract level as a synthesis of art and science. As is usually the case however the devil is in the detail. Below we begin to unpack some of this detail by sketching two important aspects of our on-going research program.

4.1 Fluctuation to equilibrium via evolutionary algorithms

The first sub-project of ‘ecological design from concept to the creation’ is to simulate the self-organisation of open systems evolution. As argued by (Nicolis and Prigogine [14]) open systems are actually dissipative structures that continuously make use of the inputs for their long-term survival. The attraction of dissipative structures is the transformation between complexity and simplification, between vibrant fluctuation and smooth equilibrium. Certainly, for dissipative structures producing fluctuation is unpleasant and energy consuming. Our work is aimed at developing an approach to speed-up the time-consuming process of evolution in open systems by efficiently controlling the release of energy so as to achieve sustainable design in the context of architecture.

4.2 System structure and performance

The second sub-project is entitled ‘the channel of the system performance and the system structure for resources distribution’. We are investigating how the allocation of each individual agent in the system, e.g. the privilege and available access to the resources, the authority of freedom, the scope of the activity field, etc, affects the performance of the system at the global coordination scale; and how system performance is determined by the structure and pattern of resource distribution in the system.

Until each agent is sufficiently intelligent as indicated by the entropy level (i.e. has evolved enough), the whole system will not work properly as an intelligent system for the optimisation of its performance. The identification of a system's 'intelligence' requires information about the system, the level of uncertainty about the system state etc. For example, as usually suggested from natural evolution theory, each biological system barely develops an adaptive structure to solve the present problem imposed from their niche in Nature.

5 Conclusion

In conclusion, self-organisation during the evolutionary phase of an open system is suggested as a mechanism to self-generate a structure for the optimisation of resources distribution. Also self-organisation results in the minimisation of entropy towards the completion of the evolutionary phase. These two desirable effects are identified as the emergence of order in the system. The mechanisms of open systems evolution, generalised in this paper, suggest a new paradigm for sustainable ecological design, i.e. microscopically self-organising a topological structure for energy and resource distribution within the system, thus optimising environmental performance by minimising the negative environmental impact on the natural environment. A holistic information system is designed for effective control and adaption of environmental performance of systems using the mechanisms of open systems evolution.

References

[1] Adami, C., What is complexity? BioEssays, vol. 24, pp 1085-1094, 2002.
[2] Bergós, J., Gaudí, the man and his work, Boston, Little, Brown and Company, 1999.
[3] Dmitry, K. C., The Main Principles of Simulation Modelling of the Sustainable Development Complexes System: Case of World Economy Complex Sciences, Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, Springer Berlin Heidelberg, 2009.
[4] Davies, P., Cosmic blueprint: new discoveries in nature's creative ability to order the universe, Philadelphia, Templeton Foundation Press, 2004.
[5] Emergence, Organisation and Dynamics of Living Systems, Santa Fe Institute, www.santafe.edu.
[6] Frazer, J., An Evolutionary Architecture (Themes VII). London, Architectural Association Publications, 1995.
[7] Ingersoll, R., Second Nature: On the Social Bond of Ecology and Architecture. Reconstructing Architecture: Critical Discourses and Social Practices. T. A. Dutton and L. H. Mann. Minneapolis, University of Minnesota Press, 1996.
[8] Jin, Y. L., Daoism, Nature and Man, 2005. 金岳霖, 道 , 自然与人 生活·读书·新知三联书店.

[9] Kauffman, S. A., The Origins of Order: Self-organisation and Selection in Evolution. New York, Oxford University Press, 1993.
[10] Kauffman, S. A., Investigations, New York, Oxford University Press, 2000.
[11] Kuhn, T. S., The Structure of Scientific Revolutions, Chicago, The University of Chicago Press, 1962.
[12] Leach, N., Swarm urbanism, Digital Cities, Architectural Design, 2009.
[13] Moore, S., Architecture, Esthetics, and Public Health. The Hand and the Soul: Ethics and Aesthetics in Architecture and Art. S. Illescu. Charlottesville, VA, University of Virginia Press, 2006.
[14] Nicolis, G. and I. Prigogine, Exploring complexity: an introduction. New York: W.H. Freeman, 1989.
[15] Prigogine, I., Introduction to thermodynamics of irreversible processes. New York, Interscience Publishers, 1961.
[16] Prigogine, I., The arrow of time. IN C.ROSSI & E.TIEZZI (Eds.) Ecological Physical chemistry. Amsterdam, Elsevier, NL, 1991.
[17] Prokopenko, M., Boschetti, F. & Ryan, A. J., An information-theoretic primer on complexity, self-organisation and emergence The 8th Understanding Complex Systems Conference, UIUC, 2007.
[18] Rogers, E. M., Physics for the inquiring mind; the methods, nature, and philosophy of physical science, Princeton, N.J., Princeton University Press, 1960.
[19] Shannon, C. E., The mathematical theory of communication, Urbana, University of Illinois Press, 1949.

Passive design strategies for residential buildings in a hot dry climate in Nigeria

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Abstract

The hot dry climatic zone of Nigeria is characterized by a period of high temperature and low relative humidity between February and May. Between these months, the daily mean maximum indoor temperature of most buildings is about 37ºC with low indoor air velocity. A study of residential buildings in Bauchi state, Nigeria shows that most occupants of the buildings have persistent and growing problems with the indoor environment due to high indoor temperature. Most buildings are characterized by poor design in relation to the climate, which requires a great deal of energy for cooling during climatic extremes. Other problems are poor natural ventilation, inadequate surface–volume ratio and poor building orientation. This has led to negative consequence that affect the occupant's physiological comfort, capacity for mental and physical work, health and leisure. This paper identifies passive design strategies that can be adopted in this climatic region to minimize the use of energy for cooling, improve occupant's comfort and enhance low energy architecture. The objective is to reduce overdependence on electricity demand and energy use in residential buildings. The result of the study shows that adopting certain passive design strategies through appropriate selection of building materials, proper building orientation, adequate natural ventilation and application of some design elements can provide natural cooling and reduce the energy used for cooling in the buildings. The paper concludes that this will limit the energy demand for cooling and will also result in an adapted architecture to the climatic environment, which will encourage innovation design solutions for building professionals in a hot-dry climate.
Keywords: architecture, buildings, climate, cooling, comfort, design, energy, passive, residential, strategies.

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1 Introduction

In most developing countries, especially those situated in tropical regions, with a hot dry climate, extreme heat presents special problems in urban areas because of the retention of heat by buildings if ventilation for cooling at night is inadequate (Weihe, [1]). In many of these climatic regions, many of the residential buildings are not suitable for the occupants because a large proportion of the buildings are poorly designed for the climate. In addition, because their economies cannot provide mechanical air conditioning for the majority of their urban housing; the comfort and wellbeing of the occupants therefore depend entirely on the design and construction of the houses.

In Nigeria, designs of apartments in general are not responsive to the requirements of the tropical climate. Residential buildings are designed without giving due importance to the parameters that are responsible for enabling thermal comfort without much dependence on energy use. Dependence on artificial lighting and ventilation is therefore common in all apartments. However, frequent power disruption and load shedding in Nigeria, sometimes over six hours a day, amid hot and dry conditions, have made the life of urban dwellers miserable. As the load-shedding situation continues to worsen, the excessive heat drives people to use more electricity at their homes and offices. The situation becomes worse during the peak dry season from mid March to early May when the ambient temperature becomes very high. During this period, the demand for electricity use goes up to its highest level because of hot weather, as well as a huge need for cooling energy. Because of the increase in energy demand and with its inadequate supply, buildings without active climatization will engender a poor indoor climate, which leads to fatigue, health risks and inefficiency. It is against this background that this study is designed to describe the passive design approach for residential buildings in the hot climate of Nigeria.

2 Methods

2.1 Description of the study area

Bauchi is located is the north-eastern part of Nigeria at latitude 10º 17'N and longitude 9º 49'E. The climate is characterized by high temperatures and low humidity in the dry season. The diurnal temperature varies from an average daily maximum of 31.6ºC to a daily minimum of 13.1ºC.The mean relative humidity is highest in August (66.5%) and lowest in February (16.5%). The mean annual rainfall ranges between 800-900mm per annum in the southern part and only 700mm per annum in the extreme north. The dry season occurs between September and May, while the rainy season is between May and September. The hottest month in Bauchi is April with 40.5ºC, while the coldest months are December and January, with 6.11ºC and 7.22ºC respectively.

2.2 Method of investigation

100 urban residences in Bauchi were taken as objects and questionnaire surveys and field measurements on the nature of residential thermal environment were conducted from February-May 2009.

2.3 Outline of survey

100 households were the objects for questionnaire survey. Temperature, relative humidity and air velocity measurements were taken. Each household was given questionnaires depending on the number of adults (i.e.16years old above) in the family, 3 liquid crystal thermometers were hung onto the wall at a height of 1.2m, one for the living room, bedroom and the other for outside under a shaded wall, together with a wet and dry bulb hygrometer. Residents were required to fill the questionnaires while the research personnel record the environmental measurement thrice in a day (7-10am, 12-3pm, and 5-8pm). The contents of the questionnaires mainly include resident's demographic and socio economics characteristics, building characteristics, thermal comfort perception of the living spaces etc.

2.4 Outcome of investigation

Cement sandcrete structure plays an important role in the building enclosure with the proportion of 48%, while 20% of the buildings are built with mud bricks and another 15% with stone structures, 6% with burnt clay bricks and compressed earth bricks while just 5% are built of thatch. The mean size of sleeping room per-household floor areas is from 10.28m^2 while the average room height is 2.7m.The average window area is 0.89m^2.From the environmental measurement carried out, the temperature measurements in the buildings shows that the conditions are bad since the indoor temperature rises to extremely high value of 37ºC in the afternoon (figs 1,2).

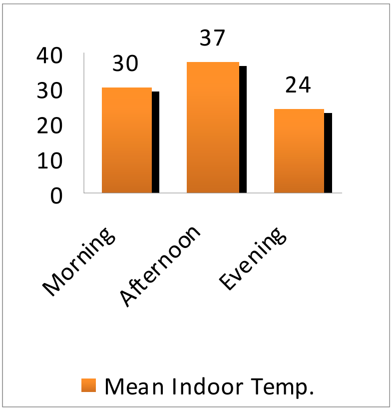

Figure 1: Mean indoor temperature.

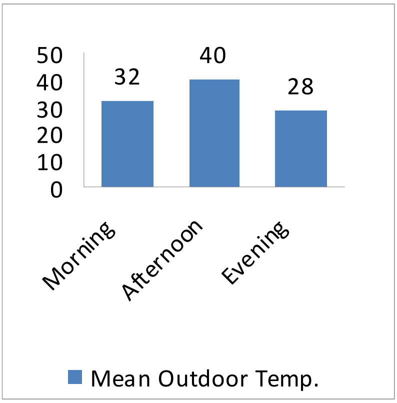

Figure 2: Mean outdoor temperature.

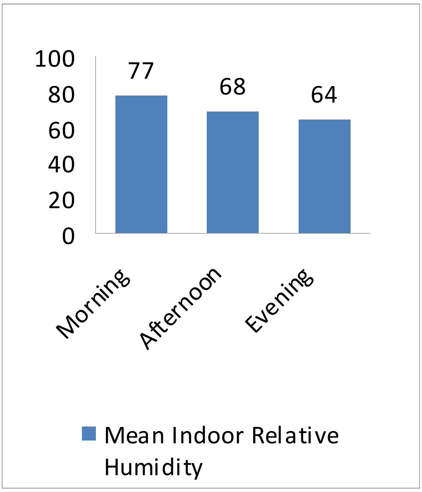

Figure 3.

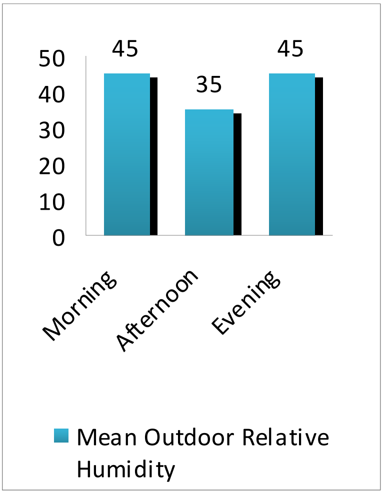

Figure 4.

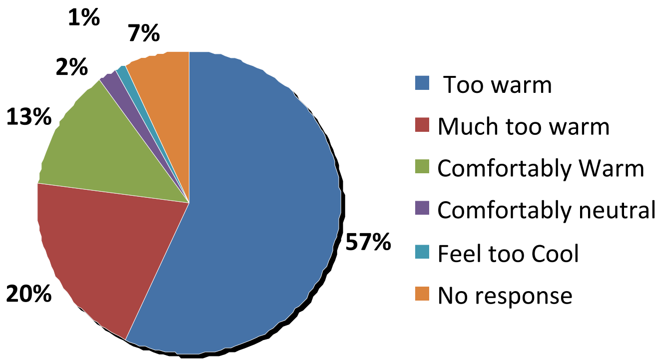

Figure 5: Thermal comfort vote.

The mean outdoor relative humidity is very much lower compared to that of the inside especially in the afternoon as a result of fluctuations in air temperature (figs 3, 4).

Further investigations shows that the mean indoor air velocity in the day (i.e.morning (0.12m/s), afternoon (0.11m/s) and evening (0.12m/s) is very low hence lead to much dependence on mechanical cooling for comfort. A large portion of the occupants of residences find their thermal environment too warm (57%), much too warm (20%), comfortable warm (13%), and comfortably neutral (2%) (fig 6).The thermal preference of the occupants of the residences shows the need for indoor cooling of the building for occupants comfort. Greater percentage (88%) of the occupants prefers a cooler indoor even though they rely mainly on natural ventilation through the use of window (figs 5,6).

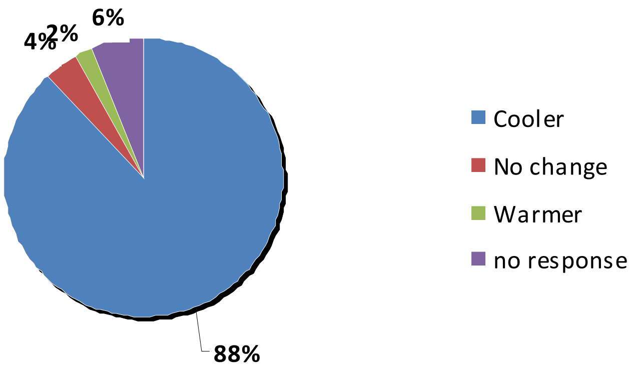

Figure 6: Preference thermal comfort vote.

3 The need and benefits of passive design approach in residential buildings

The global trend in the design and construction of buildings is that of using passive and low –energy strategies to achieve environmental quality especially in hot-dry climate. The hot-dry climate poses environmental challenges of high temperature and this extreme temperature has to be catered for at the design stage to avoid absolute dependence on active energy systems for indoor comfort. In Nigeria, where power supply is epileptic and erratic, most residential buildings depend on energy excessively to attain indoor comfort particularly in buildings that are not passively design. When considering economy of use and unavailability of power supply and even the resultant effect in the green house emission it is better to avoid dependence on active energy system for indoor comfort. Likewise, since mechanical indoor comfort provision accounts for a sizeable percentage of energy use in most buildings, definite approach must be adopted to minimise or eliminate the use of active energy. Low-energy building can be achieved through deliberate choice of passive design approach that suit a particular climate for indoor comfort provision and to accomplish this passive design strategies are needed. Passive design is a low energy-intensive method of keeping a building cool by relying on architectural design. Heat avoidance techniques, natural lighting and natural cooling methods are incorporated in the structure to minimise energy consumption while improving the indoor comfort level. The benefits of passive design are obvious; considerable peak load reduction for the utility company, improved comfort, lower utility bills and little additional cost to the builder.

4 Passive design strategies for hot dry climates

Well-designed passive buildings maintain the best environment for human habitation while minimizing the cost of energy. The objectives of passive buildings are to improve the comfort levels of the occupants and reduce energy use (electricity, natural gas, etc) for heating, cooling and lighting. According to

Hyde [2] passive building design is of importance in hot climate because of limitations of conventional energy a source in terms of both cost and availability. It is evident from the above that passive building design is vital for many reasons. Having justified the needs for passive buildings, it is important to focus on the basic design principles that can bring about energy efficiency and improvement of thermal comfort in residential buildings in Nigeria. The following design strategies are considered for application in hot dry climate in Nigeria:

4.1 Site selection, analysis and planning

There are many sources of energy available locally within a building site. These include direct and diffuse radiation from the sun, air movement from winds and temperature differences, biomass from vegetation, as well as geothermal and hydro-kinetic sources. The site is a living and working ecosystem (Yeang, [3]) therefore site selection, analysis and planning constitute the first step of passive design strategy. Adoption of environmental criteria in site selection is proportional with success of other stages directly. The most appropriate ecological, economic and physical fit between site, building development and the resulting cultural landscape is a product of sound site analysis and assessment. Hence, a careful site assessment can enable developers to capture the land's potential views, solar access, natural drainage opportunities, natural shading through vegetation, cooling from prevailing wind while minimizing or avoiding damage or disturbance to the site and surrounding areas. Therefore a proper understanding and analysis of the site resources, relationships, and constraints will enable the designers to maximize energy efficiency while conserving and restoring ecological and cultural resources. UNEP [4] warns that improper planning of the site can result in 'heat island effect'.

4.2 Building orientation

In Northern Nigeria, proper orientation of most houses are not given due considerations. Properly oriented buildings take advantage of solar radiation and prevailing wind. According to Gut and Ackerknecht [5], the longer axis of the building should lie along east-west direction for minimum solar heat gain by the building envelope. Wong and Li [6] performed field measurements and computational energy simulations to examine the effectiveness of passive climate control methods such as building orientation in residential buildings of Singapore. Their results state that the best orientation for a building in Singapore with its tropical climate is for the longer axis of the building to lie along east-west direction. They also conclude that the cooling load for a residential building can be reduced to 8% -11% by following this orientation.

The passive design feature on orienting the longer axis of the building towards east- west direction, as suggested Wong and Li may not always be possible, especially due to actual orientation of the site, that is, when the site itself is longer on the west and east sides. In such a case, the west facade needs more attention because it heats up in the afternoon and important rooms such as bedrooms are generally used later during the day when residents return from office. The east side is less problematic as it warm only in the morning when only few households occupy the major rooms.

4.3 Surface-to-volume ratio

The volume of space inside a building that needs to be heated or cooled and its relationship with the area of the envelope enclosing the volume affects the thermal performance of the building. This parameter, known as the S/V (surface-to-volume) ratio, is determined by the building form. For any given building volume, the more compacts the shape, the less wasteful it is in gaining/ losing heat. Hence, in hot, dry, regions and cold climates, buildings are compact in form with a low S/V ratio to reduce heat gain and losses respectively. Also, the building form determines the airflow pattern around the building, directly affecting its ventilation. The depth of a building also determines the requirements for artificial lighting - greater more the depth, higher the need for artificial lighting and greater the energy demand of such building.

4.4 Room orientation and floor plan zoning

According to Gut and Ackerknecht, the arrangement of rooms depends on their function and according to the time of the day, they are in use. Watson and Labs [7] have claimed that a house can be made more energy efficient if it is planned according to solar orientation and prevailing wind direction. However, they did specify how much energy saving is possible through such planning. Overheating due to solar radiation is the prominent problem in Northern Nigeria especially in Bauchi during the dry season in the daytime. Givoni [8] points out that cross-ventilation can be used to enable faster cooling and better ventilation. He stresses that building layout which provides good potential for cross-ventilation is more appropriate for developing countries in hot-humid regions where the vast majority of people cannot afford to buy air conditioners. He recommends a spread out building with openable windows to facilitate cross-ventilation. According to Gut and Ackerknecht, bedrooms can be located on the east side where it is coolest in the evening. Rooms which are in use for most times of the day, such as living rooms should be located on the northern side. Stores and other auxiliary spaces should be located on the disadvantaged side, mainly on the western sides. Provided the kitchen is used during morning and midday hours, it can be located on the west side as well. Rooms with high internal heat load, such as kitchens, should be detached from the main rooms. The usual trend for orientation of rooms in residential buildings of Nigeria is to give maximum priority to master bedroom followed by other bedrooms.

4.5 Building envelope

Heat enters and leaves a home through the roof, walls, windows and floor. Internal walls, doors and room arrangements affect heat distribution within a home. These elements are collectively referred to as the building envelope.

Envelope design is the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings. Good envelope design responds to climate and site conditions to optimise the thermal performance. It can lower operating costs, improve comfort and lifestyle and minimise environmental impact. As the main goal in building design of tropical climates is reduction of direct heat gain by radiation through openings and reduction of internal surface temperature, the building should be designed with protected openings and walls (Gut and Ackerknecht [5]). The external walls can be protected by designing the roof so that it extends far beyond the line of walls and has broad overhanging eaves. Cheung *et al.* [9] had conducted a study to reduce the cooling energy for high-rise apartments through an improved building envelope design. Their study shows that annual cooling has an almost linear relationship to the solar absorptance (amount of solar energy that passes into a material) of the external surfaces. Energy savings were found to be high with lower solar absorptance. A 30% reduction in solar absorptance can achieve a 12% saving in annual required cooling energy. They concluded that 12% saving on cooling energy could be obtained from using white or light colour external wall finishes.

4.6 Utilizing natural resources as building materials

Generally materials used in modern buildings obstruct the flow of air, making the use of mechanical ventilation essential. In Nigeria, buildings are usually built with cement blocks but in recent times, the use of local materials is being promoted and a lot of research is being done into its efficiency and sustainability for achieving good indoor climate. In almost all localities, nature has provided us with some good quality materials to build with and some of these materials require little processing or transporting. Some of these materials are renewable resources like trees and straw, and some may be so abundant that their supply seems almost inexhaustible like rocks, clay and sand. One of the beauties of building with local materials is that they seem to fit well with the feeling of the place naturally (Hart and Hart, [10]). Fortunately, most of these materials are readily available in Nigeria but are not used optimally. The issue of indoor temperature and energy use is often dependent on the building materials. Mud brick (adobe) is an extremely valuable building material, useful for both walls and floors. It is composed of between 20 and 30percent clay, with the rest mostly sand. Such soil is common in many areas of Nigeria, though buildings made of adobe are mainly found in the northern part and this has been mostly adopted for economic reasons and for a good indoor temperature due to the extremely high temperature found in the area. Irrespective of where the mud bricks are used, they are often known for their cooling effect. Especially at night, residents can be assured of a good indoor climate without the use of any mechanical effects. A significant development on this material has been the manufacture of cement stabilised compressed earth block. Soils used in these blocks are clay based weathered rock. The blocks are stabilised with as little as 5% off white cement and compressed to give a mass of 2,200kg/m3 houses built from these blocks have maintained comfort conditions in a wide variety of climatic zones. They take maximum advantage of the fact that small changes in mean radiant temperatures have a far greater effect on the comfort of the occupants than similar changes in air temperatures

4.7 Natural ventilation

Living in hot climate can quickly become uncomfortable for its inhabitants with the extreme heat that is built up by midday. That is why it is important for the building structure to have effective ventilation and an internal temperature below the outdoor level. Natural ventilation keeps the air moving within the indoor environment and, therefore, keeps the inhabitants cooler even without the use of energy. Wong and Huang [11] made a comparative study on the indoor air quality of naturally ventilated and air-conditioned bedrooms of residential buildings in Singapore. They observed that CO2 levels of bedrooms using air conditioners are consistently higher than those utilizing natural ventilation. Thermal comfort comparison of the air-conditioned bedrooms and naturally ventilated bedrooms indicate that the air-conditioned bedrooms are usually substantially overcooled, resulting in extremely high PPD (Percentage People Dissatisfied). Whereas, in natural ventilated bedrooms, the utilization of fans was sufficient to achieve the required thermal comfort. They also found that occupants utilizing air conditioners exhibited more SBS (sick building syndrome) symptoms than those utilizing natural ventilation. Liping *et al.* [12] also conclude that natural ventilation is an attractive alternative to reduce the associated problems with air-conditioned buildings because natural ventilation has potential benefits such as reduced operation costs, improved indoor air quality and satisfactory thermal comfort.

5 Application of design elements for natural cooling in residential buildings

Some common design elements that directly or indirectly affect thermal comfort conditions and thereby the energy consumption in a building includes:

5.1 Landscaping, vegetation and greenery

Landscaping is the most under utilised area of domestic architecture in spite of the fact that it is probably the cheapest and most effective way of improving year round comfort and energy efficiency. In Nigeria, vegetation grows rapidly around and can be use as an architectonic element either vertically or horizontally in the shape of pergolas, screens, vegetated atriums, patios, flower pots, and others, in order to create microclimates and to favour architectural design. Internal and external vegetation could be considered as a potential design element. The idea is to use it as an essential characteristic to reflect the architecture of the area and to produce the benefit of a microclimate that adapts buildings to their immediate environment. The use of vegetation provides shade and freshness almost the whole year. When the buildings in hot climates are surrounded with vegetated screens, a natural freshness that isolates the building from sun rays is achieved. Raeissi and Taheri [13] acknowledge the beneficial effects of trees and vegetation. They state that plantation of trees can result in energy saving, reduction of noise and pollution, modification of temperatures and relative humidity and psychological benefits on humans. Their study on proper tree plantation for energy saving concludes that the cooling loads of a house can be reduced by 10%- 40% by appropriate tree plantation. Even though appropriate tree plantation can bring significant amount of energy savings, this design principle can only be applicable in buildings of Nigeria if adequate space is left open either as a set back area or as designated green space within the residential environment.

5.2 Enclosed courtyard between buildings

Another common natural ventilation and thus cooling technique is the use of atria and courtyards. Courtyards can reduce the cooling energy needs of residential buildings in a very significant way especially if carefully designed.

5.3 Introduction of fountain between buildings for evaporative cooling

Evaporative cooling lowers indoor air temperature by evaporating water. It is effective in hot-dry climate where the atmospheric humidity is low. In evaporative cooling, the sensible heat of air is used to evaporate water, thereby cooling the air, which in turn cools the living space of the building. Increase in contact between water and air increases rate of evaporation. The presence of a water body such as a pond, lake, sea etc. near the building or a fountain in a courtyard can provide a cooling effect. This process is called adiabatic with no heat being gained or lost (fig 7).

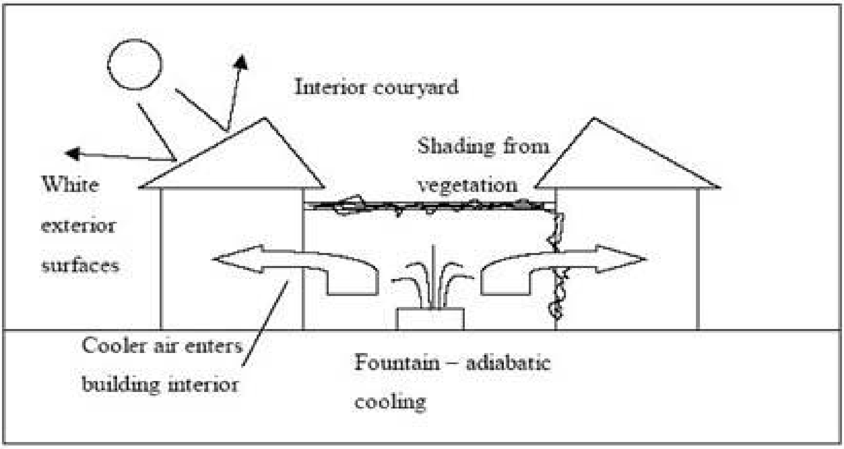

Figure 7: Evaporative cooling through the application of a fountain between buildings.

6 Conclusions

Buildings will cause thermal discomfort if an effective strategy is not adopted to reduce the extra heat going into it. Out of the numerous passive design strategies that have been adopted by others in different climates, only those strategies discussed in this study have been chosen that can meet the purpose of this study and can be applied in the context of hot dry climate of Nigeria. The strategies selected pertain only to possible energy savings and enhancing low energy architecture in tropical climate. By adopting the above mentioned design strategies this will limit the energy demand for cooling and will also result to an adapted architecture to the climatic environment which will encourage innovation design solutions for building professionals in hot-dry climate.

References

[1] Weihe, W.H. Life expectancy in tropical climates and urbanization. World Climate Technical Conference. Geneva, World Meteorological Organization, pp. 313-353(WMO No.652), 1985.
[2] Hyde, R. Climate Responsive Design. E and FN Spon. London, U.K., 2000.
[3] Yeang, K. Designing with Nature, Mcgraw Hill, USA, 1995.
[4] UNEP. Eco-housing Guidelines for Tropical Regions. Bangkok: United Nations Environment Programme Regional Resource Centre for Asia and the Pacific, 2006.
[5] Gut, P. & Ackerknecht, D. Climate Responsive Building: Appropriate Building Construction in Tropical and Subtropical Regions. Switzerland: SKAT,1993
[6] Wong, N.H. & Li, S. A Study of the Effectiveness of Passive Climate Control in Naturally Ventilated Residential Buildings in Singapore. Building and Environment, 42 (3): 1395-1405, 2007.
[7] Watson, D. & Labs, K. Climatic Building Design: Energy-Efficient Building Principles and Practice. New York: McGraw-Hill, 1983.
[8] Givoni, B. Climate Considerations in Building and Urban Design. New York: Van Nostrand Reinhold, 1998.
[9] Cheung, C.K., Fuller, R.J. & Luther, M.B. Energy-Efficient Envelope Design for High-Rise Apartments. Energy and Buildings, 37 (1): 37-48, 2005
[10] Hart, K., and Hart, R. Keep Your Cool. Retrieved on 2005-06-09 from http://www.greenhomebuilding.com/recyclematerials.htm 2005
[11] Wong, N.K. & Huang, B. Comparative Study of the Indoor Air Quality of Naturally Ventilated and Air-Conditioned Bedrooms of Residential Buildings in Singapore. Building and Environment, 39 (9): 1115-1123, 2004.
[12] Liping, W., Hien, W.N & Shuo, L. Facade Design Optimization for Naturally Ventilated Residential Buildings in Singapore. Energy and Buildings, 39 (8): 954-961, 2007.
[13] Raeissi, S. & Taheri, M. Energy Saving by Proper Tree Plantation. Building and Environment, 34(1999): 565-570, 1999.

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Sensitive apertures

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Abstract

Light, vision and perception are fundamental aspects of our conception of space and our experience of architecture. The perception of light is affected by the composition and surface of materials, by the geometry of space and by the physiology of the sense of sight. This is a study of 'light itself as a material,' carried out as a Material Technologies Master's Thesis. The research is focused on light at dawn and dusk, when twice a day photoreceptive cells in our eyes, cones and rods, reach a crossover point of equal efficiency. This perceptual phenomenon within the 'mesopic vision range' marks a unique moment of visual awareness and the threshold for a search for the 'right' kind of light. It begs the question: Right kind of light for 'what'? What if through the free and ordered play of light we are able to fine tune the coordinates that affect our inner sense, seeking points of passage in a hypothetical matter-space and time-spirit continuum? What follows is a series of logical propositions, perceptual observations, physical experiments and 'hardware-software' simulations that examine the hypotheses and generate possible heuristic evidence.
Keywords: light, material, geometry, spatial and temporal perception, reflection, refraction.

1 Introduction

Rather than dimming daylight after using large expanses of translucent materials such as plastic or glass, this study is focused on using opaque materials pierced with small, solar oriented, refractive apertures to admit and redirect a limited amount of light onto the interior surfaces of space. When the direction of the sun and the geometry of the light containers align, light will fill the spaces uniformly. At all other times, the enclosure will admit light in a dynamic way that will reveal the changing light and the passage of time.

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Structurally, this is proposed as a cellular network of ceramic light containers shaped to receive light from the apertures. Together, these cells will form a field of roof or wall enclosures within an otherwise dark space. As vision in the mesopic range primarily affects our ability to distinguish detailed shapes and color, the scale of the light containers and the presence of refracted color will be fine-tuned to highlight this change in our perceptual capacity.

2 Solar origin

It appears that most life forms have evolved in response to the radiative power emitted by the sun. Therefore, it is not surprising that the evolution of our sense of sight is genetically linked to the sun's spectral properties. An overlay of the spectral distribution of power from the sun and our range of vision demonstrates that the evolutionary target of human visual sensitivity to light matches the range of most abundant wavelengths of the sun.

Radiative absorption by molecules in our atmosphere significantly impacts energy received at sea level. Note the drastic valleys of irradiance caused by absorption, especially in the longer wavelengths. Radiation within the visible range, however, remains relatively smooth. Within the range of visible wavelengths (380nm - 780nm) our vision has varying sensitivity. Generally speaking, sensation peaks in the middle of this range (around 555nm) and is very week toward the ultraviolet and infrared boundaries—Figure 1.

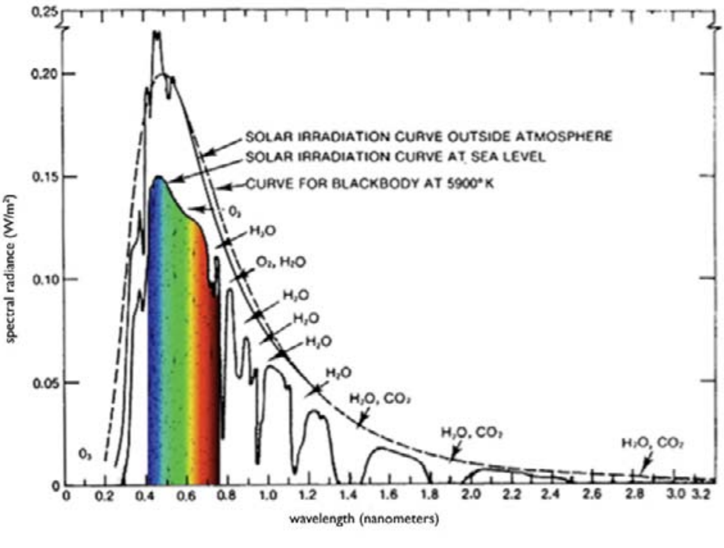

Figure 1: Solar irradiation [1].

2.1 Spectral sensitivity

A more subtle fact is that this spectral sensitivity curve changes relative to the amount of light present in our visual field. Our vision goes through three major wavelength sensitivity changes. These are called the photopic, scotopic, and mesopic visual ranges—Figure 2.

Most of our daily visual experience occurs within the photopic range (> 3 cd/m2). This is our light-adapted vision. At these levels, cone cells are the most active. Strong signals from the three types of cone receptors allow us to maximize our sensing ability for color and detail. The great majority of cone cells are packed in the fovea of the eye—Figure 3—, which corresponds to the center of our vision.

Vision in the scotopic (< .001 cd/m2) range requires dark adaptation. At these light levels, rod cells are the dominant receptors and cone response is nearly non-existent. Because there is only one type of rod cell, scotopic vision is color-blind. What rods lack in color detection, however, is made up for by an increased ability to sense peripheral vision, detect movement, and detect subtle changes in shape and contrast. An example of this phenomenon occurs during stargazing when an object in the sky is invisible to the center of vision but is revealed when we avert our eyes slightly to allow more rod cells to pick up a response.

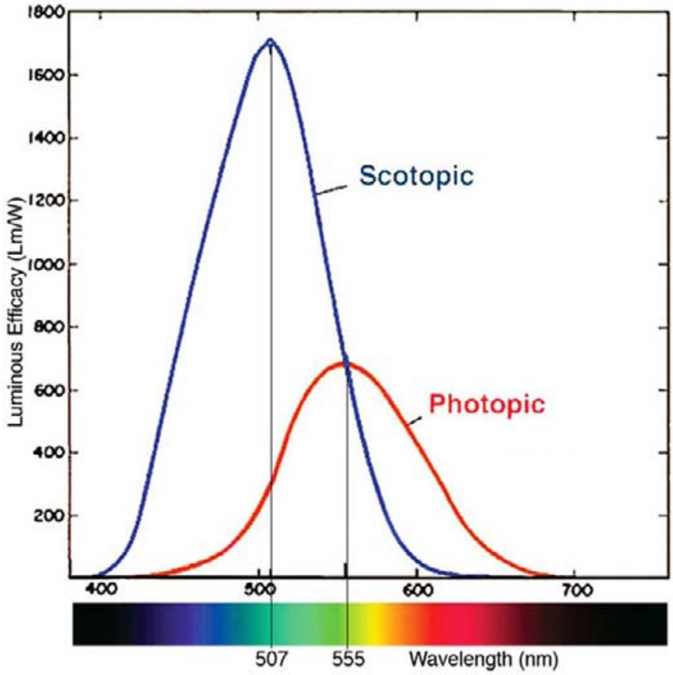

Figure 2: Luminous efficacy functions [2].

Finally, mesopic vision range (.001cd/m2 - 3 cd/m2) occurs in between light and dark. Within this range, rod and cone response is shared. As of yet, there is no standard luminous efficacy function for mesopic vision. It appears that vision in this range undergoes rapid changes that are the result of a complex set of factors including illumination level, spectral content of the image, and adaptation time. Owing to a lack of scientific knowledge relating to the mesopic range, it might be best described experientially as a combination of photopic and scotopic vision. Color and detail are simultaneously detectable with peripheral vision, motion detection, and light sensitivity.

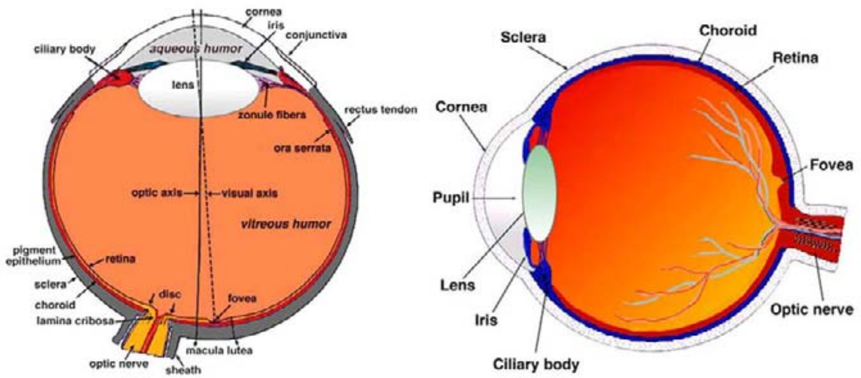

Figure 3: Sagittal horizontal and vertical sections of the adult human eye [2].

2.2 Pupil aperture

Adaptive pupil size helps the eye to accommodate the broad range of light levels spanning photopic and scotopic vision. Beyond the basic principle of letting more or less light into the eye, the size of the pupil—Figure 3—also determines the region of the retina that receives light and helps to explain the perceptual changes of dark versus bright environments. In bright light, the pupil contracts and limits incoming light to distribution in the center of vision containing most of the cone cells. In diminished light, muscles in the iris relax, resulting in an enlarged pupil that admits light to a much larger portion of the retina, thus allowing rod cells increased opportunity for response.

2.3 Light and awareness

The study of light, particularly since the invention of the electric variety, has had a strong connection with productive activity—for good cause, since we need light to do most things. We need light to bathe, cook, read, work, play, etc. A lot of effort has been put into finding the most appropriate light levels to facilitate productive efficiency. Organizations like the IESNA (Illuminating Engineering Society of North America) have published recommended light values for tasks ranging from writing, to assembly-line production, to casual reading in bed.

This study is not focused on the production-based tradition of light investigation. After initial unbiased examination of spaces with very low light levels, it was evident that this work was not aimed at probing the use of light for conventional tasks like reading, working or recreation. Instead, what emerged was a desire to study the kind of light that is most conducive to the act of thinking—or meditation.

While it is possible to think in the dark, or with closed eyes, it is plausible to make an argument that our mind is stimulated and merged in a continuum with our senses, and that an environment that is fine-tuned to sharpening sensorial perception may also be one that opens our mind to more creative thinking.

3 Light measurement and perception

A large part of this study investigates the relationship between ambient light level and perceptual awareness. To test this relationship, a method was needed for recording objectively light along a smooth gradient from bright to dark. The transitioning sky during twilight emerged as the ideal environment for doing this. The sky offers a uniform field of light that eliminates potentially distracting detail.

Light level recording is a complicated task. Until recently, without significant financial investment on sensitive luminance meters, it has been difficult to find an affordable and accurate device that is adjustable to the unique sensitivities of human vision. Recently, however, it has become possible and affordable to measure light data with greater accuracy using an average digital camera. In fact, any picture taken with a calibrated digital camera can be interpreted by a software program to measure accurate luminance values (visual power per unit area, measured in candelas/m2) for each pixel of the image. The advantage of this method is that the record of light is closely matched with the field of interest to the observer.

In this study, the field was an observed area of the sky. Using the imaging software, a reliable average luminance value was calculated over a selected area of the image. This value was then associated with the perceptual observations taken at the same time during twilight.

3.1 Recording software

Photosphere (software written by Greg Ward, Anywhere Software) was used to measure luminance values [3]. The first step of the process involved calibrating the user camera to the software. A series of 9-bracketed photographs were taken of an interior scene with a large range of light values. These photographs were then merged in Photosphere to create a single high dynamic range (HDR) image that was stored as the calibration data.

Figure 4 shows a typical example of an HDR image displayed in Photosphere as a false color luminance map. This particular image is from the overhead sky at 7:35 on May 9th (west is up). Even though the brightness of the sky was

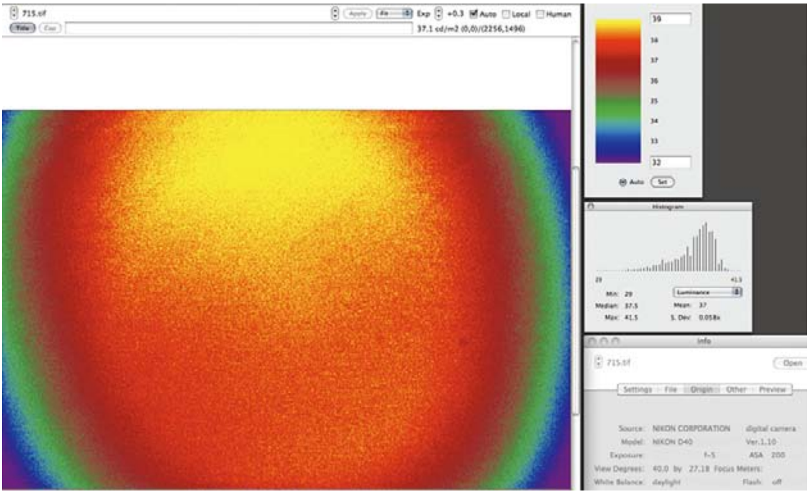

Figure 4: Photosphere false color luminance of zenithal sky at twilight.

relatively consistent to the naked eye across the image, the luminance map clearly shows more brightness, as it should, toward the western-setting sun. Because the range of luminance values is so narrow (32-39 cd/m2), the luminance value recorded for this time is an average of the entire image.

Proceeding this way, average luminance values corresponding to observed areas of sky were recorded for each image. Another way to visualize luminance values across an entire twilight session can be done by setting a custom range for the false color map based on the brightest values from the early photo and darkest values from the latest photo.

3.2 Perceptual observations

The twilight observation sessions provided a good deal of insight into how light levels affect perception. After the first few evenings a series of indicators emerged which became useful to record and track within and between evenings.

"To what is it due, this sense of infinite calm emanating from these [twilight] light phenomena? Compare them with the rainbow, arousing feelings of cheerfulness and joy [4]."

3.2.1 Floaters

One of the first, readily perceived phenomena was the visual presence of 'floaters'. These are microscopic fibers within the vitreous humor (the clear gel that fills the space between the lens and the retina) that have clumped together. These clumps of debris float around within the vitreous cavity, and they can cast tiny shadows on the retina. The degree of distraction these floaters cause varies widely among subjects but what was interesting to note was that they disappeared when there was no longer sufficient light to cast their shadows—and how at that moment seeing became more pleasurable.

3.2.2 Stars

A subtler phenomenon was the occurrence of a field of ‘shooting stars’. These random-appearing, uniformly distributed flashes were most visible during the early part of twilight. However, slowly as the sky darkened, they became less and less visible until a certain time when they would vanish completely. Again, this phenomenon is highly variable from person to person. If extreme, they can be the sign of some type of eye disease—but normally the explanation is that the vitreous is tugging on the retina, causing the flashes and shooting stars. The fact that this phenomena disappeared beyond a particular light level suggests the over abundance of light contributes to the friction between the vitreous and retina. Because it was also observed that the most comfortable light level was consistently experienced within minutes of the absence of visual stars, there is reason to think that visual comfort is directly related to the light level that causes the least physiological tension within the eye.

3.2.3 Periphery

Peripheral vision is another factor relevant to the degree of perceptual awareness and comfort level. As the sky gradually darkened, it was possible to experience the increasing awareness of visual periphery. In bright light, most of our visual attention is given to the center of vision where cones provide the dominant response. This limits our visual awareness because we do not get much feedback about a broader spatial environment. Of course, the opposite is true in darkness when peripheral vision is good but we struggle to see color and detail. During the twilight studies, it was observed that there is a middle ground where both rod and cone vision is enabled without sacrificing too much of one or the other. This condition was found to heighten the state of perceptual awareness.

3.2.4 Sound

Though most attention during the observation sessions was given to visual perception, the emergence of a heightened acoustic sense was also noticed. Offering a reason for this goes beyond the intent of this study, but the experience was straightforward; it was sensed that during twilight a general white noise gradually receded, creating an acoustic calm in which the range of hearing increased, allowing wildlife, or human chatter, or distant cars to stand out and be heard much more clearly.

3.3 Analysis

Once the perceptual values could be matched with numerical luminance data, it was possible to graph the outcome and look for trends. Across all observations, the ideal comfort luminance level ranged between 3.92 and 8.00 cd/m^2. This consistency within a much larger range of observed light levels was not expected. It suggests that an ideal luminance level for perceptual awareness may exist and opened a window for future investigations.

4 Light containers

To set up a space conducive to perceptual awareness and thinking, the final stage of this study was to create an architectural enclosure system that could function as an analogue of the desired luminance level of the twilight sky. The first major constraint of this system was that the light levels needed to be drastically reduced from outside to inside. To accomplish this using predominantly opaque material, a field of apertures was proposed to evenly distribute small quantities of light.

Secondly, the light that was allowed to enter through the enclosure needed to be as uniform as possible. This requirement sparked the notion to use refraction at the aperture and spatial depth within the enclosure in order to spread the light on the inside surface of the enclosure. Using packing geometry from previous cube corner experiments to create a uniform field, it made sense to place the aperture at the apex of a tetrahedral geometry—the light 'container'.

4.1 Refraction studies

A series of diagrams and graphs looked into the range of possible refraction angles using materials such as acrylic and glass. These clearly indicated that the more refractive materials are able to more effectively bend the light. These diagrams were then used to create the specific geometry of a typical light container needed to contain the refracted light.

Lead crystal glass, with an index of refraction (n) of 1.60 was chosen for the final form. To ensure that the surface of the light container captured the refracted light, the form was made slightly steeper—Figure 5.

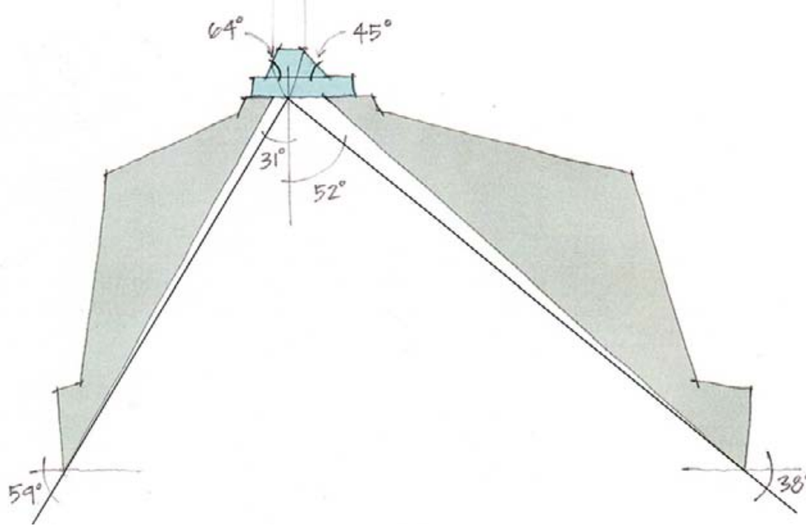

Figure 5: Typical container refraction analysis.

4.2 Aperture fabrication: glass

A strict requirement of the apertures was that they had to be optically clear—the surface of the glass had to be smooth and specular. Any light scattering at the surface would have hindered the refractive performance of the glass.

After talking with glass fabricators, it became clear that graphite might be a perfect mold material for casting glass. Even though graphite is an ideal material for casting glass into, it is prone to oxidation when exposed at temperatures above 480°C. This required glass to be melted in a crucible first, then poured into the graphite mold and subsequently placed in a separate oven for annealing—fortunately, graphite's oxidation threshold was also the annealing temperature of the lead crystal glass used for the casting.

After annealing, the glass apertures required grinding to remove the upper half. This was followed by wheel polishing using water-lubricated abrasive pads decreasing in grit size from 240 to 400 to 800 to 1200. A final polish was made using a 9-micrometer polycrystalline diamond lubricant.

4.3 Light container fabrication

Slip-cast ceramic was chosen as the material for the light containers for its white firing color, structural integrity, and ability to provide insulation as a hollow form. Mold making became a critical process for producing the slip cast containers. Corian countertop material was tested for its machining ability and was eventually chosen as the ideal material for casting molds because it did not require any sealing treatment beyond spray mold release.

The surface finish of the light containers greatly affected the quality of light. To reinforce the intention of an evenly scattered interior light, a matte white glaze was chosen to minimize any specular behavior. After an initial bisque fire, the light containers were glazed using a spray applicator.

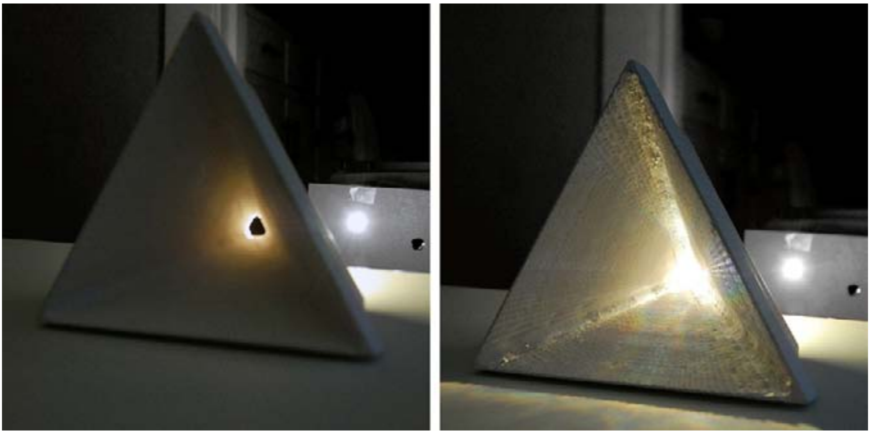

Figure 6: Light test, without aperture (left) and with aperture (right).

4.4 Assembly

Individual light containers were bonded into larger cell assemblies using fiberglass and epoxy resin. The space between cells on the outside of the enclosure provided opportunity for reinforcement, weather sealant, and additional insulation. Prior to the assembly of a large number of cells, a brief light study looked at the refractive performance of one container. The performative difference between aperture and no aperture provided some assurance that the cells would function as designed—Figure 6.

5 Experiencing light

Refractive colors were very visible in most of the cells and showed how the light was redirected. Irregularities in the geometry of the light path caused light to spill past the boundary of individual cells, as seen projected onto the walls of the drum in Figure 7. Finally, an HDR image of the enclosure was made to demonstrate the proposed method for analyzing the resultant luminance values. Despite the arbitrary luminous intensity of the projected light source, Figure 8 shows significant presence of light levels falling near the target luminance values at the upper boundary of the mesopic vision range.

The initial hypothesis of this research posed a provocative phenomenal question that has not yet been sufficiently addressed: that is how light affects our inner sense, our mental disposition. The empirical and epistemological method of that research is still elusive and is proposed as a topic for future studies.

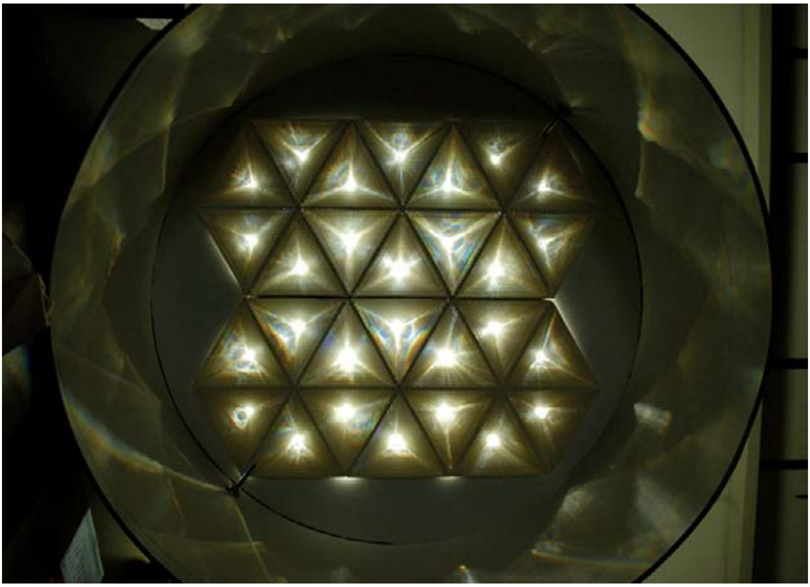

Figure 7: Light container assembly.

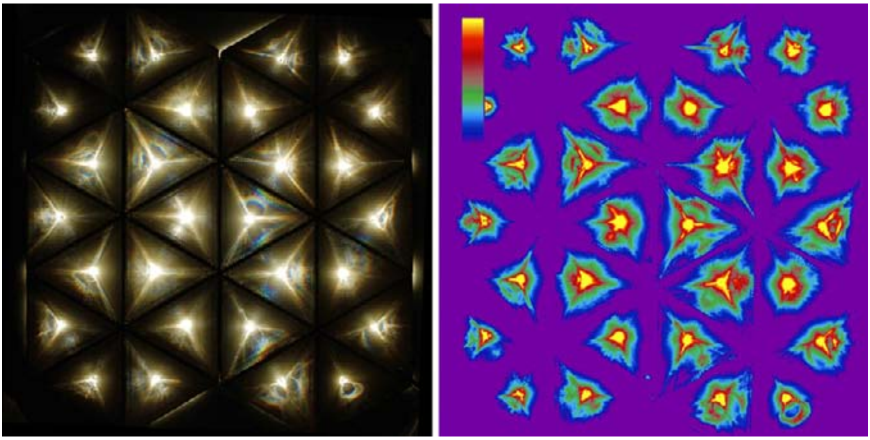

Figure 8: HDR composite photo (right), false color luminance image for values between 10 and 0.2 cd/m^2.

6 Future studies

There is historical evidence that perceptual awareness of subtle differences of intensity levels and chromatic composition of light at precise moments of the day was a key ingredient in religious celebrations and spiritual activities. It is worth noticing that a significant number of worship spaces have similar light levels to the ones investigated here. And, there is a precedent for the occurrence of spiritual rituals at precise moments of the day, namely the *matins* and the *vespers*, the first and the sixth canonical hours that are celebrated in prayer or song by many cloistered monastic orders, Benedictines, Cistercians, etc.

This intuitive cultural refinement in the selection of the nuances of light and its effect, perhaps subliminal, in our perceptual awareness and self-consciousness may have been dulled, or anaesthetized, by recent choices of a more pragmatic lifestyle. The enabling technology that brought about the advent of artificial lighting has undeniable benefits; but it has also generated as by-products the sacrifice of perceptual acuity and phenomenal loss.

A recovered knowledge and practice of the fine-tuning of light in space can bring extraordinary depth to the exploration of aesthetics in architecture; aesthetics considered not merely as a matter of conventional taste, but as a broader and finer integrative tuning of the sensual manifold, seeking both physiological comfort and mental well being. There are also precedents for the kinds of practice that require a fine-tuning of the body and relaxation of the senses to induce paradoxically a kind of *indifference*, or ‘peace of mind’: the Epicurean *ataraxia*, the Stoic *apatheia*, the extreme Stoic *adiaphora*, the Zen not-thinking, and the more general practices of ‘transcendental meditation’ [5].

Why should we seek this kind of light, this peace of mind? What may we get out of it? A simple answer may be that the benefit of such experience could have profound ethical and aesthetic consequences. It is an approach to the imagination and sensibility delineated in Kant's *Critique of Judgment*, and a reflection of the cognitive function analyzed in the "Transcendental Aesthetic," in the *Critique of Pure Reason*. Kant differentiates three kinds of syntheses that are supposed to be necessary to present objects to knowledge: synthesis of apprehension in intuition, of reproduction in the imagination, of recognition in the concept—or logical form in reason. There are two movements in the initial synthesis: one is to seize or touch, which is the inflow of the sensual manifold; the other is to bring together, to mix, the comprehension of this flow, as instantaneous intuition. The second is a fastening onto, a withholding of this intuition, and this occurs as a diachronic reproduction in the imagination. Finally, it is possible for the intuitive 'object' to be grasped out of the diachronic flow and captured through a final synthesis of recognition, a synthesis that opens the way to knowledge proper.

If there is a sufficient and necessary philosophical framework for this continued research, the proposed empirical modeling and testing will continue to follow a heuristic method, whereby the knowledge acquired will be confirmed through direct sensorial experiences leading to mental perceptions, and further on to phenomenal concepts. In the ensuing rheology, the researchers will become the prime materials of their own experiment: sensating, imagining, reasoning, emerging materials—finding stochastic portals, or inflections, in the hypothetical matter-space and time-spirit continuum.

References

[1] Valley, S.L., *Handbook of Geophysics and Space Environments*, Air Force Cambridge Research Laboratories: Bedford, Mass., Ch 16-2, 1965.
[2] WEBVISION, http://webvision.med.utah.edu/
[3] Anywhere Software, http://www.anyhere.com/
[4] Minnaert, M., *The Nature of Light and Colour in the Open Air*, Dover Publications Inc.: New York, pp. 268, 1954.
[5] Lyotard, J-F., *Peregrinations: Law, Form, Event*, Columbia University Press: New York, pp. 7-27, 1988.

Embracing nature and culture: the tropical Malay spa design

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Abstract

The tropical Malay spa design associated with a traditional Malay Single's House (*Rumah Bujang*) reveals a design construction in a setting that exploits the surroundings. It is strongly linked to the Malay heritage and cultural values. This paper explores the tropical design found in the Malay spa and how the spa activities are interrelated with the architecture that houses them. The Malay spa activities are glorified by the Malay people for the values of mysticism, spiritual enhancement, physical well being and emotional uplift and this architecture ensures the perpetuity of these cultural elements. This research ventures further into the design of the Malay spa, which can now only be found in small villages in the northern region of Malaysia and the east coast of Peninsular Malaysia. The methodology employed for this research records the visual data collection, architectural drawing documentation of spa design and observation of the activities that take place. Interviews with the owners of spas and the people receiving treatment provide a primary source of information. The Malay spa design depicts a humble vernacular architecture that nestles in a setting planted with fruit trees, flowers, herbs and spices. The Malay spa design in a Single's House can be studied as one example of sustainable tropical design. Proper planning of this architecture and its activity must be explored by complying with the traditional Malay philosophy, rituals and customs. The traditional values of the Malay people are apparent in this Malay spa, which justifies its continuation and has long been viewed as embracing nature in every sense of existence. The architectural elements portrayed are made strong with the symbiotic relationships between cultural elements and the natural surroundings.
Keywords: spiritual, rituals, natural setting, Malay spa, vernacular architecture, single's house.

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1 Introduction

This paper explores the Malay spa design associated with a traditional Malay house called a Single's House (*Rumah Bujang*), which re-emerged after the traditional Malay spa practices became publicly known in Malaysia (figure 1). The aspect of this tropical spa design clearly illustrates that the space planning and the environments are governed by the spa treatment activities. Current information available on house design only points out the basic data, which neglects the cultural and social aspects in detail. This is regarding the cultural influences particularly of the Malay culture, the philosophy and the 'whys' of the design, which were created along with the environment, within the perimeters of which this tropical Malay architecture style was erected [1].

Figure 1: Map of Malaysia.

Every space designed for the spa in this house carries its own meaning and the space planning involved speaks of a deeper cultural background. The rituals, customs and traditions that are associated with the Malay spa design present a new understanding and meaning to the interior space planning and the display of the detail embellishments. The detail embellishments relate to decorations such as a carving, air vent, interior finishes and many more detailed embellishments to the house. The 'slow death' that this style of architecture is facing has so far been ignored and overlooked in the name of development. Malaysia has developed rapidly since the economic boom in the 1980s until now. The rapid development witnesses the urge to move from the traditional style of architecture into buildings constructed with modern materials as demand for quick and cheap houses rises. It is a move from the local traditional materials, such as timber for the main structure, bamboo strips for the walls and floors, and sago palm or *nipah* palm leaves for the walls and roofs. The change appears in the application of materials, such as using bricks and concrete for the walls and clay tile for roofs. The modern houses are always built directly on the ground as opposed to the traditional house, which is always built on stilts. This is to encourage interaction with the environment while providing ventilation, protection against wild animals and avoiding flood water during the rainy season.

The current house construction also neglects the basic requirements for comfort in the warm climate as found in the traditional house design. The most apparent problem with modern house design is in the sun orientation of the building. It faces a major problem, especially during the hottest time of the day, as the sun radiation heats up the house. Unlike the modern building, the traditional Malay house orientation always points to the south-east direction, where the sun's radiation is welcomed in the morning and avoided in the afternoon. Many people do not understand the importance of the Malay spa design in terms of its design and knowledge that it imparts in its association with sustainable design, the current hot and debated issue. The Malay spa design has a lot to offer regarding the application of nature related elements, such as natural ventilation and natural lighting, which lower dependency on modern technologies and facilities. Efforts to preserve the style and meaning of this house style should be doubled; this can be achieved through awareness in printed materials as well as digital format. Hence the need to study the traditional Malay spa design as it depicts one of the most appropriate traditional Malay architectural elements. It applies materials that are sustainable. This spa design embraces the environment in a relationship that respects each other. In order to understand the tropical Malay spa design, it is vital to understand the definition of spas and how they come about. The rising demand for spas is related to the changing lifestyle that requires a person to relax, reflect, revitalise and rejoice oneself. Segerberg, an international spa professional, elaborates that spa guests have the opportunity to take time to listen to their souls and bodies [2].

2 Definition of spa

According to the International SPA Association, spas are entities devoted to enhancing overall well-being through a variety of professional services that encourage the renewal of mind, body and spirit. The Bali Spa & Wellness Association defines a similar interpretation, although with more focus on the Asian way [3]. On the other hand, Chamber's Encyclopaedic English Dictionary defines spa as a mineral water spring and a town in Belgium called Spa where such a spring was once located [4]. Spa is defined as a treatment of health to ensure total relaxation to those who receive the treatment. It can be categorised into six themes. They are [5]:

1. a resort providing therapeutic baths;
2. a resort area having mineral springs;
3. a fashionable hotel or resort;
4. a health spa;
5. a tub for relaxation or invigoration, usually including a device for rising whirlpools in the water.

Clark indicates that spas come in four types. They are the retreat spa, the resort spa, the day spa and the salon or mini spa [6]. They are all interchangeable, depending most importantly on the purpose of the spa and its location. Callen claims that the spa is no longer associated with mineral springs and therapeutic taking-of-the-waters. Spa currently comes in the form of chic pampering products that line the shelves of the plushest beauty boutiques and most desirable department stores, delicious and health boosting foods or the ultimate get away holiday destinations [7]. On the other hand, the oriental treatment of the Thai spa experience offers not just stress relief pampering but also delicious foods in exotic locations. The advantage of the Thai spa reveals that it combines traditional treatment, especially Thai massage, with a modern setting [8]. The Malay spa falls under the health category where the treatment is focussed on improving the health of spa users. This spa offers traditional beauty and health therapies aimed at enhancing well-being. It incorporates more modern therapies but is based on traditional rituals and customs. Their main focus is the body and soul, and achieving balance in one's life. Historically, the Malay spa treatment began by giving treatment mainly for women who were having problems with their health as well as post-natal treatment for new mothers [9]. Malay spa treatment for men was unheard of and never practised. This scenario was changed when the Thai spa and the Bali spa became popular in Malaysia. This paper also looks into the research objectives and the spa process requirements to be able to understand the spa design.

3 Objectives and methodology

The objectives of this research are mainly to stress the importance of recording the remaining Malay spa design in the two states of the Peninsular Malaysia, namely Kedah and Terengganu. Most of the recording and collection information for the database are produced in hard copies and digital format. The objectives are as follows:

1. to identify the interior space planning of the Malay spa design for their functions;
2. to explore the philosophy that is related to the interior space planning, the surrounding environment as well as the functions;
3. to examine the cultural influences on the interior space planning and the functions of the details embellishment and the philosophy associated with them.

The methodology employed for this explorative research gears towards content analysis and the understanding of Malay spa practices and spa design. It relies heavily on the availability of a literature review of very limited references. Most of the references pointed to the other type of spas, namely the Thai spa and the Bali spa. These also include largely references on traditional Chinese treatment through reflexology and tai chi kung and Indian ayurvedic treatment via traditional spices and herbal treatment. They can be found in a lot of old texts, scriptures and book of rituals. However, references on the Malay spa are unheard of if not too few and difficult to access. Thus, most of the information on the Malay spa relies heavily on first hand information acquired through interviews with spa owners and spa practitioners. Interviews with midwives who are still practising traditional medicine that are embellished with rituals will shed some information on the traditional Malay spa practice. These activities are done simultaneously with visits to known traditional Malay spas, such as at the Tanjong Jara, Terengganu and at the Ishan and Embun spas in Langkawi, Kedah. The rarity of the traditional Malay spas poses some challenge in the data collection process. Visual data collection activity that is done at the same time as the visits to the spas will give a clear picture on the operational process of Malay spas. The spas at the identified locations are also the case studies for this research, highlighting the meaning of the Malay spa in a proper rustic and traditional Malay village setting. Simultaneously, the documentation of the spa design takes place in the form of space analysis and the environment of the house.

4 Malay spa philosophy and rituals

According to Saad, a Malay spa practitioner, the Malay spa is not popular among Malaysians because the treatment is a well kept secret [10]. One of the excuses that contribute to the Malay spa being less known is that the Malay people do not want non-Malay people to know about the spa treatment. Only the Malay people have the privilege to inherit and learn about this traditional practice. Cultural values play important roles in keeping this tradition, which is passed down via oral traditions that embrace customs, rituals and taboos [11]. Another fear is that the Malays are very protective of their culture and this is what has kept the Malay spa alive, albeit less known. Moreover, the fear of this secret falling into the wrong hands is so strong and almost over protects the knowledge. Another reason is that the Malay spa practitioners feel that most of the treatment and rituals in Malay spas involve the reciting of the Koranic verses. This is another issue that prevents non-Muslims from using Malay spas. However, according to a few Islamic teachers, the Koranic verses that are uttered during the rituals are combined with animistic belief chants, thus making the spa practice non-Islamic. Nevertheless, the culture is still Malay and the Malay spa is only known to the Malays, but the need to expose and promote its uniqueness has become apparent. This traditional treatment deserves a better acknowledgement and appreciation for it promotes a healthy life style as well as awareness of one's' well being. Since the increase of demand for alternative health treatment, the Malay spa has been making a comeback, although at a very slow pace. The herbal treatment of the Malay spa consists of kaffir lime, pandanus leaf, cinnamon stick, black cumin, clove and many types of roots of trees. They are used for treatments with the belief that these herbs and plant parts carry some medicinal properties that would be able to heal, rejuvenate and cure the recipients of these treatments from ailments. Flowers are also used in spa treatments. The flower ingredients come from seven varieties of flower namely rose (*mawar – rosa spp*), bullet wood (*bunga tanjung - mimosops elengi*), tropical gardenia (*bunga china – gardenia augusta*), tropical magnolia (*bunga cempaka – michelia champaca*), frangipani (*bunga kemboja – plumeria acuminata*), ylang ylang (*bunga kenanga – canagium orodatum)*) and jasmine (*bunga melur – jasminum sambac*) [12].

The advantages of having a Malay spa treatment include the offering of a total health treatment where a person is treated with a proper diet to detoxify the inner body and a herbal treatment to cleanse the outer parts [13]. The pampering treatment includes a floral bath, sand heat treatment, foot bath treatment and face and hair treatment. It is known as treatment from hair to toes. All of these treatments are undertaken with specific rituals according to the requirements of the treatment. They are usually accompanied by the usage of seven types of flowers and water, as the fragrant smells of the flowers and water cleanse the physical and the spiritual entities, thus bringing good health to the spa users. The rituals are heavily embedded with traditional philosophies depicting the strong beliefs of the Malay people of supernatural powers. The Malay people, namely the rural folks, are well associated with the traditions and customs of the Malay traditional lifestyles. Every single type of behaviour calls for a proper custom that is well embedded with superstitious beliefs. These beliefs were passed on through generations via oral traditions and they have become necessary in undertaking any ritual that mainly concerns the health and well-being of a person. Osman describes that the most pervasive influence that folk beliefs have on an individual villager is in matters of health. The village practitioner in the art of curing may use herbs or even engage in bone-setting as the situation demands [14].

Although most of the medicine men practise the traditional medicine intertwined with the Islamic beliefs through the reciting of Koranic verses, the philosophy and the rituals are heavily laced with the animist and Hindu-Buddhist beliefs. The people are the same but the religious beliefs change through time to accommodate the coming of new beliefs, hence the move from the animist to Hindu-Buddhism and finally Islam [15]. However, the philosophy and the rituals remain the same but the chanting and the incantation to accompany the rituals are related to the religious beliefs at that time. Historically, the principle of mantra or incantation is basically magical. The intention is to influence the disposition of the supernatural and to make the healing process successful and beneficial to the so called sick person [16]. Specifically in the Malay spa treatment, the ritual of bathing that comes with incantations is related to Islamic beliefs and only certain herbs and flowers can be used to execute the ritual. Flowers must be fragrant and white or cream in colour [17]. All the rituals found in the Malay spa treatment take place in a secluded area within the compound of a house. As the Malay spa treatment is still considered a secret, most people will not be able to see the rituals being performed in a setting that is also known to be a hideout. Thus, the spa treatment also relies heavily on its setting and design, mainly within a traditional Malay house vicinity.

5 Tropical Malay spa design and setting

Although spa design can be interpreted in many ways according to the culture's specific requirements, the Malay spa design is confined to the tropical design parameters. The Malay spa started as a treatment mainly for women and was done in their own back yards. The tropical surrounding that contains a village provides a natural setting where the sources for the spa treatment are readily available (figure 2). These environs feature the planting of many types of herbal plants, flowers, spices and fruit trees.

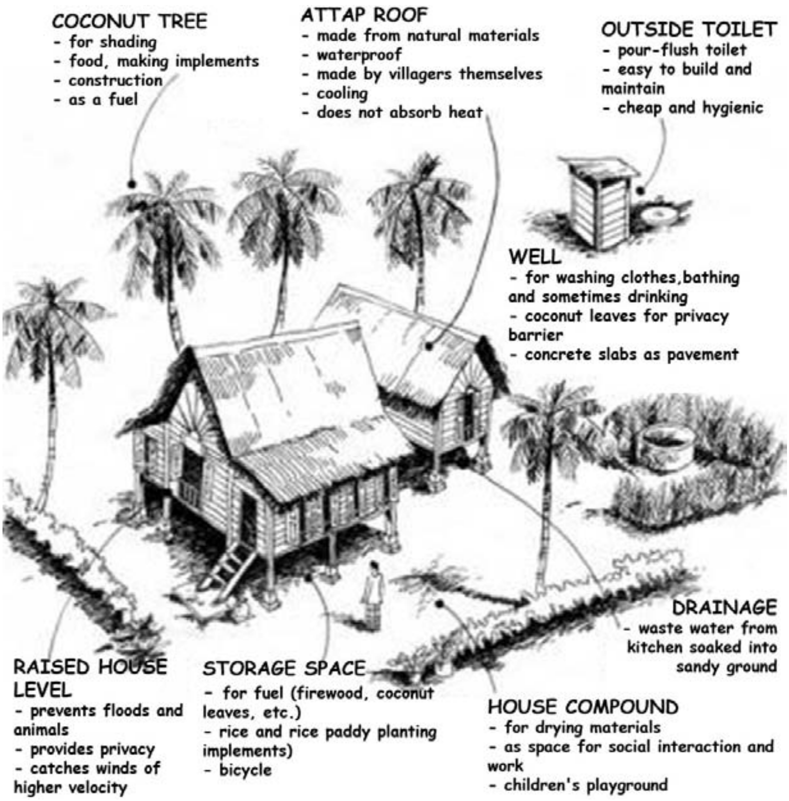

Figure 2: The environs of the house.



Figure 3: The area. Figure 4: Spice garden. Figure 5: Fruit trees.

All the ingredients needed are accessible within a few metres from where the treatment usually takes place (figures 3 and 4). Malay house is a place that provides security sheltering the inhabitants from the weather elements and also features some artistic impressions through the traditional carvings and decorative architectural components (figure 5) [18]. However, all these elements are based on spiritual beliefs that influence the surroundings as well as the house. The design of a Malay spa design has an influence on its surroundings. Associated with the traditional Malay house called the Single's House (*rumah bujang,*), its spa architecture is a three dimensional art where it combines art and functional space for the interior as well as the exterior.

A Malay spa design is built on the beliefs that every element in the house has spiritual powers that protect the owners. The surrounding is closely related to the house thus making it important to place the house in a right setting. Appropriately, according to Lim, the compound of a Malay house is planted with vegetables and fruit trees that in return create a boundary, a well shaded compound that provides privacy as well as a place to work [19]. The privacy gained from the setting of the house offers a place for spa treatment as the ingredients for the ritual are within reach and sheltered from the prying eyes. However, the Malay house within itself has different zones or domain. These domains will determine where the ritual of the traditional Malay spa will take place. Historically, as the spa treatment was only meant for women, the setting for the rituals would only be performed in the female domain namely at the back of the house using fruit trees or shrubberies as fencing for privacy. A Malay house design is divided into two main domains (figure 6). The front portion of the house is the male domain where young women are kept away while the back portion of the house is the female domain (figure 7). It is a clear indication of the relationship between male and female and reflecting formal social interactions [20]. The male domain features of more open spaces especially the veranda where interactions among males take place publicly (figure 8). The female domain is reserved for activities that are sited only in the kitchen and the side veranda (figure 9). The Malay spa is often located at the back of the house, in the side veranda area and sometimes in the dining area that is connected to the kitchen (figure 10).

This illustrates that the Malay spa is a very personal activity for it relates to the ritual of healing a sick person as well as keeping it secret from prying eyes. Since the kitchen is always close to the well, a source of water, and to the herbal

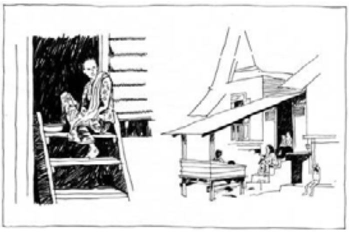

Figure 6: Domains of genders.

Figure 7: Kitchen.

Figure 8: Veranda.

plants, flowers and spice planting beds, the female domain seems the most appropriate place for the Malay spa. Malay cultural and social structures have moulded all activities according to gender. Historically, the Malay spa is far from the indulgence activities people are seeing today. It is a necessary process for healing the sick people (figure 11).The internal environment of the traditional Malay spa design designates all activities relating to private requirements to the back of the house (figure 12). Nasir indicates that a house symbolises a human body that consists of many parts [21]. Thus every part of the house has to be properly designed according to its function. Since the activities involved in the Malay spa are of a healing nature, the interior of the house is designed to cater for the activity’s requirements. At times, this is also a place for the family to wash a corpse of a relative before burial. Thus the design of the floor is equipped with drilled holes in the wooden planks (figure 13) [22].

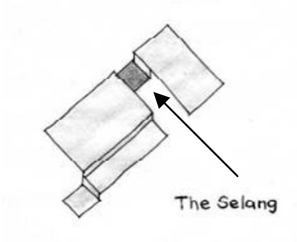

Figure 9: Passageway.

Figure 10: Passageway.

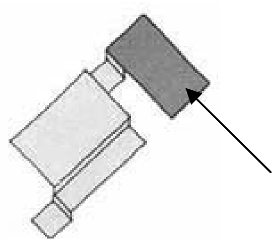

Figure 11: Kitchen.

Figure 12: Kitchen.

Figure 13: Holes in floor.

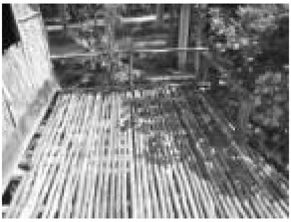

Figure 14: Bamboo floor.

5.1 Construction solutions and environmental benefits

The Malay spa design in its association with the Single's House applies a simple construction method using local materials. Timber is the main material that made up the main frame of the house. Bamboo is used as the floor material (figure 14) that provides gaps in between bamboo pieces to allow dust to fall onto the ground as well as to drain water to the ground. Materials that are used for the construction of the spa design have always been from the sources that are renewable or farmable found in the Single's House (figure 15). They contribute to the low impact on the environment as compared to the current modern materials. Furthermore, the materials are accessible and require minimal efforts to acquire them. A process that takes place in a Malay spa treatment always involves the usage of water for cleansing and herbs for healing. All of these requirements have a proper place in the kitchen or in the closed side veranda. The spaces are designed with the activities in mind before the construction of the Malay house. This is a clear indication that the Malay spa is holistic. It requires the interaction between the social and cultural values of the Malay people. It is a part of the Malay life style and is kept secret because it is known to have involved the sacred sanctity and the ritual of the society.

Internally, the house designed is not just for personal use to shelter families but also a place for communal activities, a gathering space for comfort and peace. The breakdown of the interior space planning iterates the various functional spaces. However, all of these spaces function with no definite boundaries. Only the activities can determine the use of the spaces (i.e. cooking – kitchen, communal activities – main area). The invisible borders create an openness of the interior of the house thus making the internal part seems big and airy. Since there is no ceiling constructed, the roof structure is left open directly to the underside of the roof. Spacious interior is created with almost a double volume due to the open roof configuration. This situation in the interior design of the spa design house provides a cool interior in tropical climes that is governed by sun heat, radiation, rain, wind and humidity. The components of the Malay spa go further with not only providing the basic shape and construction of a house but also displaying a lot of embellishments that function just as important as the main structure of the house.

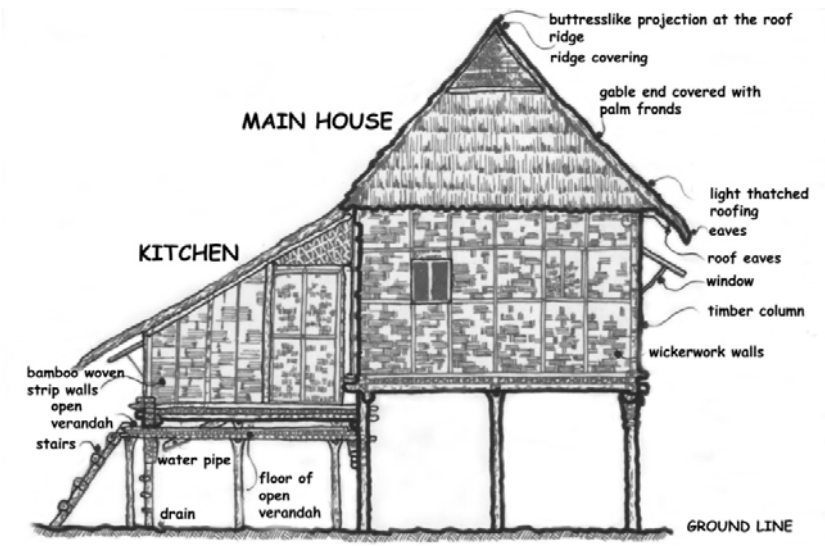

Figure 15: Construction materials of the single's house.

6 Conclusions

This paper has discovered that the tropical Malay spa design in the Single's House and its practices have long been established. The architecture and the culture associated with the spa practices indicate a sustainable scenario whereby the architecture that houses the sustainable culture is also sustainable. As the traditional Malay house is always constructed according to the surroundings, the practice of the Malay spa associated with the Malay house reveals of its spiritual elements. The house itself is embellished with cultural beliefs thus strengthening the customs and rituals practices attached to the Malay spa. In whole, the spa design housed in a traditional Malay Single's House embodies the true Malay traditions as every parts of the house and its activities are rich with philosophy and traditional beliefs. It is also known that the efforts to make the Malay spa exclusive only for the Malay people have hindered its promotion and exposure for the fear that the spa knowledge would fall into the wrong hands. On the other hand, the architectural elements portrayed are made strong with the cultural elements of customs and rituals and the natural surroundings thus signifying a symbiotic relationship. It pays respect to nature and its surrounding elements. The traditional Malay spa design though humble in its appearance has shown a house construction that is intelligent and smart in responding to nature and its surroundings. The analysis on the facts of the Malay spa design that incorporated traditional cultural issues such as philosophy, traditions, rituals and customs have resulted in the outcomes as follows:

- A comprehension of interior space planning in a traditional Malay house according to functions.
- A thorough understanding on spaces in relation to cultural requirements.
- An understanding on the interior space layout in relation to sustainable home design
- A deeper understanding of the traditional construction of a traditional Malay house according to rituals, customs and traditions.
- An understanding of the requirements of this house design for construction in specific environments and climates.

This paper has shown that the heritage and culture that is visible has been passed on through generations. However, the culture is dying out due to the modernisation and new technology in building construction. The lack of interest in this type of architecture especially among the young generations ensures the demise of the knowledge. The Malay spa design has outlined all the rules about designing in and with nature. It has also shown that mankind can coexist with nature that perpetuates their existence. The Malays spa design is the embodiment of the Malay culture starting from its uncomplicated beginning. It features knowledge that tells stories of by gone eras through its construction, embellishments, interior space planning, materials, form and shape. Most important of all, the traditional Malay spa design has put forward an identity that is intelligent in design and in combining traditional customs, rituals and philosophies in every element of the form. It is a house that displays design sustainability with aspects of economy, social and environmental as the prime factors that at the end creates its character and identity in cause that is full of history and cultural elements.

References

[1] Hanafi, Z. (1996). Pembinaan Bangunan Tradisional Melayu. Kulim: Amber-Solara.

[2] Clark, A. J. (2005). Australia's Best Spa – The Ultimate Guide to Luxury and Relaxation. Singapore: Periplus.

[3] The Bali Spa & Wellness Association (BSWA). http://balispawellness-association.org/.

[4] Robert Allen (ed.). (1994). Chambers Encyclopedic English Dictionary. Edinburgh: Chambers.

[5] Spa. http://www.thefreedictionary.com/spa

[6] Chan, B. (2006). Asia's Luxury Spas. Singapore: Page One.

[7] Callen, K. (2001). Spa – Pamper Body and Soul. London: Ebury Press.

[8] Jotisalikorn, C. (2002). Thai Spa Book – The Natural Asian Way to Health and Beauty. Singapore: Periplus.

[9] Hasan, Z., Mazlan, N.A. & Yaacob, M. (2005). Tumbuhan Ubatan untuk Kesejahteraan Wanita. Kuala Lumpur: MARDI.

[10] Daud, H. (1989). Sejarah Melayu: Satu Kajian Daripada Aspek Pensejarahan Budaya. Kuala Lumpur: Dewan Bahasa dan Pustaka.

[11] Deraman, A.A. (1994). Masyarakat dan Kebudayaan Malaysia. ed. 2. Kuala Lumpur: Cahaya Pantai.

[12] Bahauddin, A. (1999). Contemporary Malaysian Art – An Exploration of the Songket Motifs. Unpublished PhD Thesis. Sheffield: Sheffield Hallam University.

[13] Hasan, Z., Mazlan, N.A. & Yaacob, M. (2005). Tumbuhan Ubatan untuk Kesejahteraan Wanita. Kuala Lumpur: MARDI.

[14] Osman, M.T. (1989). Malay Folk Beliefs – An Integration of Disparate Elements. Kuala Lumpur: Dewan Bahasa & Pustaka.

[15] Kasimin, A. (1991). Religion and Change among the Indigenous People of the Malay Peninsula. Kuala Lumpur: DBP.

[16] Osman, M.T. (1989). Malay Folk Beliefs – An Integration of Disparate Elements. Kuala Lumpur: Dewan Bahasa & Pustaka.

[17] Yaacob, M., Maarof, M.G. & Puteh, M. (eds.). (2005). Penanaman Tumbuhan Ubatan & Beraroma. Kuala Lumpur: MARDI.

[18] Mat Jusin, Z. & Irin, M.I. (eds.). (2000). The Traditional House Architecture of Malaysia. Melaka: PMCT.

[19] Lim, J. Y. (1987). The Malay House – Rediscovering Malaysia's Indigenous Shelter System. Penang: Institut Masyarakat.

[20] Chen, V.F. (ed.). (1998). The Encyclopaedia of Malaysia Architecture. Singapore: Archipelago Press.

[21] Nasir, A.H. & Wan Teh, W.H. (2004). The Traditional Malay House. Kuala Lumpur: Fajar Bakti.

[22] Killmann, W., Sickinger, T. & Hong, L. T. (1994). Restoring & Reconstructing the Malay Timber House. Kuala Lumpur: FRIM.
Yahya, M.A. (1995). Simbolisme dalam Seni Bina Rumah Melayu. Kuala Lumpur: Dewan Bahasa & Pustaka.

The principles of Vastu as a traditional architectural belief system from an environmental perspective

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Abstract

The shortage of technological discoveries in traditional architecture - which has now made it possible to warm and cool any area regardless of considering the proper direction or geometrical shape - used to lead the habitants to make use of natural phenomena to provide physical and emotional comfort. Therefore, traditional architecture is always accompanied with a set of rules and principles that are to some extent based on environmental criteria as well as the dominant belief system of the specific culture; these two variables seem to be inter-related and in some situations dominating one another. Although assigning auspicious directions, auspicious geometrical patterns in the plan configuration, the concept of concentric zones, elongation of the whole complex and the façade considerations seem to be religious in basis or due to cultural values, still a great amount of such principles in traditional architectural guidelines are derived from the environment; thus a number of common characteristics of vernacular architecture, such as the presence of vegetation in the buildings' site, the use of local materials that create a micro-climate adaptable with human comfort and structural forms associated with the climatic positions, which can also be applied to other cultures with the same climate, are present as parts of all traditional structures.

Vastu as one of the most ancient architectural belief systems, similar to other traditional architectural sciences such as Feng Shui, also deals with the principles designed to make the most use of the environment and more specifically climate as one of its dominant factors. Based on the knowledge of the Sun Rays, the Earth's Magnetic Poles and the Geopathic Zones, many rules have been legislated in ancient Indian architecture dealing with environmental criteria that

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are now considered superstitions; however, applying them may be useful in designing buildings in complete harmony with the surrounding nature.
Keywords: principles of Vastu Shastra, the sun rays, magnetic zones, Geopathic Zones, concentric squares, the surrounding environment.

1 Introduction

Based on the chronic approach to the history of architecture, the patterns of primitive constructions were the inspiration of the natural forms and features. Therefore the surrounding environment has always imposed certain shapes and geometries to architectural constructions from the ancient times until the modern era. In contrast to such an approach, the followers of the cultural approach believe that the forms and patterns of traditional dwellings were the consequence of religious beliefs and the faith on sacred realms. However the architectural efforts of traditional societies are in fact the result of considering many factors, including both environment and religion, often called by the French word, 'genre de vie' signifying all the matters of shelter, material, technology, site, defence, economy and religion.

Basically environment as the first manifestations of shelter has always played a significant role in the process of man's evolution. Technology of construction as well as the geometrical patterns and sacred symbols are all derived from nature and its dominant laws. The laws of nature are basically beyond the physical tangible forces that used to constitute the principles of classical physics and contain all the intangible energy fields emitted from the earth as well as the other heavenly bodies, such as the Sun and the moon. The principles of ancient sciences of architecture including Vastu Shastra and Feng Shui denote the great knowledge of ancient civilizations over the universe, its orders and its analogy to the human body, which seems to be the sum experiences of traditional societies over generations. Therefore, along with the cultural considerations, a great number of principles in ancient architectural design were a response to the surrounding environment.

2 Two distinctive aspects of traditional architecture

Basically there are two different aspects of architecture as high and low. First concerns the cosmic rules to define proportion, geometry and ritual acts as representation of the universal principles in domestic art. Association of earth to vault of the sky, vertical axis and the symbolic forms of space are all manifestations of the high aspect. The latter on the other hand deals with the climatic issues, the use of materials, technologies and construction methods. While the cosmic aspect is achieved by the prolonged esoteric studies, the low scheme depends on the sum experience of generations [1]. In fact, traditional architecture is shaped in connection with culture while culture is largely dependent on the environmental context as well as cultural beliefs; along with the importance of the belief in supernatural powers and interpretations of the cosmos in forming the traditional architecture of every nation, the physical conditions and economical criteria as well as its relations to the land and the structural crisis which the dwellings are based on are also fundamental. In this way culture will shape due to four variables of space, time, meaning and communication as means to define the cultural activities and the ways of performing them not only in space but also in time. Based on these four variables, the same set of space organizations and architectural configurations may be found in different cultures with different climatic criteria. Thus comparing traditional domestic architecture in various cultures, one must consider the system of activities take place in dwellings rather than focusing on the individuals [2]. Based on this theory, despite having different environmental background, the traditional buildings of different cultures may still share some similar concepts.

Concerning the low aspect, a number of common characteristics of vernacular architecture can be the presence of environmental context in which they are raised, the use of local materials which creates a micro-climate adaptable with human comfort and structural forms associated with the climatic positions which can also be applied to other cultures with the same climate. Furthermore, the economical status of each culture and its habitants used to suggest the size of the house, its properties and decorations. In fact traditional architecture was completely dependent on the social and economical situations in the low aspect, and was basically developed to provide some specific requirements within each cultural environment [3].

However, no environmental factor is more important in the development of human life and culture, than climate. “The practical limits of human existence are largely defined by physical and psychological tolerance to extremes of heat or cold, while the effects of climate upon the distribution of vegetation have direct bearings on life support.” [3 p. 125].

It seems that combining the climatic factors with the dominant beliefs of each community which defines its culture, may provide the characteristics of its traditional built space. Therefore the face of the buildings rarely changes through the time unless the dominant culture changes in a profound level either environmental or ideological [4]. In fact the environmental criteria in proposing certain shapes and configurations to architectural efforts of traditional societies is completely inter-related to the cultural beliefs and is proper to think that nature is the context from which all the sacred forms and symbols have been derived and transferred to next generations through a set of rules and principles of architectural design. The existance of such knowldege in the sacred scriptures of India and more specifically the Vedas reveals the importance of environmental considerations of dwelling construction for the ancient civilizations which beyond symbolical interpretation, need a scientific observation.

3 Vastu Shastra as a traditional architectural science

Ancient sciences of architecture are basically a combination of rules and rituals being applied by the master builders or the local craftsmen. Although these rules were applied in almost every traditional culture which is also evident in their ritual behaviour and folklore literature, there are few written architectural guidelines remained today which Vastu Shastra is one of them [3]. The main concept of Vastu Shastra knowledge of architecture was to guide people to create spaces which harmonize with nature and with the universal forces. The use of Vastu which is rooted in Hinduism philosophy dates back to the Vedic period appeared between 4000 and 2000 B.C. A section of Yajur Veda called ‘Sthapatha Vidya’ which means the art of building, mainly deals with the principles of architecture and housing. In fact there are nearly 32 books written on the subject of Vastu from 3000 B.C. to 600 A.D. by various authors in Sanskrit language dealing with the construction methods, special placements of the house features and the rituals to be done in each stage [5, 6].

Vastu in its general sense means the place where living beings dwell while in Rig Veda it has been applied for home. Originally Vastu is derived from the Sanskrit word, ‘vas’, meaning to reside [7]. However, in ‘Samarangana Sutradhara’ the origin of Vastu is defined as ‘Vasu’ or ‘the earth’ so that the mother earth and all the creations above it are called Vastu. Literally Vastu is applied to both the site of the building, and the building itself. Hence selection of the site, architecture, landscape and the science of the structures as well as astrology are all components of Vastu science [8].

Vastu as a traditional guide to architecture aims to design buildings in harmony with the natural laws of the universe. “As Einstein Proved, everything in existence, sentient and non-sentient, is a field of energy. In this case ‘Vastu’ is referred to pure subtle energy that underlies everything while ‘Vaastu’ is the manifestation or expression of that energy as matter” [9 p. 141]. In fact, Vastu is a science of working with energy fields which used to guide the architects to design buildings in a way that their underlying energy fields are beneficially manipulated due to proportion and direction. Thus Vastu views the dwelling places as living entities that nourish our lives, rather than a ‘machine for living.’ In this science, home is a symbol of physical body which is interrelated with the universal energy field and at the same time a microcosm of its existence [10].

According to Rig Veda, architecture of the ancient times was closely associated with religion, and building a structure was recognized as a religious act. Basically it was not religious in origin but since Vastu similar to Yoga and Ayurveda, denotes the connection between the laws and processes that governs the world of nature and the laws which govern the human body, it has been perceived as religious for the ancient societies. Therefore its principles should not be interpreted as mythic superstitions, rather based on laws of nature and the surrounding environment [11].

4 The environmental principles of Vastu Shastra

The environment as the first manifestations of shelter has been the subject of many rules and principles of Vastu science of architecture. Its presence in the spatial configurations of the plan, its geometry and directions, besides the arrangements of water pools and vegetation around the building construction is highly evident through Vastu guidelines.

The first geometrical pattern applied as the floor plan is usually a mandala from which the rest of the concepts and patterns will be originated. The symbolic patterns and geometries of mandalas are environmental in origin and picture the natural phenomena and their influence in built space [12].

From the environmental features which suggest the shape and spatial arrangements of the patterns in the mandala, the Sun Rays, the Magnetic Poles, the Geopathic Zones and the Concentric Zones are the most significant of all which together has dictated certain principles of architectural construction.

For example the concept of the eight directions of Vastu Shastra science and their associated deities, from which the four cardinal directions are the most important, is in fact based on the climatic features of each direction. The Vastu Scientists has perceived the effects of each direction in the human system over centuries and found out that proper orientation with the cardinal directions aligns the built space with the energy grid of the earth and brings harmonious benefits. It also allows the house to absorb energies emitted from the sun, moon, stars and the earth itself properly. Further they have observed that energy is poured forth from the centre and the outer space to the inside through the directional lines which are called ‘Yonis’ or ‘life lines’ in Vastu. That’s why in Vastu the building should be built in alignment with the four cardinal directions [10].

In fact the categorization of each direction as either auspicious or destructive in Vastu is based on the following concepts:

4.1 The principles of sun-rays

Sun rises from the east, passes through the south and sets in the west. However due to the 23.5° inclination of the earth from its vertical axis, the east is not the first direction that receives the sun rays; it is northeast. The same application can be applied to the cardinal west. Hence if we draw an imaginary line from northeast to southwest, the southern half will be the light zone with positive energy while the northern half is the dark zone with negative energy. In this case the southeast which is in the middle of the light zone will have the natural light throughout the day and is recommended for the kitchen [8].

Sun ray consists of visible white light together with invisible infrared and ultraviolet rays. Approximately from 6 am the effect of infrared rays starts which is beneficial to the human health and has purifying effects. Hence water present at east, north or northeast becomes bacteriologically safe without deterioration of the ingredients. From 11 am to 3 pm the effect of ultraviolet rays will be very high which is harmful for the body. From 3 pm until the sunset the effect of infrared rays in heat quality will increase [13]. That’s why in Vastu guidelines it is advisable to located the water pool in north, northeast or east directions as an auspicious for placing the entrance door and openings while the southwest is often suggested to be kept heavy and closed [14].

Morning rays of the sun are naturally cool. Gradually the rays become hotter. Sun is in its hottest mood during the afternoon hours while passing through the southwest. By drawing an imaginary line from northwest to southeast, the hot and cold zones can be pointed. Thus the sector points are the best places for activities requiring balanced heat. Northeast in the middle of the cold zone is appropriate for the praying or studying while the southwest as the hottest and most destructive corner should be kept closed. In ancient times southwest was reserved as armoury to keep weapons [8].

Based on the position of the Sun in the sky during the day time, the coolest location in the house is north direction. Hence the rooms with higher priority and importance are placed in the north direction. Cow shed and paddy storage is placed in the northwest while the treasuries are kept in the north location. Library also can be a proper function for the north direction. Daily Meditations or prayer activities are done in the northeast portion, as it is the coolest corner.

East offers the morning sun which is pleasant. In modern Vastu, bathroom is placed in this direction and near the entrance hall. However in ancient times bathroom was not even included in the house planning. As southeast provides enough light throughout the day which has a sanitary effect, kitchen is the most proper function to be placed in this corner.

The light and heat of the sun in the southern portion is excessive and destructive, thus bedrooms should be placed in this direction. While bedrooms are mostly used during the night the harmful rays flowing from this direction will not disturb the habitats. This portion should be kept high, dark and closed [12].

Western portion of the house also receives the negative sunrays in a lesser degree during the day. Thus it is a better place for dining room, while only a few hours in a day will be set for dining activities.

Table 1: Spatial organization of dwelling areas based on the position of the sun.

East	Southeast	South	South west	West	North west	North	Northeast	Centre
Entrance Hall	Kitchen	Bedroom	Master Bedroom or Storage	Dining Room	Cattle	Treasury Storage	Meditation Room	Central Courtyard

In this way every function in the dwelling area used to have a suggested spatial organization in the Vastu Purusha mandala which was decided through having the knowledge of the Sun Rays and their influences on the human health.

4.2 The principles of magnetic poles

"When a magnetic needle is suspended freely, free from any outer influence, it ends rest along north-south direction of the earth's magnetic field," which proves the existence of magnetic energy field of the earth." [8 p. 27].

Basically the earth is composed of a metallic inner core in the same size as the Moon. The temperature of this metallic core is equal to the temperature of the Sun's surface and this heat in fact causes churning in the liquid outer core of the Earth. Based on the magnetic dynamo theory, the rotation of the Earth which transforms into a whirlpool of liquid, swirling around the Earth's axis, converts the planet into a geo-dynamo. Such materials that are capable of conducting electricity are called metallic that have some free to move electrical charge. One of the elements in this liquid layer is compressed hydrogen which is in a state where some of its electrons are squeezed out of the atoms and are free to move around. This moving charge will generate a magnetic field and the faster the planet rotates, the stronger the produced magnetic field. Therefore the planet earth has a strong magnetic field due its fast spinning rate and material composition of its liquid core which is more iron and nickel [15].

In fact earth has two magnetic poles which based on the compass seem to be steady; whereas in reality they are constantly moving. Ephemeral undulations, known as micro-pulsations, ripple about the ionosphere and produce magnetic disturbances capable of reaching the ground level which are common and at the same time hard to detect. The Earth’s magnetic field which is also called the Earth’s aura in fact protects the life of its occupants from the radiations of the Sun by deflecting the solar flares.

The north magnetic pole is near the south geographical direction while the south magnetic pole is near the north geographical direction. The force lines of this magnetic field travel from the north magnetic pole to the south magnetic pole. Scientifically this will provide the north geographical direction with antibiotic properties which can control infection. Thus north direction is served as the purifying direction while the south direction, has energy giving properties which can be manifested as warmth. Therefore, while the northern half of the plot is full of positive magnetic rays, the southern part will be empty or depleted. The manifestation of such phenomenon used to decide the auspiciousness of the directions and their appropriate function in Vastu Shastra guidelines [8].

In fact, cosmic energy is abundantly received in the northeast direction and directed towards the southwest. Therefore the cosmic energy will become weaker while flowing towards southwest. Northeast will be the positive terminal and southwest as the negative one. Hence the shape of the building is crucial in the energy flow pattern [9].

Based on Vastu guidelines, the northeast section of any property should be built lighter and in a lower level compared to the southwest section to receive the beneficial effects of magnetism in its highest level and to facilitate the smooth flow of mahnetic waves without any hindrance. Furthermore it is believed in Vastu that the slope of the plot should face north or east which again is designed to make use of such natural forces. However lack of enough knowledge in studying Vastu guidelines has ended in treating the concepts of auspiciousness as merely superstitious or religious beliefs.

In fact the Earth behaves similar to a living organism and seems to have the intelligent of its own. Based on biological discoveries, the oxygen level of the planet has virtually remained unchaged through the centuries and the tilting of the Earth through the northeast direction has helped it to receive the maximum amount of beneficial cosmic energies. Aligning any built structure to the axis of the Earth will generate similar effects; therefore the northeastern half of the plot will be full of fresh beneficial cosmic radiations while the southwestern section will be empty [8].

4.3 The principles of Geopathic Zones

Geo biology is a branch of modern science deals with the various energy fields. It often falls under the category of pseudoscience and operates through geometrical patterns which are the subjects of sacred geometry. The cosmic energies are emitted from heavenly bodies such as the Sun and the Moon; whereas, these radiations are called ‘telluric radiations’ and are originated from the Earth. The energy grid of the planet earth can be perceived as a web that links the Earth altogether and is influenced by many variables such as electricity, magnetism, heat, sound, light, colour and matter.

The Earth’s energy grid works through specific geometrical patterns which follow certain symmetries. The grids meet at many intersecting points creating a matrix which is very similar to acupuncture points of the human energy body. It is believed that the platonic solids including cube, tetrahedron, octahedron, dodecahedron and icosahedrons are the evolved geometrical patterns derived from the study of the Earth’s geometrical grids [16].

Doctor Manfred Curry first hypothesized the existence of a grid network of energetic pathways flowing from northeast to southwest and from southeast to northwest at a distance of 3 m to 3.5 m. This Bio Electro Magnetic (BEM) grid is sometimes called the first global diagonals which is helpful to the growth of cells. The crossing points of these lines have double positive or negative effects that can be harmful for the balance of the body. Dr Curry later linked these points with diseases and found out that sleeping on negatively charged points will cause inflammatory diseases while sleeping on positively charged points will cause cancer; thus, to remain healthy one should sleep within the grids.

Later, Dr. Hartmann discovered another pathway of energy flowing from north to south and east to west. These lines are called Hartmann lines with the spacing of 2 to 2.5 m that are essential for the formation of bones in the human body. Hartmann grid is basically the BEM grid in the cardinal directions. The Hartmann grid has been known in Chinese geomancy as Yin and Yang; while the Yin or north-south lines generates a cold energy field which acts slowly and is associated with cramps, humidity and all forms of rheumatism, the Yang or east-west lines produces a hot energy field that acts rapidly and is associated with fire and all inflammatory diseases. These lines are also dangerous for the human health. By compiling the two grids in Vastu Shastra system, the square of neutral habitation zone will be produced [8].

In fact the researches has proved that, ancient civilizations were aware of such planetary grids and used to consider these energy fields during construction. For example, in the Himalayas the houses of Buddhist monks are oriented due to the BEM grids to be placed in the neutral zone.

Besides Curry and Hartmann lines, geopathic stress can also cause imbalance of energy field. Buildings with ill energy effects are called ‘sick building syndrome’ today. Day describes ‘sick building syndrome’ as a common disease due to the improper use of materials and designing methods in today architecture which can be reduced by reapplying the principles of vernacular houses. Sick building syndrome which is now so common and well recognized, continues to be developed in high rise buildings, *"over-glazed and under-day lit"* places which extremely use the synthetic materials causing the electromagnetic confusion. Their detachment from nature has made these buildings energy dependent and unhealthy. Thus the awareness of how buildings can attach to nature and remain in harmony with it seems to be substantial for human health as well as the energy reduction. This syndrome in general includes *"headaches, irritability, hyperkinesias, learning disability, fatigue, dermatitis, asthma, rhinitis, flu mimic conditions, and irritations of the bronchia, mucous membranes, throat and eyes which are all easily mistaken for normal ill-health."* [1 p. 309].

In fact negative energy exists as a cloud which can move into the building; "stress clouds are examples of the negatively charged locked energy fields." [8 p. 37]. Basically and due to the science of subtle energy, negative and positive energies flow like water. They can be created due to various reasons such as death of a person, and can flow or trapped according to the structural forms and figures. "Some of the symptoms of such negative cloud formations are palpitation or increase in the pulse rate, home ants and termites, beehives, dampness, coldness or hotness of a specific floor area, cats frequenting the house, uncommon accidents in the rooms or dogs barking at night while looking at south or southwest without any visible reason. These stress clouds affect one's Bio Electro Magnetic level, which has a great influence on his aura or energy body." [8 p. 38].

The rules and principles of Vastu applied while in the construction of any property proves the existance of such knowledge in traditional societies which might not be completely discovered by scientists yet.

4.4 The principles of concentric zones

While square is known as a proper shape for building, pattern of concentric squares in Vastu Purusha mandala is an archetypal pattern which establishes a potent, energetic and healthy effect based on the ancient teachings. This pattern which is found in many cultures such as Egypt, America, Europe and Asia and in works of many famous architects and artists is fundamentally composed of concentric squares which infinitely recede to the unseen centre of the universe from which all the creation emerge. Pagodas and Step Pyramids are the examples of this pattern in architecture [10].

In Indian traditional geomancy, one is the symbol of the creator or God, the infinite reality or the absolute unity which is shown by point in geometrical expression. Bindu in the centre of the Vastu Purusha mandala which indicates the navel is the manifestation of this sacred concept. Two, apart from its quantitative application, is the symbol of duality in creation which is represented by yin-yang symbol in Chinese Feng Shui. Duality of Shiva and Shakti or the male and female forces is symbolized by line in geometrical realm and is known as the source of creation of the physical world. Three on the other hand is symbolized by triangle and is called the mother which signifies the process of creation from the two abstract geometrical shapes to the triangle which is a

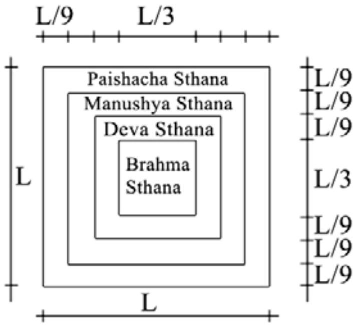

Figure 1: The concentric zones [8].

complete geometrical pattern. While three is the connecting link between the sacred realm and the built form, four is the symbol of created objects and represents ‘the first born thing’ [17]. Therefore square or rectangle were always used in designing the plan of every dwelling to represent the world of materialization or the realm of mundane which man is living on while the ceiling was considered the realm of the divine which man should ascent to [8]. The same concept is also indicated by Lao Tzu as the concept of creation which should also occur while constructing a new dwelling since it is the inferior example of the world’s creation. “The Tao gives birth to one. One gives birth to two. Two gives birth to three. Three gives birth to all things.” [18 pp. 10, 11].

Apart from the symbolic significance, based on the studies of Kumar, square is the best geometrical shape in economical and structural considerations followed by rectangle since it requires the lesser amount of construction materials on its periphery while providing the broader inner area compared to other geometrical figures. In structural terms, “square- and rectangular-shaped buildings can transfer the load safely even where the bearing capacity of soil is low, while other irregular shapes provide large contact areas more than they critically required.” [8 p. 41]. The symmetrical shape of rectangular figures also creates a predictable behaviour in terms of structural calculations and constructional methods which involve tortional behaviour problems and stress concentrations. Therefore symmetrical structures can perform better under the earthquake or wind forces.

Above all, based on the Vedic teachings, the geometry of square is in complete harmony with human proportions as illustrated by Leonardo da Vinci since human can fit harmoniously inside both square and circle [19].

In fact the ‘concentric squares’ is another symbolic diagram which was applied by Vastu Shastra specialists from ancient times in constructing their dwellings. In this diagram four belts of energy field can be recognized; the centre part is the Brahma Pada which is a highly charged zone called the ‘hot zone.’ Around the centre is the ‘luminous space’ or Deivika Pada while the third belt is called Manusha Pada or ‘conscious space’. The outermost area is the ‘gross material space’ or Paisachika Pada. The two innermost areas are the zones which should be open or constructed with minimum walls or heavy items while the two outer belts are the place of human habitation and physical structure. The reason is that the energy of the two inner zones is substantially subtle for the human body [10]. However Ashvini Kumar believes that the most inner area together with the most outer area is not suitable for human living. Comparing the Vastu Purusha mandala with the human body, these two areas symbolize the nose and skin from which the body can breathe. Thus these two areas should be open and filled with windows to serve the similar function.

The idea is to treat the plan the same way as the human body. While the central parts and organs are delicate and sensitive the minimum pressure should be applied to them [8]. This idea can be seen in the development of the courtyard houses of Japan, china and Iran. The idea of concentric zones later in 1920 was suggested by American geographer E.W. Burgess as the proper plan for developing the cities [20].

5 Conclusion

In fact there are many principles in the Vastu Shastra science of architecture that are basically designed regarding the environmental features which through the lack of knowledge have considered symbolic or ritualistic by the later generations. However the observation of natural phenomena by the ancient philosophers leading to the discovery of laws of nature and their impact on human health is the root cause of the application of the principles of Vastu and its similar systems of beliefs in other cultures as the sum knowledge, experienced by many generations.

Since it is highly believed that the architectural forms have been proposed by the environment and as a response to its orders, which share similar patterns in regions with similar climatic configurations, the rules and principles of Vastu Shastra can be discovered and applied not merely as a superstitious symbolic guideline, rather as a proper example of using the architectural forms in the context of the environment. Although the technological advancements of today make it possible to warm and cool any area regardless of its climate, the proper use of architectural forms and patterns may lead to sustainable design which decreases the rate of energy consumption as well as making a proper micro climate compatible with human needs which can also stand in complete harmony with the surrounding environment.

References

[1] Day, Christopher. *Places of the Soul: Architecture and Environmental Design as a Healing Art*. s.l. : Architectural Press, 2004.

[2] Kent, Susan. *Domestic Architecture and the Use of Space: An Interdisciplinary Cross-Cultural Study*. s.l. : Cambridge University Press, 1993.

[3] Olivier, Paul. *Encyclopedia of Vernacular Architecture of the World*. s.l. : Cambridge University Press, 1997.

[4] Gray, John N. *Domestic mandala: architecture of lifeworlds in Nepal.* s.l. : Ashgate Publishing, Ltd., , 2006.
[5] Hari, A. R. *Amazing science of vaastu.* s.l. : A.R.Hari, 2000.
[6] Bhattacharya, Trapada. *A Study on Vastuvidya or Canons of Indian Architecture.* s.l. : The United PRR Patna, 1974.
[7] Devi Vasudev, Gayatri and Dash, Nilakanth. *Vāstu, Astrology, and Architecture: Papers Presented at the First All India Symposium on Vāstu, Bangalore, Held on June 3-4, 1995.* s.l. : Motilal Banarsidass Publication, 1998.
[8] Kumar, Ashwini. *Vaastu: The Art And Science Of Living: The Art and Sciene of Living.* s.l. : Sterling Publishers Pvt. Ltd, 2005.
[9] Krishna, Talavane. *The Vaastu Workbook: Using the Subtle Energies of the Indian Art of Placement to Enhance Health, Prosperity, and Happiness in Your Home.* s.l. : Inner Traditions , 2001.
[10] Silverman, Sherri. *Vastu: Transcendental Home Design in Harmony with Nature.* s.l. : Gibbs Smith, 2007.
[11] Sahasrabudhe, Gautami. *Cosmic Science of Vaastu.* s.l. : Sterling Publishers Pvt. Ltd, 2005.
[12] *Vastu Shastra and Its Importance in Residential Buildings.* Akola, T. 2000. Department of Civil Engineering. p. 45.
[13] Vastu Facts. *Rality in Vastu.* [Online] 2009. [Cited: 5 5, 2009.] http://www.vaasthufacts.com/rlty.htm.
[14] Oldenberg, Hermann. The Grihya Sutras. *Sacred Texts.* [Online] 1886. [Cited: 7 2, 2009.] http://www.sacred-texts.com/hin/sbe29/sbe29131.htm.
[15] Strobel, Nick. Earth Magnetic Filed. *Astronomy Notes.* [Online] 9 24, 2008. [Cited: 11 24, 2009.] www.astronomynotes.com.
[16] Bachler, Käthe and Living, John M. *Earth Radiation.* s.l. : Holistic Intuition Society, 2007. 0968632351/9780968632352.
[17] Lawlor, Robert. *Sacred Geometry: Philosophy and Practice.* s.l. : Thames and Hudson, 2002.
[18] Levitt, Susan. *Taoist Feng Shui.* s.l. : Inner Traditions / Bear & Company, 2000.
[19] Marc, Olivier. *Psychology of the House.* s.l. : Thames & Hudson, 1975.
[20] R. Pitzl, Gerald. *Encyclopedia of human geography.* s.l. : Greenwood Publishing Group, 2004.

Architectural education and the idea of nature

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Abstract

When various definitions of sustainable design are articulated by several leading scholars and practitioners, several conflicts and/or contradictions in underlying definitions of *nature* are revealed. Since all of these definitions employ the word *nature,* it would seem reasonable that, to understand sustainable design, students of architecture need to have more than a passing acquaintance with the multiple interpretations of the term *nature*. Students need a fundamental understanding of humanity's relationship to *nature*, but also a more holistic method of perceiving a site. Currently few schools of architecture in North America provide their students with an opportunity to obtain either of these.
Keywords: architectural education, sustainable design, ecological design, nature, site, perception, environment, place.

> *"If I were a young architect today looking at supposed eco-architecture, I wouldn't want to do it; it's a one-liner. When ecology becomes the major issue, you're left with a scientific box that does nothing for the spirit. I cannot separate the idea of the poetic and the rational. If there's not a junction, we've got merchandise, not architecture.*"
>
> Glenn Murcutt

(As quoted by Raul A. Barreneche in an article reporting Murcutt's receipt of the 2002 Pritzker Prize, in the May 2002 issue of *Architecture* magazine.)

1 Introduction

There is currently a great deal of concern in the Unites States about the perceived lack of integration of sustainable design in the curricula of many schools of architecture. The National Architectural Accrediting Board (NAAB) recently

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revised the Conditions and Procedures for accreditation and was criticized by several groups, such as the Society of Building Science Educators (SBSE) and the American Institute of Architects Committee on the Environment (AIA COTE), for not addressing the issue more directly. In this paper I will present the case for two interrelated issues that I believe must be addressed in schools of architecture if students are to become more sensitive to the environment.

Of course, the concern mentioned above is not new. I remember a monthly column that appeared in seven issues of the *Association of Collegiate Schools of Architecture (ACSA) NEWS* during the 2000-2001 Academic Year that was intended as an opportunity for administrative officers to report on their schools' offerings in sustainable design. (The *ACSA NEWS* is the newsletter of the Association of Collegiate Schools of Architecture (ACSA). The monthly columns were co-sponsored by the American Institute of Architects (AIA) Committee on the Environment (COTE).) The authors (all deans or department heads of schools in North America) focused on the importance of integrating sustainable design into the core curriculum, discussed the difficulties in doing so, and offered suggestions for improving the situation.

Their suggestions ranged from increased support for research, more emphasis on multi-disciplinary collaboration, and a serious focus on how buildings work – to more fundamental re-evaluations of how architecture is taught and practiced. Many of them appeared to express a concern that sustainable design remains a largely marginalized activity in many schools and much of the profession. This in spite of a special report published by the Carnegie Foundation in 1996 recommended "that architects and architecture educators assume a leadership role in preserving the environment and the planet's resources" [1].

But what exactly is meant by the term "sustainable design"? Of the seven authors of these essays, only two actually defined the term. In her column affirming Carnegie Mellon's commitment to sustainability, Vivian Loftness presented a working definition that is quite specific, but very prescriptive. For her it is "a collective process whereby the built environment achieves new levels of ecological balance through new and retrofit construction, towards the long term viability and humanization of architecture" [2]. This is not likely to inspire the "deep understanding of how buildings work" advocated by Berkeley's Harrison Fraker [3], and it doesn't really address the more "radical implications of sustainability" raised by Minnesota's Thomas Fisher. Fisher suggests that if we are "to achieve a more sustainable future, we need to start talking not just about energy-conserving techniques, but about need itself and what that means in terms of architectural education and practice" [4].

While only one of these authors actually defined "sustainable design," in reading their columns one senses the subtle but significant differences in their use of the term. The seventh author, Peter Wheelwright of the Parsons School of Design, addressed this issue directly, describing sustainability as "an umbrella term for many (often conflicting) forms of proactive attempts to mitigate humanity's transformation and negative impact on particular natural systems" and "a cultural formation still very much in the making" [5].

2 Ecological design

I use the term "ecological design" not to consciously differentiate it or preference it over others, but in a broad sense, and interchangeably with "sustainable" or "green." These are simply different terms, as Ken Yeang has suggested, for designing with nature in an environmentally responsive way [6]. In the context of architectural design, I find the term "sustainable" to be too broad; and "green" somehow too limiting, being easily confused with political and/or marketing labels. The etymological roots of the word "ecology," and the appropriateness, as William McDonough has observed, of an architectural discourse about the logic of our planet's household also influence the use of the term [7]. Nevertheless, the concerns I raise apply equally to all three terms, so I use them interchangeably in this discussion to question how students of architecture can be encouraged to practice something their instructors have difficulty defining.

Ian McHarg suggested that non-ecological design is "either capricious, arbitrary, or idiosyncratic, and…certainly irrelevant" [8]. But what is ecological design, specifically in the discipline of architecture? Sim Van der Ryn and Stuart Cowan have defined it as "simply the effective *adaptation to* and *interaction with* nature's processes" [9]. For Nancy and John Todd it is "design for human settlements that incorporates principles that are inherent in the natural world in order to sustain human populations over a long span of time" [10]. In concluding his now famous "sermon" at the Cathedral of St. John the Divine in 1993, William McDonough said:

> *We have to recognize that every event and manifestation of nature is "design," that to live within the laws of nature means to express our human intention as an interdependent species, aware and grateful that we are at the mercy of sacred forces larger than ourselves, and that we obey these laws in order to honor the sacred in each other and in all things. We must come to peace with and accept our place in the natural world.* [11]

Renzo Piano, in discussing sustainable architecture, enjoins that: "Architecture is a second nature that is laid on top of the real one. When people who practice our profession speak of the environment they ought to remember this" [12]. And Ken Yeang, with a nod to Ian McHarg, titled his book on the ecological basis for architectural design *Designing with Nature.*

All of these definitions employ the word "nature," and if students of architecture are to understand ecological design, they need more than a passing acquaintance with the multiple interpretations of that word.

3 Nature

In an interview shortly before his death, Ian McHarg lamented that his book, *Design with Nature*, which, according to him, was described by the ACSA as one of the most widely read textbooks in architecture schools, has, to the best of his knowledge, had no effect whatsoever [13]. I would argue that if this is true an important reason might be that many architecture students, in my experience, have very little, if any, understanding of what the word "nature" means.

In her book *The Language of Landscape*, Anne Whiston Spirn reminds us that "nature is an abstraction, a set of ideas for which many cultures have no one name," and that "A. O. Lovejoy found sixty-six meanings of the words *nature* and *natural* in literature and philosophy from the time of the ancient Greeks to the eighteen century" [14]. Both she and I have assigned an exercise in which students must define "nature" in their own words. The responses always reveal a wide range of often contradictory and clashing perspectives; not unexpected, she points out, for a word Raymond Williams called "perhaps the most complex word in the language" [14]. And it is a word that invariably is employed by students when asked to define ecological design.

It is not within the scope of this paper to even begin to explore the relationship between the idea of nature and the discipline of architecture. Nor is it my intention to attempt to articulate an ecological design ideology based on an interpretation of our relationship to nature. What I am suggesting is that a better understanding of how the word "nature" can be interpreted would help students to sort through the complexities of new and often contradictory ideologies.

For example, in his book, *The Idea of Wilderness*, Max Oelschlaeger outlines the defining characteristics two contemporary views of nature:

> *RESOURCE CONSERVATIONISTS believe that natural systems are no more than collections of parts; Homo sapiens is related externally to the ecomachine; the ecomachine can be engineered to produce desired outcomes and prevent undesired consequences; the market objectively determines the worth and value of all things, cultural and natural; the national per capita income accounts are the ideal measure of societal well-being; and, progress can be determined according to the utilitarian formula of the greatest good for the greatest number.*
> *ECOCENTRICS believe that natural systems are the basis of all organic existence, and therefore possess intrinsic value; humankind is an element within rather than the reason to be of natural systems, and is hence dependent upon intrinsic value; and, ethical human actions (actions which promote the good life for humankind) necessarily promote all life on earth (preserves such intrinsic values as diversity, stability, and beauty).* [15]

Without a clear understanding of such seemingly contradictory positions with regard to the natural world, students of architecture have difficulty developing a clear design intent for a project, especially if it involves multiple users groups. And, of course, there are many other views of nature ranging from those of the world's religions to ecofeminism and deep ecology.

In his *ACSA NEWS* column, Peter Wheelwright described two often contradictory and conflicting approaches to ecological design in schools of architecture: the "organic," which combines an activist social agenda with a

"Wrightian" design ethic; and the "technological," which is "futurist in orientation and scientific in method." He offered a third approach emphasizing the social and natural sciences in core architecture courses. His proposal is comprised of architecture courses that "simply begin with the assumption that the affinity of architecture with natural processes is historically based, theoretically critical and a technologically inventive way to (re) inform design" is admirable, but I question the ability or even the will of many schools to effectively accomplish such a goal [16].

I argue that a fundamental understanding of humanity's relationship to nature is necessary for architecture students to learn to practice ecological design. Therefore, if a school cannot effectively encourage students to gain this understanding, it must be seen as a significant shortcoming.

4 Site and perception

A second closely related problem is the inability of many students to perceive a site, especially a "natural" site, as a human construct and to conceptualize its potential to be reconstructed and interpreted through architecture. Over the past decade, I have returned many times to a site that demonstrates these fundamental questions about humanity's place in nature.

The site is known as Pinecote and is part of the Crosby Arboretum in southern Mississippi. Pinecote, meaning pine shelter, consists of 64 acres in the process of being transformed from an abandoned strawberry field and pine plantation into savanna, bog, woodland, and freshwater wetland. These landscape exhibits are compressed, dramatic expressions of the natural features common to the Piney Woods of the Deep South, made famous by the writer William Faulkner. It was designed by landscape architect Ed Blake, who lived on the site for four years before beginning the transformation process. The only buildings on the site are a trailer that serves as a temporary visitor's centre, and the award-winning Pinecote Pavilion, designed by the late Fay Jones. The projects undertaken by my students have ranged from designing a new Visitor's Centre to the design of individual interpretive stations.

The question I pose is whether this unique site can establish a framework that encourages, as David Orr has suggested for all architecture curricula, "a more sophisticated and ecologically grounded understanding of place and culture" [17]. The goal is an understanding that fosters design solutions that are not abstract impositions upon the landscape, but that are derived from explorations of a specific place and the ways that built form could reveal and possibly reinforce a cultural narrative. In this case the measurable indicators would fall into two broad categories: the ability to go beyond the more traditional methods of site analysis and represent the experiential character of the site, (As, for example, discussed in Chapter 6 of Kevin Lynch's seminal text *Site Planning* [18]. While there is a fairly thorough discussion of "the sensed landscape," there is little reference to specific perceptual methodologies and the discussion of means of representation or "languages" is marginal at best.) and the ability to use these perceptions in the sensitive integration of buildings within the landscape.

The stated learning objectives of most of these design studio projects included the development of skills in identifying relationships between a specific site and architectural program that would assist them in accomplishing the goals outlined above. The clearly revealed cultural construct of the site combined with programs that, in part, sought to create a framework for interpreting this unique setting should have offered opportunities to encourage these objectives. However, with a few notable exceptions, the first projects undertaken on the site failed to fully capitalize on this opportunity.

Why this failure? First, the students were not provided with an effective methodology for exploring and representing their perceptions of the physical, experiential qualities of the site. They were encouraged to essentially invent their own without any specific guidance. Secondly, even those students who were able to develop a reasonably clear perceptual model of the site were often unable to re-envision the site in a way that didn't impose a preconceived idea upon it. Their design solutions often had little relationship to the specific nature of this site and more to do with their own preconceptions about "nature."

Specifically, the students often employed traditional forms of site analysis such as overlays of contours, soil types, vegetation, drainage patterns, etc. in hopes of discovering a "natural" solution. This desire often resulted in very synthetic solutions with little reference to the sensual experience of the place. Although reading and interpreting a site is always a process of abstraction, a reliance on purely quantifiable data to define an "environment" without attending to the more qualitative attributes of "place" results in distancing the student from the experiential dimension – in the words of Christian Norberg-Schulz, the "qualitative, 'total' phenomenon, which we cannot reduce to any of its properties, such as spatial relationships, without losing its concrete nature out of sight" [19].

5 Conclusions

So how do we overcome these interrelated shortcomings? In the first case, I suggest that architecture students be required to take a course exploring how a society's predominant conception of nature might affect its relationship to its environment. Ideally such a course would fulfil a general education requirement, would occur as early as possible in the students' academic careers, would include an architectural component, and would be interdisciplinary in nature (possibly part of a larger "learning community").

The National Architectural Accrediting Board (NAAB) currently requires that forty percent of the courses in accredited programs must be non-professional (i.e. liberal arts and science) courses. In most schools the majority of these courses are part of a university-wide general education core, and, while I am sure there must be notable exceptions, I suspect that most of these core curricula do not require students to take courses that explore humanity's place in nature. Many institutions offer such courses, (According to the Boyer Report, William McDonough taught a required course in "Environmental Choices" that involved more than a dozen faculty and visiting lecturers from a variety of disciplines when he was Dean at the University of Virginia. I am not sure if it is still required or even taught. Of course, William Cronon, Neil Evernden, Leo Marx, Caroline Merchant, Donald Worster, and Michael Zimmerman (to name just a few) have taught such courses for years.) but I question how many architecture students take them.

In the second case, I believe there are two strategies to explore. First, introducing students to novel ways of perceiving and representing environments, such as those employed by artists and naturalists, may be a more productive approach.

For example, artist and naturalist Hannah Hinchman has demonstrated methodologies that encourage students to develop their own means of representation. The fact that her work is aimed at *observers* rather than *designers* of the physical environment is potentially very helpful in this context. She offers no prescriptive form of representation that would suggest an answer to students, but rather a methodology – a way of seeing. She encourages the intelligent observation of a world of "events," as opposed to the identifying of "things." In her book *A Trail Through Leaves: The Journal as a Path to Place*, she observes:

> *The idea of encouraging event perception occurred as I noticed, in my teaching, that would-be naturalist/journal-keepers are* prevented *from seeing the natural world. They are prevented first by categories…second, by the habit of seeing the world as dead.* [20]

The second strategy would be to encourage students to view the site as a construct shaped by climatic and geologic forces (air, earth, water, and fire), and the actions of organisms, including humans – these are the "events" suggested by Hinchman. In this light, the site is seen not as a fixed, inert entity but as an evolving project. This is certainly not a new idea. Most ecologists view "disturbances" as integral processes in many ecosystems, (for an interesting discussion of this, and ecological systems in general, see Reichman [21]) and landscape architects are usually quite attuned to this way of viewing a site. In their book *Inside Outside: Between Architecture and Landscape*, Anita Berrizeitia and Linda Pollak construct a framework of interpretation that consists of five "operations," each of which articulates a conceptual approach to relations between architecture and landscape. All of these "operations" could be very useful tactics to employ in this strategy, but their notion of "reciprocity" is directly applicable.

> *The operation of reciprocity subverts the hierarchy embedded in the historical dichotomy between architecture and landscape, which has construed landscape as merely the ground on which architecture rests. It recognizes the identity of both landscape and architecture as constructed. This formulation challenges the architectural paradigm of the machine in the garden – a vision that opposes architecture's progressive alliance with technology to a nostalgic formulation of landscape as timeless and untouched nature.* [22]

By consciously encouraging students to view their work in this manner, and providing them with more effective methodologies for perceiving and representing the experiential dimension, their preconceptions may be overcome. By engaging in a dialogue with a site in an attempt to identify its potentiality – its intended character or essence – the students might, in the words of Norberg-Schulz, "concretize the genius loci." They would design "buildings which gather the properties of the place and bring them close to man" [23]. I believe this is very similar to David Orr's description of ecological design as "a kind of navigation aid to help us find our bearings again." He goes on to say that "getting home means remaking the human presence in the world in a way that honours ecology, evolution, human dignity, spirit, and the human need for connection" [24]. Norberg-Schulz provides a description of architecture that for me captures the essence of this task, and admirably summarizes my points.

> *The basic act of architecture is therefore to understand the 'vocation' of the place. In this way we protect the earth and become ourselves part of a comprehensive totality. What is here advocated is not some kind of 'environmental determinism.' We only recognize the fact that man is an integral part of the environment, and that it can only lead to human alienation and environmental disruption if he forgets that. To belong to a place means to have an existential foothold, in a concrete everyday sense.* [25]

As mentioned above, more recent student studio projects on the same site have been much more successful than earlier ones. I attribute this to the new strategies that were employed.

The two problems I have identified are by no means the only shortcomings in contemporary architectural design education that inhibit students' abilities to design ecologically, and I do not claim that my proposed changes are a panacea. But I do believe that they might provide some of the tools necessary to foster the "more sophisticated and ecologically grounded understanding of place and culture" suggested by David Orr. They might also help to encourage Glenn Murcutt's "junction" of "the poetic and the rational."

References

[1] Boyer, E. L., & Mitgang, L.D. *Building Community*. Carnegie: Princeton, p. 43, 1996.
[2] Loftness, V. Carnegie Mellon is Committed to Sustainability – What About You? *ACSA NEWS*, 30(2), p. 6, 2000.
[3] Fraker, H. Is Sustainable Design still Marginalized in the Schools? *ACSA NEWS*, 30(3), p. 10, 2000.
[4] Fisher, T. The Needs of Sustainability. *ACSA NEWS*, 30(1), p.6, 2000.
[5] Wheelwright, P. M., Texts and Lumps: Thoughts on Science and Sustainability. *ACSA NEWS*, 30(4), p. 5, 2000.
[6] Yeang, K. *Designing with Nature*. McGraw-Hill: New York, p. 1, 1995.

[7] McDonough, W., Design, Ecology, Ethics, and the Making of Things. *Theorizing a New Agenda for Architecture*, ed. K. Nesbitt, Princeton Arch. Press: New York, p. 402, 1996.
[8] McHarg, I. L., Ecology and Design. *Ecological Design and Planning*, ed. G. F. Thompson & F. R. Steiner, Wiley: New York, p. 321, 1997.
[9] Van der Ryn, S. & Cowan, S., *Ecological Design*, Island Press: Washington, p. 18, 1996.
[10] Todd, N. J. & Todd, J., *From Eco-Cities to Living Machines*, North Atlantic: Berkeley, p. 1, 1994.
[11] McDonough, W., Design, Ecology, Ethics, and the Making of Things. *Theorizing a New Agenda for Architecture*, ed. K. Nesbitt, Princeton Arch. Press: New York, p. 407, 1996.
[12] Piano, R., *Logbook*, Monacelli: New York, p.248, 1997.
[13] McHarg, I. L., Why is Architecture Oblivious to the Environment? *Design Outlaws on the Ecological Frontier*, ed. C. Zelov & P. Cousineau, Knossus: Cape May, p. 54, 1997.
[14] Spirn, A. W., *The Language of Landscape*, Yale: New Haven, p.248, 1998.
[15] Oelschlaeger, M., *The Idea of Wilderness*, Yale: New Haven, pp. 287, 289, & 294, 1991.
[16] Wheelwright, P. M., Texts and Lumps: Thoughts on Science and Sustainability. *ACSA NEWS*, 30(4), pp. 5-6, 2000.
[17] Orr, D., Architecture, Ecological Design, and Human Ecology. *Paradoxes of Progress: Architecture and Education in a Post-Utopian Era* (Proceedings of the 89th ACSA Annual Meeting), ACSA: Washington, p. 23, 2001.
[18] Lynch, K. *Site Planning*, 3rd ed. K. Lynch and G. Hack, MIT Press: Cambridge, MA, pp. 153-192, 1998.
[19] Norberg-Schulz, C., The Phenomenon of Place. *Theorizing a New Agenda for Architecture,* ed. K. Nesbitt, Princeton Architectural Press: New York, p. 414, 1996.
[20] Hinchman, H., *A Trail Through Leaves: The Journal as a Path to Place*, Norton: New York, p.150, 1997.
[21] Reichman, O. J. *Konza Prairie: A Tallgrass Natural History*, University Press of Kansas: Lawrence, KS, 1987.
[22] Berrizbeitia, A. & Pollak, L., *Inside Outside: Between Architecture and Landscape*, Rockport: Gloucester, MA, pp. 11-12, 1999.
[23] Norberg-Schulz, C., The Phenomenon of Place. *Theorizing a New Agenda for Architecture,* ed. K. Nesbitt, Princeton Architectural Press: New York, p. 426, 1996.
[24] Orr, D., Architecture, Ecological Design, and Human Ecology. *Paradoxes of Progress: Architecture and Education in a Post-Utopian Era* (Proceedings of the 89th ACSA Annual Meeting), ACSA: Washington, p. 30, 2001.
[25] Norberg-Schulz, C., The Phenomenon of Place. *Theorizing a New Agenda for Architecture,* ed. K. Nesbitt, Princeton Architectural Press: New York, p. 426, 1996.

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Contemporary practice in sustainable design: appraisal and articulation of emerging trend

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Abstract

Sustainable design is a phrase commonly used in the realms of design practice and yet the definition of the same remains quite fuzzy, thus providing the motivation for this research. The paper looks at contemporary sustainable design practices in the area of architecture design, building construction and landscape architecture. The objective is to understand what the term "sustainable design" really means as used in practice and what strategies are being employed towards the goal of sustainable development. The practices are assessed for their empathies as per the currently defined social, ecological, economical well-being goals of sustainable development. The paper concludes that out of the conventional triad of social, economic and ecological well-being, the socio-ecological well-being is emerging as the prevalent trend among the contemporary sustainable design practice. The trend needs to be continuously refined in this direction through intelligent employment of social and economic capital.
Keywords: sustainable design, sustainable development, eco-architecture, urban design, landscape.

1 The concept of sustainable development

As currently being advocated, "sustainable development means that the needs of the present generation should be met without compromising the ability of future generations to meet their own needs" [1]. This understanding of sustainable development is a progressive refinement of the concept outlaid in the Brundtland commission report in 1987 and then at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. The Rio declaration was based on the premise that the development and environment issues are mutually

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impacting and should be approached as such, through an integrated approach to improve the conditions of impoverished human living and deteriorating ecosystems. "We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being. However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can – in a global partnership for sustainable development" [2].

Agenda 21 affirmed the inter-connections and decreed the conservation and management of resources towards the aim of sustainable development and thus the social, economic and ecological well-being of human society. Social and economic dimensions listed poverty eradication as a high priority followed by issues of consumption patterns, health conditions, human settlements [2]. There seems to be a consistent attempt in communicating the inter-connected nexus among these factors and the issue of the natural resource conservation, but the details of the mutually impacting interconnection have not been clearly put forth.

A not much publicized document by the Barbara Becker in 1997 makes an observation about the inter-linkage of sustainability with the conceptualization of sustainable development [3]. She says "The importance that the term sustainability has gained in international debate can be attributed to its use in the Brundtland Commission's report [4], Our Common Future, which linked the term to development". Another prevalent understanding of sustainability the one cited within The mission statement of Consultative Group on International Agricultural Research also gives insight into another prevalent understanding of sustainability, where it is referred to as a successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources and the ecology related understand that used the term in relation to productivity of the ecosystems [3].

Sustainability as understood currently can be inferred as a tripartite balancing act between the economic, environmental and social concerns for the well being of the triad of: social, ecological and economic community [5].

2 Sustainable development and design

There has been no clear and strong reference to the role of design in above discussions on sustainable development as yet. And yet, the contemporary design world is abuzz with the word sustainable development. This indicates that the design profession is taking responsibility for its role in supporting sustainable development.

While the understanding on sustainable development and sustainability is still evolving, the content and scope of sustainable design also needs to be clearly articulated. As McLennan notes "…. the terms sustainable design…have come to mean so many different things to so many different people that, despite the growing interest, most have little true understanding on the subject" [6]. The contemporary designers' ambition to support sustainable development through design is being under-served by the generic, sporadic articulation of the term "sustainable design".

An appraisal of contemporary design practice aiming towards sustainable development collates the sporadic information together and is presented below.

2.1 Sustainable design: a snapshot of prevalent understanding

2.1.1 Multimedia stocktake

McLennan's definition of sustainable design as "... a design philosophy that seeks to maximize the quality of the built environment, while minimizing or eliminating the negative impact to the natural environment" [6] frames the concept within the classic, conventional tenets of deep ecology and sustainability. Subsequent attempts at defining the term and thus responsibility of the design profession include "Sustainable design is essentially about the reduction of impact." [7] and "...Sustainable design expands the role of design program, moving the design goal from object to community, and then designs the connections…" [8]. Both attempts reflect the struggle to articulate the concept in a way that is immediately useful to an active, professional designer.

The information available on the topic in the world of interactive web-based media was also studied as a critical marker since as it not only informs and influences popular understanding but also is indicative of public opinion. To get a snapshot of the prevalent mass opinion or information available to them, the phrase "sustainable design" was used for a keyword search on the popular media websites. Google showed 18,800,000 results, YouTube showed 2,220 results and TED showed 100 results on 21st May 2009 [9].

Google results on first page included *Guiding principles of sustainable design* (*www.nps.gov/dsc/dsgncnstr/gpsd*), which opens with concerns about overconsumption of natural resources leading to extinction of biodiversity and references to excessive living leading to environmental imbalances and global warming, book results such as *Sustainable design: ecology, architecture, and planning by Daniel Edward Williams; The philosophy of sustainable design by Jason F. McLennan; Sustainable design: the science of sustainability and green engineering by Daniel A. Vallero, Chris Brasier, and links to related resources, blogs, forums and businesses (en.wikipedia.org/wiki/Sustainable_ design, www.gsa.gov/sustainabledesign, www.sustaindesign.net, www.sustainabledesign.com, www.asid.org/designknowledge/sustain, www.aiasdrg.org, www.sustainabledesignforum.com, www.inhabitat.com/tag/ sustainable-design, www.sustainabledesignguide.umn.edu)* [9].

TED – Technology, Entertainment, Design, since is an invitation-only event where the world's leading thinkers and doers gather to find inspiration thus TED website had a list of talks be such leading thinkers. The topics included *learning from nature by Janine Benyus, open source architecture by Cameron Sinclair, sustainable fridge by Adam Grosser and, human-centered design by David Kelley among other topics on city design by Jaime Lerner and sustainable future by Alex Steffen*. These are not the only prominent voices and concepts on the topic but certainly the most heard ones thus highly influential in shaping the thinking of the masses [9].

For a cursory idea, nine out of twenty results on the first page of YouTube related to the description of sustainable design practices of the practitioner *:Tom Dixon on Sustainable Design,* of the firm: *The Triple Bottom Line, How Going Green Is Compatible With Corporate Profitability, FICOTechTalk; Digital Eskimo on sustainable design, wwfaustralia; 100% Design – Sustainable Design, 100percentlondon; Sustainable Design in Laguna Beach by LPA Inc., lpainc; Sustainable Design in Brea by LPA Inc., lpainc; A sustainable design agency in Sao Paulo-Report-EN-FRANCE24, france24english; Sustainable Design: A Conversation with Design Publishers, inhabitat*; or of the city : *e2 design II — Bogotá: Building a Sustainable City, kontentreal*. While these videos serve as free promotion and advertising mechanisms with wide outreach, they also act as indicators of current state of thinking and practice related to the topic. Four videos could be interpreted as inquiring into the concept of sustainable design: *Janine Benyus – 12 sustainable design ideas from nature, TED talks Director; Sustainable Design – Janine Benyus, Medicinal Rock; Composition of sustainable design, aikokey; UC Davis Newswatch: Sustainable Design, uctelevision*. The videos are not always uploaded by the firms and individuals in the videos themselves but patrons and fans implying that these videos reflect the ideas that the popular mass relate to or patronize. Six of these video uploads were outreach initiatives by the educational institutions advertising their interest in the topic and ability to educate in currently hot topics: *UC Davis Newswatch: Sustainable Design, uctelevision; Sustainable Design/Build Course at Philadelphia University, egret584; Conway and Sustainable Design, Conway Design School; Trent Jansen: Sustainable Design, unsw; Sustainable Design with Architectural Precast Concrete 1of6, pcieducation*. Two related to the interpretation of sustainability for software engineering world*: Technical design: Kevin Lynch, Adobe Systems Incorporated, Sustainable Design for a Multiscreen, Info-Overloaded World; Oreilly Media; What Sustainable Design Means to the Bottom Line, BNETvideo;* and three relate to documentaries on topics of sustainable design or perceptually related to it: *Sustainable Design (play all, Pale Blue Dot (3:59), Global Warning (4:43), The 11th Hour Trailer (2:19), 22 videos, gmachadodesign; discovery channel, Janine Benyus: 12 sustainable design ideas from nature (23:59), Sarah Susanka: Sustainable Architecture (4:07), Sarah Susanka: Home Design and Money (2:59), 73 videos auvjam; E&ETV: Sustainable Design – Green Skyscrapers, kpatterson1* [9].

Additionally, a keyword search was done on popular phrases related to sustainable, such as sustainable design, sustainable buildings and sustainable landscape, on YouTube [10]. Figure 1 presents a summary of the results and shows that the sustainable buildings topic had most videos uploaded and increasing over the week, with sustainable landscape being the least populated topic. However, when the components of sustainable landscape such as green roofs and living walls were keyed in, the results were markedly high for living walls than the sustainable buildings topic and even the topic of green roof, indicating the high level of interest in the area or that maybe the green roofs

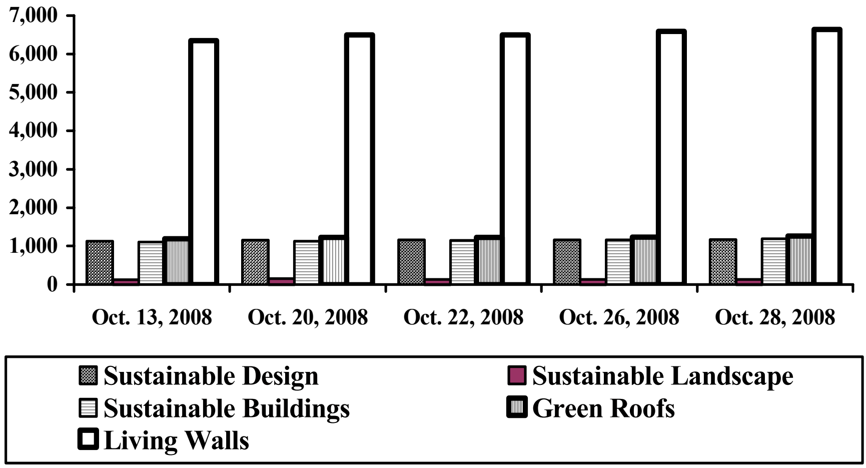

Figure 1: Snapshot of sustainable design related videos on one of the interactive mass communication medium – YouTube.

topic has been already popularized enough for producers as well as consumers while living walls is relatively new area to be tapped by both the commercial producers and mass consumers.

2.1.2 Local survey

To take stock of local familiarity with sustainable design, a survey was conducted on the University of Tennessee campus as a part of the introductory sustainable design course offered by the author. A list of sustainable design related keywords was generated by the students based on the review of available literature in the realms of sustainable practice. The keywords are listed below [11]:

> recycling, reducing waste, organic food, permaculture, local agriculture, local business, biomass fuel/energy, biodiesel, nuclear energy, solar power, geothermal energy , photovoltaic panels, passive solar energy, carbon-trading, green turf or roof, storm water management, fluorescent light bulbs, invasive species, native vegetation, sustainable design, compost, mass transit, heat island effect, carrying capacity, water reclamation, environmental or ecological footprints, rain gardens, leadership in energy and environmental design, cradle to cradle, industrial ecology, eco-psychology, hydroelectric power, tidal power, wind power, global warming, food security.

These keywords were included in a survey form and handed out to people asking them to estimate their familiarity with the keywords in the range of very familiar, somewhat familiar, and not very familiar. About 200 surveys were handed out at the University of Tennessee, Knoxville campus with approximately 100 responses. The survey showed that the respondents had highest familiarity with the aspects of recycling and waste reduction. Terms embedded with conceptual rethinking related to sustainable design, such as eco-psychology, industrial ecology and carrying capacity, were noted as least familiar.

All the sustainability keywords respond to either or all of the sustainability goals of social, ecological and economical well-being goals as currently identified by the United Nations [2, 5] and Chapman and Gant [7]. These sustainable practice related keywords are indicative of currently operational sustainable design tools. Table 1 categorizes these as per the obvious realms of action and primary empathies within the sustainable development triad of social, ecological and economical well-being.

Table 1: Operational tools of sustainable design and corresponding realms and empathies.

Operational sustainable design tools	Predominant realm of action	Primary empathies
native vegetation storm-water management composting green roofs living walls bioswales constructed wetlands and ponds rain gardens recycling waste reduction	landscape urbanism and policy design	socio-ecological
mass transit storm-water management water reclamation rain gardens organic food permaculture	urban design and policy design	social
biomass fuel biodiesel nuclear energy solar power photovoltaic panels passive solar energy geothermal energy hydroelectric power tidal power wind power fluorescent light bulbs	technology and policy design	socio-economical
local agriculture local business carbon-trading food security	economy and policy design	socio-economical

The survey when analyzed based on the above categorization indicates that the respondents had highest familiarity with sustainable design tools situated within the realm of landscape urbanism and with predominantly socio-ecological empathies.

2.3 Sustainable design: a snapshot of prevalent practice

2.3.1 Construction and development industry

A number of suggestions have been put forth to facilitate environmentally accountable or sustainable architectural design and construction. Efficient and optimum use of natural resources is being emphatically advocated. A sustainable architectural design practice has been recommended through employment of renewable resources, and, low energy-consuming techniques, for construction and continuous running of buildings through due attention to issues of insulation, ventilation, lighting design, day lighting and end-of the life recycling potential of the materials. Guzowski too emphasizes that sustainability aspect of architectural design could be improved through better use of day lighting [12].

Use of sustainable and /or indigenous materials and products is being highly recommended [13, 14]. The translation of this concept into practice is reflected in the private game reserve lodge in South Africa at Sabi Sabi Private Game Reserve. The lodge uses locally resourced materials such as sand, cement and grasses cut from the surrounding hillside. The lodge has been finished with a cement plaster blended with the natural materials such as straw, and stone. Other suggestions on recycling materials from demolished buildings, using concrete from old runways and building foundations for the foundation of new buildings and retaining walls [15] have been made towards the objective of resource conservation.

Towards increasing the mass awareness regarding resource efficiency and green residences, a system of labelling homes to display the information such as electricity use, carbon emissions, and insulation efficiency is being advocated, predominantly by Architect Michelle Kaufmann [16]. This is similar to eco-labelling concept generated in the realm of industrial ecology. Simultaneously, a new tool called Living Building Challenge is being proposed as a “move toward true sustainability” [17]. This system is idealistic and warrants for ‘NetZero’ prerequisites such as zero percent wastage or a hundred percent reuse of resources, for example, rainwater. Williams [8] also strongly supports the idea of efficient or almost complete re-use of all the rainwater falling on the land area of the building site.

2.3.2 Architecture and landscape architecture profession

Conservation of natural resources is a concern not limited to architecture profession. A number of contemporary practices reflect an integrated approach in designing the built and landscaped environment. Campus planning of Emory University was aimed towards sustainability [18]. The steps taken towards the goal of sustainability included construction of dormitories integrated with rainwater collection systems. The rainwater collection system is activated through a combination of architecture and landscape design. The runoff collected from the roof is directed down through downspouts to fall into brick runnels within the exterior landscape and then into a bio-swale for removal of silt and pollution. From the bio-swale the water is transported to a below grade cistern, with a capacity to hold enough water to flush toilets on a daily basis for several weeks.

Green roofs is another approach bordering architecture and landscape architecture professions that is widely used and advocated as sustainable design practice. Green roofs serve multiple purposes of harvesting rainwater, managing the storm water and insulating the building, which in turn reduces energy costs. Sky vegetables was a brainchild of Keith Agaoda [19, 20] to grow vegetables hydroponically on the rooftops of grocery stores, proposed for the University of Wisconsin School of Business G. Steven Burrill Business Plan Competition. Agri-based green roofs provide an option to backyard kitchen gardening and community gardening. Urban-agriculture concept of greening roofs for economic gains may have indirect ecological benefits in terms of reducing pressure on land for farming purpose and by bringing in a variety of other plants and associated communities thus adding to the richness of urbanized biodiversity.

While rainwater conservation is a prevalent trend, storm water management is also a common and popular practice. The neighbourhoods in Seattle, Washington had several problems with storm water runoff, including muddy streets, and other flooding problems. The problem was resolved through incorporation of bio-swale as a remedial strategy. This would not have been possible without the pro-active role of residents who went through petition process for the approval of the bio-swale incorporation [21]. Another storm water management strategy is to use the porous paving materials thus facilitating percolation of water into the soil for recharging the sub-surface basin, watering the landscape and reducing the surface water run-off. Chicago is considering implementing the strategy by replacing the existing asphalt with pervious concrete on existing pavements as a step to reduce the storm water runoff and meet new storm water management requirements; pervious concrete mixes contain limited or no fine aggregates, which produces concrete with approximately twenty percent voids [15]. Other porous surfaces that are generally being recommended as permeable surfaces include are grass pave, and geocells placed under the sod of a site [22].

Rain gardens too have the ability to survive drought and floods and could be planted with native plants to create a basic filtration system and to hold soil on steeper slopes with their root systems. Williams recommends the wider use of rain gardens for educational as well as water conservation purposes [8]. A study on park designs by Cranz and Boland observed that approximately 86% parks out the ones they looked at exhibited traits of sustainability such as interventions encouraging on-site recycling, use of native plantings and exercise areas [27]. The authors suggest that more urban parks need to incorporate these sustainable design strategies.

Sustainable site design is another concept that figures prominently in architecture as well as landscape design practice as in codes laid out by LEED- the Leadership in Energy and Environmental Design [23] and sustainable site initiative of ASLA- the American Society of Landscape Architecture [24]. These and other similar discussions advocate for the use of existing features and natural resources of the project to design the site with less environmental impact and a more efficient use of resources in a way that helps prevent natural hazard risks like landslides and erosion [25, 26]. Consideration of pre-conditions of the site from the initial design stages itself is another aspect being emphasized.

3 Discussion and further direction: socio-ecological well being as the emerging trend

All the design practices documented in this paper aspire to align with the sustainable development goal of maximizing use of available resources with minimum environmental impact. Key sustainable design strategies in place to towards the goal of sustainable development are:

- Consideration of tapping from alternative energy resources such as photovoltaic panels and geothermal sources, where possible
- Rain water collection and reuse through a combination of water collection ponds, green roofs, bio-swales and rain gardens
- Storm water management through a combination of constructed wetlands, porous pavements and bio-swales
- Environmentally judicious response to given landforms, materials and ecological processes occurring on the site
- Optimized use of other natural and renewable resources through designing for best use of sunlight and wind
- Use of on-site and locally available material and indigenous vegetation.

  While onsite consumption and recycling of resources has been heavily emphasized by contemporary design practice, onsite recycling of waste needs to be acknowledged as equally important sustainable design practice.

These practices indicate that the design profession is taking its role seriously in contributing towards sustainable development. Yet, the global statutory bodies driving the sustainability agenda such as the European Union and the United Nations need to clearly articulate "product design: architectural, landscape, urban, industrial" as one of the key drivers and indicators of sustainable development.

Although economic well-being may have been a tacit driver of contemporary sustainable design practice, the increasing trend seems to be empathizing equally with social and ecological issues. I am thus compelled to acknowledge the practice through the term socio-ecological well-being as the contemporary trend being favoured by prevalent sustainable design practices. The quantification of empathies outlined in this paper would help in validating this conclusion, understanding the extent to which the social, ecological and economic concerns are being favoured and aiding in balancing out these favours if the need be.

Being a society constantly developing for its own sake, it is only fair to be concerned about the existence of human species. That we are concerned about the extinction of other biotic species is also for our own sake because it is linked to our own existence through some eco-systemic connection. The shift to socio-ecological trend should thus be further investigated and encouraged rather than being undermined for its secondary emphasis on ecological issues. As a further research, the trend needs to be carefully assessed and operationalized in terms of design: drivers, objectives and outcomes. Besides, whether we are doing enough towards a sustainable future is a question that needs to be continually asked.

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References

[1] The Council of European Union, Review of the EU Sustainable Development Strategy- renewed Strategy, Brussels, June 2006.

[2] United Nations, Agenda 21, 1992, http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter1.htm, retrieved on 21st May 2009.

[3] Becker, B., Sustainability Assessment: A Review of Values, Concepts, and Methodological Approaches, Issues in agriculture 10, the Consultative Group on International Agricultural Research (CGIAR): Washington D.C. 1997.

[4] United Nations, Report of the World Commission on Environment and Development: Our Common Future. http://www.un-documents.net/wced-ocf.htm (WCED 1987). retrieved on 21st May 2009.

[5] Haenn, N. and Wilk, R., (ed), Agenda 21, United Nations, 1992, NY University Press, New York: 2002.

[6] McLennan, Jason F., The philosophy of sustainable design: the future of architecture, Ecotone Publishing LLC, Washington: 2006.

[7] Chapman, J. & Gant, N., Designers, visionaries and other stories: a collection of sustainable design essays, Earthscan, London, UK: 2007.

[8] Williams, D.E., Orr, D.W. & Watson, D., Sustainable design: ecology, architecture, and planning, John Wiley and Sons, NJ: 2007.

[9] Google, www.google.com; YouTube, www.youtube.com; TED, www.ted.com; retrieved on 21st May 2009.

[10] Lilard, C. and Carr, A., 2008, http://comprehendingsustainabledesign.blogspot.com/ retrieved on 25th May 2009.

[11] Budipradigdo, M. & Miller, W., 2008. http://comprehendingsustainabledesign.blogspot.com/ retrieved on 25th May 2009.
[12] Guzowski, M., Daylight for Sustainable Design. McGraw-Hill, New York: 2000.
[13] Calkins, M., Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials, Wiley, John & Sons, New Jersey: 2008.
[14] John St. Andrew., (ed), Sourcebook for Sustainable Design: A Guide to Environmentally Responsible Building Materials and Processes. Boston Society of Architects, Boston: 1992.
[15] Prokopy, J., Recycled Resources, Environmental Design + Construction, BNP Media, Michigan: 2008.
[16] Adams, C., Green Architect Michelle Kaufmann Calls for Sustainability Nutrition Labels, GreenSource, The McGraw Hill Companies: 2008.
[17] Woolliams, J., A LEED of faith, Canadian architect, vol.52, no.5, Toronto : 2007.
[18] King, W. Scott., Come Rain or Shine', Eco-Structure Magazine, p 56-61, Chicago: September 2008.
[19] Baratta, K., Sky Vegetable: farming is revolutionized on rooftops. Eco-structure magazine, Chicago: 2008.
[20] Keenan, L., 2008, Skyvegetables, www.skyvegetables.com. retrieved on June 2009.
[21] Viani, L.O., Stormwater, Landscape Architecture Magazine, p 100-111. Washington: October 2007.
[22] McIntyre, L., Grassroots green roof: A green roof on a Virginia condominium shows the possibility for low-cost retrofits, Landscape architecture, Washington: December 2007.
[23] U.S. Green Building Council., Leadership in Energy and Environmental Design-Sustainable Sites. 2008, 2009.
[24] American Society of Landscape Architects., Lady Bird Johnson Wildflower Center. and United States Botanic Garden., Sustainable sites initiative guidelines and performance benchmarks- draft. 2008.
[25] Ozdemir, A. Preventing Natural Hazard Risks through Sustainable Site Design. Polish Journal of Environmental Studies, vol. 17, no. 4, pp. 457-462: 2008.
[26] Baird, S.L., Sustainable Design: the Next Industrial Revolution? The Technology Teacher: December/January 2008.
[27] Cranz, G. & Boland, M., Defining the Sustainable Park: A Fifth Model for Urban Parks, Landscape Journal 23:2–04, p.102-120: 2004.

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Section 2
Ecological and cultural sensitivity

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Traditional urbanism and lessons for global cities: the case of Isfahan

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Abstract

This paper is about a discussion and a record on the ways traditional places can help us re-establish meaning and a sense of belonging, in a world now increasingly defined by pointlessness. The traditional city of Isfahan is selected for discussion and analysis because Isfahan, through its methodical urban development, maintained a balance that stood between nature, culture and society and is the result of an evolving process through many generations. With its marvelous architecture, of pavilions, gardens, mosques and lavish ornamental profusion of building facades, Isfahan bears the hallmark of a culture and architecture that provides us with lessons of history and opens up for us the imaginative myth of human consciousness. Traditional architecture and planning is adoptable to our modern needs and aspiration and can enrich our lives beyond the material and mechanical capacity.
Keywords: traditional city, nature, culture/society, architecture and urbanism.

1 Introduction

In our current time the spirit of the modern city is one of globalism. This theme perpetuates itself at all levels of society from the work place, to the market, to transportation, to entertainment and architecture. No matter where one travels, modern cities are no longer organized according to regional identity, but rather to a manner that is ephemeral and without a sense of history.

During the last century, the modern world has been on a course of persistent change and innovation. The desire, to see truth as strictly the product of rational constructions, has given rise to a world in which rituals, myths and traditions in general are at best interesting relics of the past and at worst invalid and marginal. Once the tradition is seen in a residual as opposed to cyclical terms, tradition

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then falls prey to irrelevancy. In this sense, tradition is associated with backwardness, lack of creativity, boredom and stagnation. Edward Shills warns about the damaging effects that the cult of scientism has had on tradition, and says that in seeing itself as the sole harbinger of originality and thus progress, it has unnecessarily devalued the role of the past [1]. The transient and alien city condition is nothing new and has been with us for at least the last one hundred years. One of the issues that impelled the Dadaists into radical action at the outset of the 20th century, for instance, was their view that the city had become such a rational, mechanical entity, that there was little room for us to intuit in it [2]. Their option to work with montage was in effect to exemplify the breakdown of traditional unities that had constituted the web of daily events. Cause and effect were no longer as tightly connected as before and in some cases had already broken apart completely.

Tradition itself, at the end, is not in essence about dogma, but about shedding light on knowing our place in the community, our shared history and giving us guidance as to the dignified manner with which we need to engage each other and all the environment around us. In fact, traditional places are more than physical entities, one should become exposed to a survey of life in its totality. Heidegger revered such places as the cultivation of identity and saw in the idea of “building,” the origin of neighborliness, signaling for us a conviction that place is not about change but about staying, cultivating, repeating; in short about tradition itself [3].

We have grown so accustomed to thinking of history in spectacular terms, incidents that the judges of culture and scholarship have considered worthy of our attention, but which we have no practical use for it any more outside the realm of interest and curiosity [4]. History in this sense is a body of information that we engage ourselves with from a distance in time and place, or perhaps even strengthening our appeal for a nostalgic time. To traditional cultures, history never fades away but is persistently exercised as a way of enriching our lives and passing on critical knowledge. There is of course history in the grand sense of epoch formation and a singular object or an image that outshines the rest, but that does not deter us from the fact that smaller histories are daily siphoned through as a matter of keeping the culture alive [4]. Whether through the telling of stories or through the passing of practical knowledge, the emotional and intellectual span between one generation and the next is never severed.

2 The case of Isfahan

Rich in culture, art and architecture, Isfahan maintains a poignant position and pride of traditional architectural legacy amongst traditional Islamic cities. Isfahan tells us much about why an authentic “sense of place” is necessary to our experiential identity and intellectual capacity, particularly in the Islamic tradition. The cosmopolitan city of Isfahan, much of its urban development that dates back to the early 17th century, a time when the *Safavid* dynasty ruled the city, but also one in which various global forces had begun to converge on the region: British-India and China from the east and the Ottomans and Imperial Europe from the west. Due to its unified and dynamic urban structure, Isfahan synthesized faithfully the changing economic and political global role of 17th century and yet it preserved successfully its subtle cultural and historical affluence.

Having served as an important political and administrative center during the *Seljuk* dynasty in the 11th century, the city later witnessed the dismal misfortunes of war, distraction and massacres during the *Mongol* and *Timurid* periods of the 13th and 14th centuries, but Isfahan would regain its splendid importance again during the *Safavid*in 17th century. During this period ambitious building programs were initiated with the construction of magnificent mosques, public gardens (*char-baghs*), bridges, caravansaries and urban plazas (*Maidan*). At its height Isfahan is reputed to have had over 160 mosques, nearly 50 *madrases*, 1,800 caravanserais, 273 bath-houses (*hammams*) and numerous glittering gardens and covered bazaars [5]. It is estimated that the population of Isfahan at this time was 500,000 inhabitants. [6]

In urban terms, Isfahan is built around the boundaries of three types of architecture order: the square called the *maidan*, the thoroughfares, known as *kucha*, and the dense clusters of residential districts, the *mahala*. Depending on the degree of enclosure, each property offers specific spatial qualities that constitute points of departure for these urban forms. The particularity of how these places are used is clearly the job of culture and is locally determined. Internally these places contain sub-places, which serve different purposes in the settlements. Here we find the essence of in-between with its artifacts that define the innermost goals, and their various structural properties that clearly emphasize the form of life.

The construction of the new city during *ShaAbas*'s reign (1587-1628) begins around the Great Square (*Maidan-i-Shah*) to the southwest of the old city. The new *Maidan* functioned as a polo ground, a public square for caravans and an open marketplace for the villagers (Fig.1). *ShaAbas* established his center to the lower West Side of the *Maidan*, which already had a *Timurid* gatehouse, the *Ali-Qapu*, or the high gate and constructed palaces and gardens scattered behind it to the west of the square. *Ali Qapu* holds the symbolic point of contact between the past on one hand and is a visual connecter between the private quarters of the palace and the public outside. While modest in term of facade appearance, this structure is in actuality a very elaborate work of six stories high, which served as the principle reception pavilion where *ShaAbas* received his courtiers and attended banquets (Fig.2). The eastern facade adjoining the great *Maidan* on the public side consists of a monumental gateway, which also permitted passage to the bazaar, encircling the entire square. On the upper floor above the gate stood the elaborate platform, *talar*, or loggia with sumptuous ornamentation. From here the king would attend and observe military parades and civil and religious activities that were a custom of the time. Probably the most important room in the building is the vast winter throne hall on the same level as the grand *talar* and extended as high as the *talar* roof. This room consists of a clerestory for light from above, decorated with rich patterns of stucco and *Muqaranas* (Fig.3).

Figure 1: View of the southern end of the *Maidan* with *Masjid-i-Shah* in the background. Note, on the one hand, the wall separating the *Maidan* from the *Masjid* and the grand portal entryway on the left.

Figure 2: View of Ali-Qapu as it overlaps with the commercial arcade traversing longitudinally. Note the elaborate platform *talar* or loggia on the upper story overlooking the *Maidan.*

The rich pattern of natural light that penetrates through the arched clerestory windows admitted from above casts a playful interplay and mosaic of shadows [7].

Named after *Sha-Abbas's* father in law, *Masjid-i-ShaykhLutfullah* is situated directly opposite the *Ali Qabu* palace and to the lower east perimeter of the *Maidan* (Fig.4). The most unusual features of the mosque are the lack of minarets and central courtyard in direct contrast to that of *Masjid-i-Sha*.

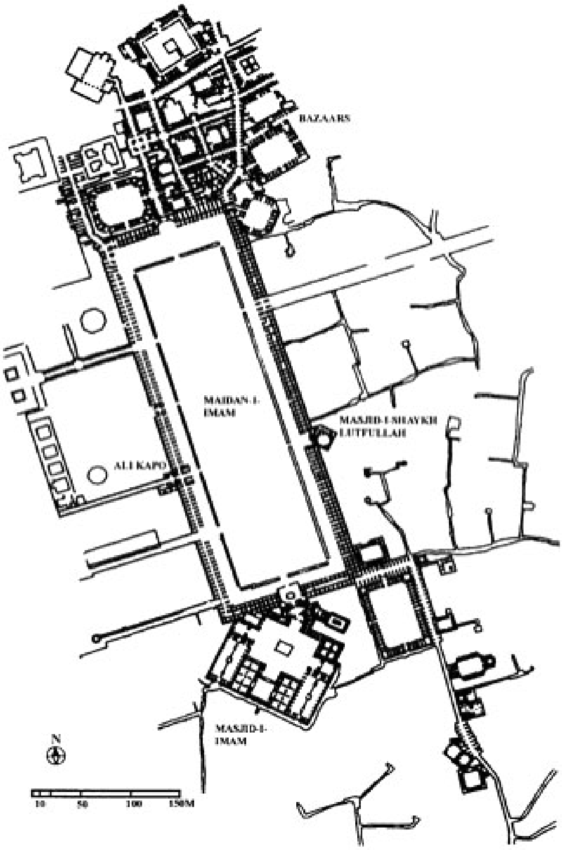

Figure 3: Plan of the *Maidan-i-Imam*, which provides passage to the bazaars encircling the entire square.

Entering the *Masjid* through a half domed portal entry *Aiwan* leads the worshippers to the main praying hall facing the *Qibla* and *Mihrab*. The main praying hall is covered with a magnificently decorated dome that sits on a well-lit drum. The light enters through sixteen double grilled windows positioned proportionately around the drum.

In 1611 *Shah Abas* authorized the construction of the great mosque *MasjidSha* and it took 28 years to entirely complete the building. A grand entry portal allows passage to the mosque stands, which are about 90 feet tall and recessed deeply from the perimeter of the south wall of the *Maidan,* inviting the worshipers inside the mosque. Richly decorated with a mosaic of tiles and patterns of *muqaranas,* the portal provides remarkable sense of refinement and verticality.

Entering through the gateway one faces a critical transition of a long cavernous passageway and vestibule that are supported by intricate structures of arches and a vaulted ceiling. Unlike the overlap at the gatehouse, here unity is handled in terms of mass and void. When the passageway interacts with the entry portal of the *Masjid* there occurs the situation in which the mass is seen carved away and a void is made available. At this juncture the void is indicative of the fact that while in it you would neither be in the *Maidan* nor in the *Masjid* but in a unity between the two. The passageways gradually unfold and open up to the great central four *aiwan* courtyard of the mosque. The four-*aiwan* courtyard is a classical prototype, which has been in use since the architecture of the *Timurid period* and culminated a thousand years of evolution [8].

Inside the courtyard one is struck by a sense of tranquility amplified by encrusted blue colored tiles on the surrounding walls. As John D. Hoag remarks, “if the goal of Islamic Architectural ornament is the dissolution of the solid mass, it reaches perfection here” [9].

The gradual transition from open courtyard to the interior sanctuary which is located to the southwest of the courtyard, provides a structured and rhythmic transition. In the main sanctuary, all chambers are of square plan rising from the base on majestic piers arching at the top and form an octagon, from which subsequently through arching mechanism and the use of *Muqaranas* emerges the basic resolution of the circular dome. The circular band of the base of dome is embellished with colorful floral patterns, and *Quraanic* calligraphy [9].

The bazaar represents the primary movement system and commerce activity for the entire city. It commenced from the north gate and passed through the old *Maidan*, built during *Suljuq* period, and continued to expand during 16th century *Safavid* to the south even further and terminated at *Pul-Khwaju* bridge built over the *ZendaRud* river.

Its moving system in the hierarchy of linear circulation links open booths, *carvanserais*, *hammams* and associated mosques together to the physiognomy of the whole city. In the Bazaar the traffic ways are sheltered from the sun by being completely covered. These partly or completely covered ways, however functional in the physical sense, also emphasizes the atmosphere of enclosure and seclusion to welcome the citizens [10].

Like most Islamic places, the world of commerce and the world of the mosque do not represent two distinct realities, often they are juxtaposed with each other. In Isfahan this view holds true, but only to a limited extend; namely that while business and religion stand to be at odds with each other, they do not constitute two distinct opposing realities but opposites within a singular reality. This is made clear by the way the wall between *Maidan* and *Masjid* is inhabited by merchants who sell their ware to those strolling around in the *Maidan*. Here we see the passageway, which had at one point skirted around and overlapped with the palace and then the *Masjid-i-Lutfullah*, now entering a new phase and playing the double role of edge and center simultaneously; edge to mosque and *Maidan* and center to market. As the three come together there arises the profound sensibility that while divisions in the way we live may be inevitable, these divisions need not be alienating but can be graced through the connective tissue of unity.

Residential quarters are fed by narrow and labyrinthine pathways that link the residential and private domain of courtyards to that of major network of bazaars and essential nodal activities. The narrow pathways abutting the courtyards get wider as they leave the residential precinct. Small shops, local mosques, and bathhouses are dispersed throughout the network of the pathway. These narrow networks as shaded by the masses of courtyards and walls provide condition of comfort for its user, which is very vital in the dry arid climate of Isfahan. Street intersections are small activity nodes where a small shop or a local mosque may be seen. A wider pocket in the corner may add to this communal and public function where male adults and elderly get together and socialize.

The intricate and compact orders of streets, which tend to show localized spaces, are the outgrowth of practical necessities. Street serves more than channels of mobility. Its complex territories are intensely three-dimensional and bordered by adjacent walls that add properties of verticality. The monotonous linearity of the thoroughfare is broken into smaller intimate sequences of spatial continuity that acquire a sense of individuality and place identity in every level.

The penetrated gateways, *dahlans*, underpasses, and building projections make the theme of *kocha* continues as unbroken container. The three-dimensionality of container and its power of directional and thematic qualities accomplish something equal to the quality of interior. For the moment the pedestrian feels the intimacy and security of dwelling and exhilarating extension of their actions into the surrounding space. The effect of verticality is explicitly spelled out through narrow and continuous massing indicated by the gateways surmounted by projection from upper stories. An over pass *dahlan*, the minaret and elevated dome of the mosque each of them counterpoint and adds vertical accent to the horizontally of *kucha*.

Entry to the houses is normally indirect and exaggerated - entering this realm visitors find themselves first in a small entrance hall - but then one has to traverse long corridors (*dahlan*), before entering the courtyard. These entry halls provide access to several neighboring courtyards. The house gateway is often emphasized by the construction of monumental and sometimes highly decorated features. Metal and brass decoration and inscriptions, skeletal and bulkiness of doorway represent usual features and often-important indicator of the family status. The door serves to conceptualize the relationship of inside and outside and its position in the continuity of the massive wall, give emphasis to enclosure of the interior. This relationship creates an atmosphere of spirituality, which makes it meaningful, having direct contact with the substance of culture. The doorway offers us entry to the house but at the same time stops us to pause and think which is a temporary suspension of our passage to inside.

Passing the entry *dahlan* at the center stands *haweli*, the courtyard - the heart and the locus of the domestic life. *Haweli* makes the total amalgamation of in-between places possible. Once we are inside *haweli*, we are between the entire experiences of in-between - situated between entire groups of interiority. It is visually connected to the whole sequence of the interior spaces, running like a thread. Here, moving everywhere in both horizontal and vertical directions, one finds all dimensions of place real and tangible. The facade on all sides punctuated with verandahs, porches, *sakoonchas*, and *aiwans* and what even lies behind it, circumambulate and linger alongside the center of *haweli* - dark deep shaded windows of interior rooms drew us into the comfort of interior rooms, *khana*.

The courtyard is where all diversities of life come together; it is the center, which constitutes the ultimate “inside”. The character of the inside is vivid and warm. Family activities populate this place and provide an architectural counterpart. Being familiar with its ambiance, there is an intense feeling of belonging, not because being there for the moment - but because being so much within its ambience - and memories that are so much with us - that we seem to belong to each other.

The center is the powerful focal point of the courtyard and is often explicitly marked by a fountain, a pool, or flower boxes. The idea of center finds multiple expressions in the courtyard house. As rooms open up and expand towards the edges, its inhabitants move accordingly and seat themselves around the periphery, allowing for an uninterrupted contemplation of the center. Of the more profound spatial provisions for such an intervention is the place of the *aiwan*, an open room that occupies the middle ground between the interior and exterior of the house and one that embraces the outer edge of the courtyard.

3 Conclusion

The defining universal values that are shared by the traditional architecture of Isfahan can help us reestablish meaning and a true sense of place. I will assign three values that appear to fulfill the criteria of relevance and deep attitudes that are essential to both arts of urban planning and architecture in the Islamic world. These distinctions are the following:

Tradition and spirituality: What differentiates a traditional urbanity from its modern counterpart is the belief that buildings are treated less as objects in the landscape, and more as conduit through which man can engage with his universe meaningfully and find spiritual fulfillment. The aim here is not so much aesthetic as it is experiential, meaning that what matters most to those societies who seek and preserve the integrity of urban form is less the image of things and more the way those very same things are able to connect individuals and bring a sense of purpose and spirituality to their presence on earth. In a place like Isfahan, this emphasis on connectivity is reflected in the way public square *(Maidan)*, buildings and other public spaces are wrought together into a pattern of localizing spatial forces. While the modern spatial example is established on the premise that outside and inside constitute two different worlds, in Isfahan the two melt together into a singular conception of special space; here where there is society, community, there is no outside, only inside. Going from home, to street, to mosque, to bazaar, and back again, you do not go back and forth from inside to outside but remain in one world, from inside to inside, where you stay connected with others and protected from inimical forces. To be sure, going from home to street can be said to reflect the familiar scenario of going from inside to outside, but that is only true in pedantic terms; in spiritual terms and because of the fact that streets and public spaces are so inextricably linked with private buildings in the Muslim tradition, the situation is such that here one does not feel as if he or she is ever leaving, but only entering. And the consequences are that places like Isfahan ultimately work to first reduce hierarchy and second to eliminate the distinction between the sacred and the profane. In the view of tradition all inhabited spaces are considered sacred.

Being inside holds a special sway in the Muslim tradition. It is not only important spatially, giving the Muslim the means with which to maintain privacy and protect his family, but more importantly spiritually. To the medieval Muslim scholar IbnSina, to be inside was tantamount to being with god; whereas the outside world represented the world of appearances, a world defined by much corruption and vanity, the inside world reflected man's only capacity and only conduit with God [10]. Inside is a quiet, introspective and deeply pious world where both space and time dissolve in favor of the feeling of the eternal.

Tradition and nature: In view of tradition the transformation of nature should not summon an emotionless connotation, or an attainment of lust and greed for unconditional economic gain. To this end, the present trends of global developments and the resultant environmental degradation, the prospect of a new century raises serious questions about the health and viabilities of our civilization. In the last century with the abandonment of traditional built environment, towns and cities transformed significantly from an efficient human scale fabric to a sprawling low-density fragmentation, which adversely impacted our natural habitat. Most traditional cities and building practices evolved out of necessity and not a supply-driven ideology. Their sense of sustainability emerged from having found resonance with nature, its pace and cyclical progression. This way nature is never so transformed to the point to treat it as a residual quality and more as a body whose presence already has a system of built-in efficiency that if understood and appropriately manipulated can yield to a greater abundance. To this end traditional societies assign nature a sacred quality and treat it as a gift, not from another person or from a manufacturer, but from God, thereby placing it on equal footing with our deepest emotions and needs. This way when we come to displace nature from its origin, we do not do it with the idea of exploitation, where the end justifies the means, but with the idea that we have to take care in ensuring the continuation of a life already in process [11].

In this equation the making of architecture requires a conscious realignment of our hearts as well as our minds in order to intimately engage with properties of nature and acquire a unified totality. Architecture must be able to speak to the sun, to the wind, to the soil to the heat and to the cold; in short it must perpetuate the true spirit of place.

Tradition and community: Community is the setting up of the stage for human interactions to take shape, akin to the larger scheme and needs of the society. Here activities are seen as flowing and ebbing without resistance and without the pressure of operating under the hegemony of contesting goals. Like an organism, society finds maturity in the way it leaves itself open to changing conditions and to the unknown down the line.

Tradition never enters into the definition of the polarity between the regressive and the progressive; rather it takes shape through a list of activities and rituals whose whole aim is to perpetuate humanity and community from one generation to the next. Progress is never quite an autonomous endeavor to be taken up with intention and action, but something that is already underway and evolving behind the scenes. This means that nature here is considered just as much part of a progress as their animate counterparts and that when one extracts as much as a stone to build a house, one does not do so independent of progress but very much part of it. Unlike techno-cultures where success is hyperactively measured by the degree to which reality can be distorted, in traditional cultures progress is not considered the hegemony of man but man the hegemony of progress, which has its own pace and its own regulating ways [11].

In architectural terms, we find that traditional settlements are atoned to the above collective community cultural requirements, which is strengthened through social bonds and mutual responsibilities within the community. Here, architecture is conceived as being a living entity with its fluid and organic fabric that facilitate distinct needs of social and cultural requirements. Towns and cities are defined by dense townscapes that are firmly unified buildings and land uses showing a high degree of complexity and cohesiveness [12]. The result is a rich urban tissue endowed with much aesthetic appeal and distinguished cultural history. These settlements are cloaked in their organic spontaneity and fluidity that drive the design and create a sense of place which breeds community solidarity and cultivate a rich urban cultural fabric.

The globalized vision of 21st century offers us tremendous cross-cultural opportunities to shape the built environments of cities in this vast global arena. But this opportunity also burdens us with greater responsibility and humility that our decisions must become knowledge based, more innovative and more sustainable. As we master the art of gaining access to knowledge of culture in a differentiated world and serve new societies, it is architecture that shapes the environment of global communities to live a noble life and maintain their cultural identity with dignity.

References

[1] Shills, Edward. On Tradition, p-22, The University of Chicago Press, 1981.

[2] Hanne Bergius in “Architecture as the Dionysian-Appollonian Process of Dada,” *Nietzsche and An Architecture of Our Minds*, Getty Research Institute, Los Angeles, CA, 1999

[3] Kazimee, Bashir and Rahmani, Ayad. *Place, Meaning and Form in the Architecture and Urban Structure of Eastern Islamic Cities,* p- Edwin Mellen Press, Ltd, New York, 2003.

[4] Irving Wohlfarth in "Construction has the Role of Subconscious: Phantasmagorias of the master Builder," *Nietzsche and an architecture of Our Minds*, Getty Publishers, 1999

[5] Oliver, Paul. (Binerism in Islamic City). Islamic Architecture and Urbanism, p.121-146. King Faisal University, Dammam, Saudi Arabia, 1983.
[6] Arabi, G. Hossein. Isfahan, Yasavoli Publishers, Tehran, Iran, 1999.
[7] Kazimee Bashir. "*UNDER THE SHADOW OF WALLS: Place, Meaning and Form in the Islamic Architecture and Urban Structure of Isfahan,"* p.112-116, proceedings, ACSA International Conference, Istanbul, Turkey, ACSA Press, June 2001.
[8] Michell, George. Architecture of the Islamic World, Its History and Social Meanings, Thames and Hudson, 1995.
[9] Hoag, John D. Islamic Architecture, Electa/Rizzoli New York, USA, 1987.
[10] Auguste de Montequin, Francois. The Essence of Urban Existence in the World of Islam, Islamic Architecture and Urbanism, King Faisal University, p-43-64, Dammam, SA., 1983.
[11] Kazimee, Bashir and Rahmani, Ayad. *Place, Meaning and Form in the Architecture and Urban Structure of Eastern Islamic Cities*, Edwin Mellen Press, Ltd, New York, 2003.
[12] Kazimee, Bashir. *Learning from vernacular architecture: sustainability and cultural conformity.* "*Eco – Architecture: Harmonization between Architecture and Nature*", pp 3-13, edited by G. Broadbent & C.A. Brebbia, WIT Press, UK, 2008.

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Thermodynamics-based indicators for environmental management and sustainability policies

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Abstract

Human activity is deeply funded on the availability of natural resources. They are mostly provided for free by the environment and often neglected by traditional accounting systems since it is difficult to express their contribution or their physical weight in monetary unit, more familiar to most people. Inventorying all the flows of energy and matter that feed a territorial system and giving them a non-market value plays an important role in the field of natural resources management, sustainability policies and territorial planning. A physical based environmental accounting method is implemented in order to evaluate all the resources used within the area on a common basis, beyond the economic scheme, which allows a deeper knowledge of the system. The tool is emergy evaluation, a thermodynamics-based approach, introduced by Howard T. Odum during the 1980s. The use of emergy enables one to calculate some sustainability indicators (such as Environmental Loading Ratio, Emergy per Person, Empower Density, Emergy Investment Ratio), and is able to give a systemic and holistic picture of the system from an environmental point of view. The paper presents a sustainability assessment at regional level by monitoring the use of resources and the results of the analysis could be used to design different development models and scenarios with several implications for the administrative activity. The results orient environmental management solutions for territorial planning and sustainable policies.
Keywords: territorial planning, resource management, emergy evaluation; indicators.

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1 Introduction

The evaluation of energy and material flows supporting a territorial system can be used to describe the rate of exploitation of the available resources and design environmental management strategies.

This paper presents the results of the emergy evaluation (EME) of an area, namely the Province of Ancona, Italy. The aim of the study is to show a comprehensive assessment of the environmental sustainability of the territorial system as a whole by means of the analysis of emergy flows and indicators. In this way, a “check-up” of the system is provided in order to know the level of environmental stress and the degree of compatibility between human activities and natural cycles, and highlight the environmental criticalities induced on local ecosystems. The results of the analysis can be a valid tool to measure the environmental support to the local inhabitants’ lifestyle and the efficiency in the use of energy and matter under a sustainability viewpoint. In fact, in order to implement a correct environmental management programme, before any “sustainability therapy”, it is necessary to implement a “sustainability diagnosis” on the basis of a deep objective analysis of the environmental platform which human activities are based upon. Currently, the lack of suitable diagnostic instruments may be revealed when a policy towards sustainable development is programmed [1]. In this sense, emergy evaluation can be included in the class of systemic environmental accounting methods, together with Material Flow Accounting [2], Environmental Space [3], Exergy Analysis [4, 5], Ecological Footprint [6, 7].

2 Methods: emergy evaluation

During the 80’s, an ecologist, Howard T. Odum, proposed a thermodynamic description of the energy transformations within the biosphere. It is a flexible and intuitive idea that is based on the concept of emergy. Odum sought to show quantitatively the fact that, in order to obtain a certain quantity of energy of one kind, a larger quantity of energy of lower quality is necessary [8-10]. To produce high quality energy, for example electricity, we need a lot of low quality energy, for example chemical energy in fuels. Supposing that solar energy is the basic energy of all natural processes and energy transformations, he defined emergy as the quantity of solar energy necessary (directly or indirectly) to obtain a product or energy flow in a given process. Emergy could be defined as the memory of all the solar energy consumed during the process. Hence, the greater the emergy flow necessary to support a process, the greater its environmental cost. Any system needs several inputs to survive and the emergy of all inputs is calculated in terms of solar emergy joules (sej) by means of suitable transformities. Transformity is the factor to convert each kind of energy in terms of emergy (i.e. equivalent solar energy) and its unit is sej J^{-1} (when expressed in other units, e.g. sej/gram or sej/litre, the factor is called specific emergy). It represents all past environmental work necessary to obtain one unit of a given resource.

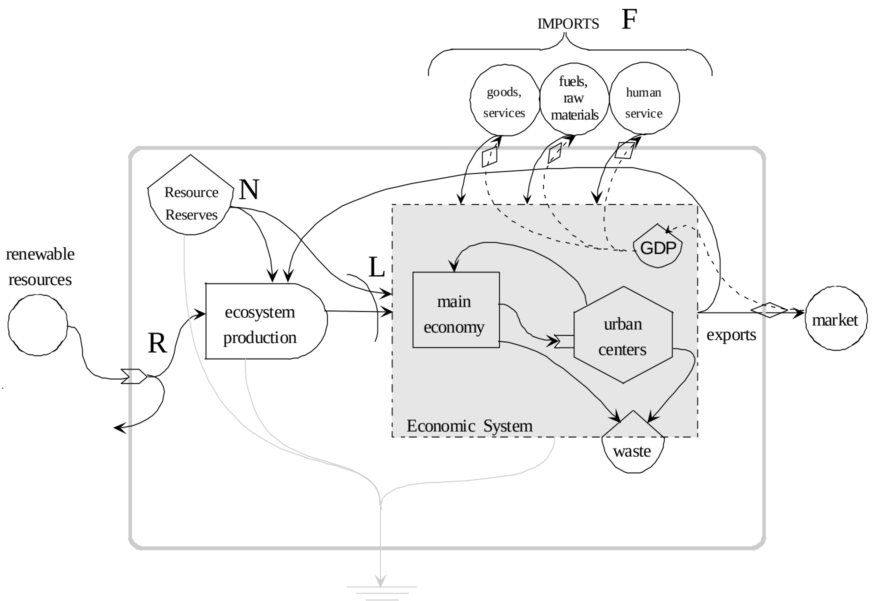

Figure 1: Basic emergy diagram for a typical territorial system with its major resources inputs.

Once all the resources supporting a system have been defined, they can be classified into categories. As showed in Figure 1, the total emergy of a territorial system is divided into renewable (R) non-renewable (N) and imported from outside inputs (F). Renewable and non-renewable flows, (R) and (N), are locally available and derive directly from the environment; the imported flows (F – feedback flows) are come from the market, outside the system.

The emergy use (total emergy flow) of a system is given by the sum of all its emergy-based inputs, renewable non renewable and purchased from other ecosystems, calculated in sej yr^{-1}. Hence: EM = R + N + F.

After calculating and analysing the total emergy supporting a process or a system, some indicators can be obtained by putting into relation the different categories of inputs.

The environmental loading ratio (ELR) is the ratio of non-renewable indigenous emergy and imported emergy to renewable environmental emergy. This indicator represents the unbalance between non-renewable and renewable resources and constitutes a proxy of the environmental stress. Formally: ELR = (N + F)/R.

The emergy yield ratio (EYR) is the total emergy supporting the system divided by the emergy of the inputs F, coming from the economic sector (i.e. not provided for free by the environment). A high value of the EYR indicates whether a process can compete in supplying a primary emergy source for an economy. Formally: EYR = (R + N + F) / F.

The Emergy Investment Ratio (EIR) is the emergy of the inputs from the economic sector (i.e. not provided for free by the environment) divided by all local emergy both renewable and non-renewable. A high value of this indicator represents fragility of the system due to the high dependence on other ecosystems or economic systems out of control. Formally: EIR = F / (R + N).

The areal empower density (ED), the emergy flow per unit area, is a measure of spatial concentration of emergy flow within a process or system. In Western countries, the high value of ED suggests that land is a limiting factor for future development. It is expressed in sej m^{-2} yr^{-1}. Formally: ED = (R + N + F)/area.

The emergy per person (EpP) is given by the ratio of total emergy supporting a region to the population. It represents the contribution to unsustainability of each inhabitant, depending on the type of resources that are used up (R, N or F). Its unit is sej $inhab.^{-1}$ yr^{-1}. Formally: EpP = (R + N + F)/population.

Emergy evaluation gives information about actions and policies with respect to sustainability beyond the boundaries of market [see, for example, 11–14]. The set of emergy-based indicators is proposed to evaluate different scenarios and policies comparing emergy inputs, efficiency, correct use of local resources and their degree of renewability. It also describes the development of a region on the basis of the geo-localization of the flows, diversifying the areas according to the intensity of these flows.

3 Case study

Ancona is the main Province of the Marche Region. It is located in the centre-east of Italy in front of the Adriatic Sea. It covers an area of 1,940 km^2 (see Figure 2).

Its territory is mainly hilly (66%) and mountain (34%). It has a high population density (229 inhab. km^{-2}) that is higher than the Italian average density (191 inhab. km^{-2}). In particular the coastal areas along the Adriatic Sea

Figure 2: Map of Regione Marche and the Province of Ancona.

are the most populated and industrialized. Ancona is a dynamic Italian Province. Its economy is based on heavy manufacturing industry and services. Four districts, with different socio-demographic features, within the Province were distinguished and studied separately. The "*Comunità Montana Alta Valle dell'Esino*" (38% of the total area) has a low population density, paper industries and agriculture. The district "*Media Valle dell'Esino*" is located in the centre of the Province and is the smallest one. The other two districts, "*Valle del Misa*" and "*Osimo-Ancona-Falconara*" (OAF), are located along the seacoast with a high population density and dynamic centres of services and tourism.

4 Results and discussion

Statistical data was collected in order to quantify the resources that are necessary to supply the area of the Province of Ancona. Inputs to the system were given in energy and mass units (see Table 1 and 2) and transformed into equivalent solar emergy joules through suitable transformities. Results (emergy flows and indices) are summarized in Table 3.

As shown in table 3, the total emergy used is 3.50×10^{22} sej yr^{-1}. The analysis of flow-categories shows that the system is mainly supported by non renewable resources (N+F=99%) with only 1% of renewables (R). The emergy of import (F) is about 86%, divided into imported energy (9%) and purchased goods and services (77%). The non renewable local resources (N) account for 13% and are mainly derived from materials extracted, in particular sand and gravel.

Results therefore show clearly that the regional system acts as a transformer of imported goods and services more than a consumer of local resources.

Table 1: Local inputs and energy use in the territorial system (expressed in energy or mass units); [*See Appendix for references of transformities].

		Unit	Province of Ancona	Ancona-Osimo-Falconara (AOF)	Bassa Valle del Misa	Media Valle dell'Esino	Comunità Montana Alta Valle dell'Esino	Transformities (sej unit^{-1})	Ref.*
LOCAL RENEWABLE RESOURCES (R)									
1	Sunlight	J	7.39E+18	2.10E+18	1.26E+18	1.21E+18	2,82E+18	1.00E+00	*a*
2	Rain	g	1.96E+15	5.22E+14	3.33E+14	3.15E+14	8,65E+14	1.45E+05	*a*
3	Wind	J	7.04E+15	8.44E+14	1.15E+15	1.59E+15	3,99E+15	2.47E+03	*a*
4	Geothermal heat	J	2.14E+15	6.62E+14	3.65E+14	3.50E+14	7,01E+14	3.02E+04	*a*
LOCAL NON RENEWABLE RESOURCES (N)									
5	Sand and gravel	g	1.43E+12	-	6.75E+11	5.61E+11	-	1.68E+09	*a*
6	Clay	g	1.40E+11	7.14E+10	5.25E+9	6.30E+10	-	1.68E+09	*a*
7	Limestone	g	1.06E+12	1.06E+12	-	-	1.06E+12	1.68E+09	*a*
8	Loss of topsoil	J	4.09E+14	2.39E+14	5.16E+13	5.33E+13	8,42E+13	1.24E+05	*a*
9	Water	g	4.50E+13	2.66E+13	5.43E+12	6.68E+12	6,37E+12	1.95E+06	*b*
IMPORTED ENERGY SOURCES (F1)									
10	Fuel	J	1.54E+16	8.49E+15	2.41E+15	2.42E+15	2.08E+15	1.11E+05	*c*
11	Natural gas	J	2.13E+16	1.17E+16	3.34E+15	3.36E+15	2.88E+15	6.72E+04	*c*
12	Electricity	J	7.52E+15	4.02E+15	9.14E+14	1.23E+15	1.36E+15	2.30E+05	*p*

Table 2: Imported goods and materials (expressed in energy or mass units) [*See Appendix for references of transformities].

	Unit	Province of Ancona	Ancona-Osimo-Falconara (AOF)	Bassa Valle del Misa	Media Valle dell'Esino	Comunità Montana Alta Valle dell'Esino	Transformities (sej unit^{-1})	Ref.*
IMPORTED GOODS (F2)								
13 Crops	J	1.41E+16	4.56E+15	3.20E+15	3.07E+15	3.25E+15	2.67E+05	*d*
14 Legumes	J	5.56E+14	1.80E+14	1.26E+14	1.21E+14	1.28E+14	1.39E+05	*e*
15 Fruits	J	4.52E+12	1.47E+12	1.03E+12	9.86E+11	1.04E+12	4.82E+05	*d*
16 Filamentose vegetables	J	1.33E+11	4.31E+10	3.02E+10	2.90E+10	3.07E+10	3.19E+06	*f*
17 Seeds	J	1.60E+15	5.18E+14	3.63E+14	3.48E+14	3.69E+14	1.33E+06	*d*
18 Spices	J	3.05E+13	9.87E+12	6.92E+12	6.64E+12	7.04E+12	3.36E+05	*f*
19 Plants and flowers	g	2.17E+09	7.03E+08	4.93E+08	4.73E+08	5.01E+08	4.74E+09	*g*
20 Products of breeding	J	9.15E+13	2.97E+13	2.08E+13	2.00E+13	2.11E+13	5.33E+06	*h*
21 Products of forestry	g	3.44E+09	1.12E+09	7.82E+08	7.51E+08	7.95E+08	1.68E+08	*f*
22 Prod. of fishing and hunting	J	2.76E+13	2.44E+13	2.85E+12	8.29E+10	2.76E+11	2.27E+08	*i*
23 Metallic minerals	g	2.92E+09	1.49E+09	7.91E+08	1.34E+08	5.00E+08	1.68E+09	*h*
24 Non metallic minerals	g	3.37E+12	8.77E+11	1.32E+10	7.87E+09	9.83E+09	2.76E+09	*j*
25 Food industry	J	3.68E+14	1.43E+14	4.50E+13	1.48E+14	3.27E+13	5.33E+06	*h*
26 Tobacco Industry	J	3.07E+09	9.96E+08	6.98E+08	6.70E+08	7.10E+08	1.76E+05	*h*
27 Leather industry	J	2.03E+12	5.70E+11	5.32E+11	1.62E+11	7.65E+11	1.44E+07	*k*
28 Textile industry	J	1.00E+14	3.12E+13	2.88E+13	2.55E+13	1.48E+13	6.38E+06	*f*
29 Furniture and fixtures industry	J	8.67E+13	4.01E+13	2.45E+13	1.36E+13	8.46E+12	6.38E+06	*f*
30 Wood industry	g	1.42E+11	9.18E+10	2.47E+10	1.37E+10	1.20E+10	3.90E+09	*l*
31 Paper industry	J	7.83E+15	1.18E+15	1.76E+15	4.09E+14	4.48E+15	3.61E+05	*f*
32 Graphic industry	J	1.25E+12	8.74E+11	9.54E+10	1.38E+11	1.43E+11	3.61E+05	*f*
33 Metallurgical industry	g	2.85E+11	1.46E+11	7.72E+10	1.31E+10	4.88E+10	1.13E+10	*f*
34 Mechanic industry	g	1.20E+11	4.91E+10	1.05E+10	2.68E+10	3.40E+10	2.10E+10	*m*
35 Industry of minerals	g	8.72E+10	2.27E+10	2.76E+10	1.64E+10	2.05E+10	3.09E+09	*n*
36 Chemical industry	g	4.46E+11	3.55E+11	2.95E+10	2.53E+10	2.01E+10	6.38E+08	*o*
37 Industry of rubber	g	1.15E+10	6.24E+09	1.45E+09	2.44E+09	1.39E+09	7.22E+09	*f*
38 Other industries	g	1.42E+10	9.40E+09	1.93E+09	2.31E+09	5.99E+08	5.81E+09	*h*

Table 3: Summary of general data. Emergy flows and emergy indices.

	Unit	Expression	Province of Ancona	Ancona-Osimo-Falconara (AOF)	Bassa Valle del Misa	Media Valle dell'Esino	Comunità Montana Alta Valle dell'Esino
GENERAL DATA							
Area	km^2		1,940.00	552.05	330.39	317.2	740.52
Population	inhabitants		444.056	244.692	69.511	69.917	59.936
Population Density	inhab. km^{-2}		229	443	210	220	81
EMERGY FLOWS (expressed in 10^{20}sej yr^{-1})							
Local renewable emergy	sej yr^{-1}	R	3.49	0.96	0.59	0.56	1.47
Local non renew. emergy	sej yr^{-1}	N	45.61	2.01	11.59	10.67	21.36
Emergy of imported energy	sej yr^{-1}	F1	31.61	17.13	7.02	7.77	7.36
Emergy of imported goods	sej yr^{-1}	F2	269.03	128.72	46.93	34.99	49.42
Total Emergy	sej yr^{-1}	EM	349.75	148.83	66.13	54.00	79.60
EMERGY INDICES							
Empower Density	10^{13}sej m^{-2} yr^{-1}	EM / area	1.80	2.70	2.00	1.70	1.07
Emergy per Person	10^{16} sej inhab^{-1} yr^{-1}	EM/inhabitants	7.88	6.08	9.51	7.72	1.33
Emergy Investment Ratio		F / (N + R)	6.12	49.09	4.43	3.81	2.49
Environmental Loading Ratio		(N + F) / R	99.21	154.55	110.42	95.09	53.29
Emergy Yield Ratio		EM / F	1.16	1.02	1.23	1.26	1.40

The emergy yield ratio (EYR) is 1.16. It highlights that the system depends from external non renewable resources. The more the EYR value is close to 1, the more the system is based on resources from outside the system and the contribution of the environment is negligible. The EIR value of 6.12, due to the high contribution of imported goods and services (F), confirms a high dependence on external flows of resources.

The ELR shows a high use of non renewable resources (F+N) with respect to renewables (R). The ELR value (99.20) is consistent with the presence of important industrial activities and high population density. This indicator can be read as the contribution of the local system to global non-sustainability because of the high use of non renewable resources.

These results are supported by the analysis of the areal empower density, $1.80\text{x}10^{13}$ sej m^{-2} yr^{-1}, that could be considered as a measure of the anthropic pressure on the regional system. In this case, space can be a limiting factor for future development due to high concentration of resources in the area.

Emergy Evaluation has been also performed for the four districts, in order to provide specific information on different subsystems.

The AOF district uses 43% of the total emergy in connection with 55% of the total population and about 50% of employments in industries. Also the emergy indices have higher values in this district that plays a critical role within the region in terms of environmental resource use.

The other 57% of emergy flow is almost homogeneously distributed among the other three districts. In general, in the four districts the contribution of local renewable resources is low and the contribution of local non renewables increases from east to west, from the coast to the inland. The inland district *Comunità Montana Alta Valle dell'Esino* is the one with the lowest impacts.

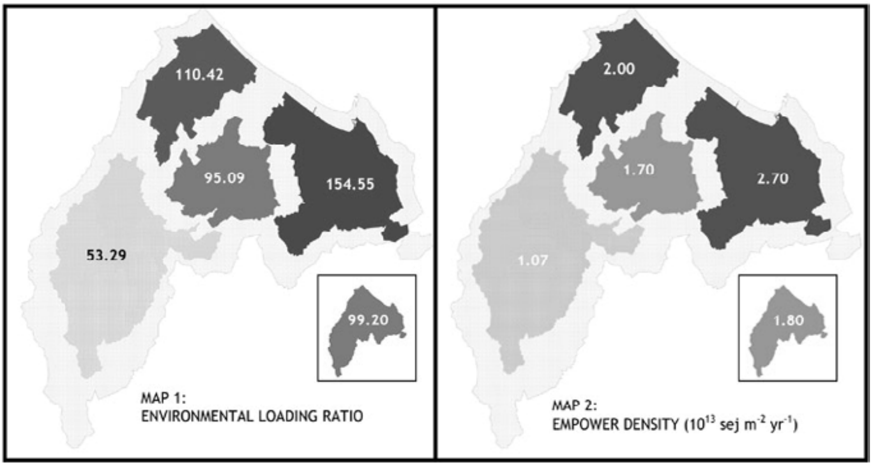

Figure 3: Maps of ELR (left) and ED (right) for the Province of Ancona and its four districts.

High values of ELR and ED indicate a high anthropic pressure due to a high demographic density and an intensive presence of industrial activities (Fig. 3). Resources imported from outside are more concentrated in the areas where the main industries and cities are located. Cities are dynamic systems able to produce welfare and services, labour and capital, interaction factors and communicability, opportunities to create and diffuse information, culture and news. This kind of production justifies the presence of intense flows of matter and energy in spite of high values of environmental loading ratio compared with the other parts of the region. In a sense, territories characterized by low environmental pressure should be preserved as a counterpart of high anthropized areas.

In the Province of Ancona, the region can be ideally classified into two macro-areas according to the quantities of energy and matter that supply activities and human settlements: the urban and the natural (rural) areas, which correspond to the coastal and the mountain system, respectively. Practices of territorial planning in this province should follow two different strategies to drive local development and environmental management, according to this classification.

The first strategy, to be applied in urban areas, is based on the idea of an urban development able to rationalize the use of energy and matter. Sustainability requires one to leave gradually and clearly the practices based on the aggrandizement of cities. The empowerment density just says that space is limited and it is no more sufficient to sustain the pressure of cities. Considering the relationship existing between urban areas and natural areas, a sustainable planning of urban areas has to figure out new organizational configurations coherent with their local contest and able to decrease, for example, energy consumptions in buildings.

The second strategy, to be applied in natural areas, is based on the idea of a rural development, strikingly at variance with those activities that intensively use resources. This should imply the rational exploitation of renewable resources and direct choices towards activities not based on economic growth or urban sprawl. Activities based on local products from both agriculture and craft, on traditional gastronomy and on the preservation of typical goods are consistent with this idea of local development. Sustainable tourism and agriculture have to be promoted as well as diffuse services in order to facilitate life in villages and to stop the exodus of people towards the cities along the coast. An energy program has to act for reducing consumptions in the small centres and, where it is possible, developing an energy production by small hydroelectric, aeolian or photovoltaic plants, obviously taking into account their impacts on the environment.

From a sustainable viewpoint, territorial planning must relate as much as possible its strategic choices to the local vocations of various territorial areas. Choices and actions have to work according to a common idea of development. The role of the environmental platform, as resource reservoir or wastes and emission absorber, must be enhanced and promoted.

5 Conclusion

A sustainability analysis based on Emergy Evaluation has been performed for a territorial system, the Province of Ancona (Italy). The results describe a variegated system where a high population density and the manufacturing activities produce a relevant impact on the territory. This corresponds to a high emergy flow that supply the region ($3.50x10^{22}$ sej yr^{-1}), mainly composed by non-renewable imported resources (F=86% of total emergy). This is also highlighted by high values of indicators of environmental stress, such as the Environmental Loading Ratio and the Empower Density. Emergy Analysis also shows that the Province is largely dependent on imported and non renewable resources with a low exploitation of local renewables (as indicated also by the Emergy Investment Ratio).

The emergy evaluation of the province of Ancona provided powerful information for territorial planning. In particular, the analysis of subsystems indicated different strategies to direct future development which preserve the diversities and heterogeneities inside the region against the negative influence of economic growth and globalisation. The key points are: a) to emphasize natural capital; b) to control the availability and the renewability of resources and the state of the environment; c) to evaluate the degree of exploitation of natural resources; d) to systematically collect statistical data about land, activities and environment; e) to enhance the diversities of geomorphology, society, economy and to consider them as an opportunity for a future sustainable development.

Appendix: references for transformities

(a) Odum, H.T., Brown, M.T. and Williams, S.B. (2000). Handbook of emergy evaluation: a compendium of data for emergy computation issued in a series of folios. Folio #1 - Introduction and Global Budget. Center for Environmental Policy, University of Florida, Gainesville, FL.

(b) Tiezzi, E. (Ed.) (2001). Implementazione di un sistema di contabilità ambientale su scala provinciale e intercomunale. Experimental project sponsored by Italian Minister for the Environment. University of Siena and Province of Bologna, Bologna, Italy. Available at http://www.provincia.bologna.it/ambiente/pdf_pubblicazioni/contabilita_ambientale.pdf.

(c) Bastianoni, S., Campbell, D., Susani, L. and Tiezzi, E. (2005). The solar transformity of oil and petroleum natural gas. *Ecological Modelling, 186,* 212-220.

(d) Ulgiati, S., Odum, H.T., Bastianoni, S. (1993). Emergy analysis of Italian agricultural system: the role of energy quality and environmental inputs. (Eds.) Bonati L, Cosentino U, Lasagni M, Moro G, Pitea D and Schiraldi A. Proc. 2nd Int. workshop - Trends in ecological physical chemistry. Elsevier, Amsterdam, The Netherlands, 187-215.

(e) Bastianoni, S., Brown, M.T., Marchettini, N. and Ulgiati, S. (1994). Assessing energy quality, process efficiency and environmental loading in

biofuels production from biomass. (Eds.) Chartier Ph, Beenackers A A C, and Grassi G. Proc. 8th European Biomass Conference - Biomass for energy environment, agriculture and industry. Pergamon, Oxford, 2300-2312.

(f) Brown, M.T. and Arding, J.E. (1991). Transformity Working Paper. Center for Wetlands, University of Florida, Gainesville, FL.

(g) Tiezzi, E., (Ed.) (2000a). Analisi di sostenibilità ambientale del Comune di Pescia. Unpublished report, Siena, Italy.

(h) Ulgiati, S., Odum, H.T., Bastianoni, S. (1994). Emergy use, environmental loading and sustainability. An emergy analysis of Italy. *Ecological Modelling, 73*, 215-268.

(i) Tiezzi, E., (Ed.) (2000b). Studio per un progetto di valutazione di scenari per uno sviluppo sostenibile della Laguna di Venezia, Unpublished report, Siena, Italy.

(j) Odum, H. T. (1992). Emergy and public policy (part I–II).Gainesville, FL: Environmental Engineering Sciences, University of Florida.

(k) Odum, H.T. and Odum, E.C. (1987). Ecology and Economy. Emergy Analysis and Public Policy in Texas. Lyndon B Johnson School of Public Affairs, Policy Research Project Report n. 78. Austin, TX.

(l) Odum, H.T. and Arding, J.E. (1991). Emergy analysis of shrimp marine culture in Ecuador. Department of Environmental Engineering Sciences, University of Florida, Working paper prepared for Coastal Resources Center, University of Rhode Island, Narragansett, RI.

(m) Odum, H.T. and Odum, E.C. (1983). Energy Analysis Overview of Nations. WP-83-82, International Institute for Applied Systems Analysis, Laxenburg, Austria.

(n) Bjorklund, J., Geber, U. and Rydberg, T. (2000). Emergy analysis of municipal wastewater treatment and generation of electricity by digestion of sewage sludge; a Swedish case study. *Resources Conservation & Recycling 31 (4)*, 293-316.

(o) Odum, H. T. (1996). Environmental accounting: Emergy and environmental decision making. New York, US: Wiley.

(p) Bastianoni, S., Marchettini, N., Principi, I. and Tiezzi, E. (2001). Sviluppo di un modello di analisi emergetica per il sistema elettrico nazionale. Unpublished report, Siena, Italy.

References

[1] For an overview of sustainability indicators and their application at the territorial level, see the Journal of Environmental Management, Volume 86, Issue 2, January 2008, pp. 329-426, Special Issue on “SPIn-Eco: Sustainability of the Siena Province through Ecodynamic Indicators”.

[2] World Resource Institute, Wuppertal Institute, Netherlands Ministry of Housing, Spatial Planning and Environment, National Institute for Environmental Studies “Resources Flows: the material basis of industrial economies”, 1997, Washinghton D.C., USA.

[3] Hille, J. (1998). The concept of environmental space. Implication for policies, environmental reporting and assessment, EEA.
[4] Wall, G. (1990). Exergy conversion in the Japanese society. *Energy, 15,* 435-444.
[5] Sciubba, E. (1995). Modelling the energetic and exergetic self-sustainability of societies with different structure. *J. Eng. Res. Techn., 117(6),* 75-86.
[6] Wackernagel, M., Rees, W. (1996). The Ecological Footprint: reducing human impact on the Earth, New Society, Gabriola Island, BC, Canada.
[7] Wackernagel, M., Onisto, L., Bello, P., Callejas, L. A., López, F. I., García, J., Guerriero, A., Guerrero, S. National natural capital accounting with the ecological footprint concept. *Ecol. Econ. (29)3,* 375-390.
[8] Odum, H.T. (1988). *Science, 242,* 1132-1139.
[9] Odum, H.T. (1996). Environmental Accounting: Emergy and Environmental Decision Making", John Wiley and Sons, New York (USA).
[10] Some historical backgrounds of the concept of emergy can be found in Brown, M., Ulgiati, S. (2004). Energy quality, emergy, and transformity: H.T. Odum's contributions to quantifying and understanding systems. *Ecological Modelling, 178 (1-2),* 201-213.
[11] Ulgiati, S., Brown, M.T., Bastianoni, S., Marchettini, N. (1995). Emergy based indices and ratios to evaluate the sustainable use of resources. *Ecological Engineering, 5(4),* 519-531.
[12] Campbell, D.E. (1998) Emergy analysis of human carrying capacity and regional sustainability: an example using the state of Maine. *Environmental Monitoring and Assessment, 51(1-2),* 532-569.
[13] Pulselli, R.M., Rustici, M., Marchettini, N. (2007). An integrated framework for regional studies: emergy based spatial analysis of the Province of Cagliari. *Environmental Monitoring and Assessment, 133 (1-3),* 1-13.
[14] Higgins, J.B. (2003). Emergy analysis of the Oak Openings region. *Ecological Engineering, 21(1),* 75-109.

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Vernacular architecture as a model for contemporary design

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Abstract

The quest for a deeper approach of contemporary architecture to nature sometimes conceals the achievements of the past. Vernacular architecture is, by its definition, aim and structure, the most integrated architectural form in communion with the environment. Two important traces of vernacular architecture can be resources for contemporary architecture: the deep respect and perfect communion with the natural environment the perfect relation and understanding of users needs. The result of a complex balance between material, shape and natural context, vernacular architecture could become an extremely useful model of inspiration for the present. From the intimate and personal experience with the wooden and wattle and daub architecture of South Eastern Europe, we noticed that the mentioned triad created very efficient eco-design outcomes that could be used today as models to generate an architecture closer to nature. This paper will describe a series of case studies of vernacular architecture from different zones of the Carpathians and the Danube area, which could function as models for an eco-architecture model. Modern perspectives on the mentioned values include a new approach of specialists and communities, having as a purpose the understanding and integration of vernacular experiences and values in today's projects in order to enable architects to be an active part in plural-disciplinary teams, to promote their responsibility to conserve and valorize built and landscape heritage and the re-use and integration of existing buildings, technologies and skills in contemporary design.
Keywords: clay, adobe, wattle and daub, vernacular architecture, eco-architecture, education, cultural models.

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1 Age old materials – new uses and technologies

Traditional building materials, such as timber, stone and clay, are undergoing a revival in that they offer sustainability where the more labour intensive and costly materials, such as (reinforced) concrete, fibreglass, glass and steel, are unrealistic in terms of budget (Buchanan [5]; Keddie and Cleghorn [14]; Parry [24], Spence and Cook [26]). The large scale use of traditional building materials comes at a time when carbon footprinting, along with affordability, are becoming a necessary option, especially in those areas of the world where dwindling natural resources are becoming a cause of concern. Much of the technology and material properties used in traditional building construction have their origins with the first farmers, some 10,000 years ago, and little has changed in terms of technological input since this time. People still construct buildings using clay, timber and stone, however the way these [raw] materials are applied entails many years of research, experimentation and *alloying* with other materials. Indeed, clay products such as brick still use the same processes of extraction, production and use, albeit on a more industrial scale. At Stewartby in Bedfordshire, England up to 18 million bricks were manufactured each week during the 1970s and 1980s when brick production in Britain was at its peak (Nash [22]). At this time 24 Hoffmann Kilns were in operation. The use of clay as a building material is a world phenomenon and like food production, is arguably an essential and sometimes a finite resource (e.g. Bonner [3]; *c.f.* Zhang Kunyuan [28]). In this paper we wish to briefly highlight a number of ancient and historical examples that clearly show the durability and tactile nature of our most basic of raw material – clay. Using the archaeological and historical records, along with an experimentation project at Vadastra in southern Romania, we will advocate the remarkable qualities of the traditional uses of clay and suggest that in an economic climate of sustainability this material, along with timber and stone, may provide some of the answers to the pressure of providing affordable and eco-centric housing and a return to Romania's local/regional rural vernacular.

Clay is a natural material that is malleable, composed primarily of fine grained [platelet] minerals and can be worked in many ways, achieving many architectural and structural outcomes (e.g. ceramic brick and tiles, fig. 1). In the world of construction the technological processes to produce a clay product are relatively simple – the base clay, fire and water in varying quantities and temperature being the ingredients to achieve a desired result. Clay as a building material not only provides an aesthetic value to, say, a building vista but it can also provide the structural value a building needs in order to stand. Aesthetically, clay can be moulded and shaped to produce ornate tiling, facades and if refined and produced to a particular standard, terracotta ceramics can be made.

Clay is an argillaceous detrital sedimentary rock/soil that is gauged on its particle size – less than 1/256mm. Based on the moisture content – its plasticity, clay in its natural form can be colloidal and based on the geographic location and can contain all manner of sedimentary and igneous material. In terms of its

Figure 1: Bricks, bricks and more bricks: a southern Romanian brickworks in the Olt County, Vadastra commune.

atomic structure, clay is basically from a layer-lattice group of minerals, occurring as platy crystalline particulates. The geomorphological characteristics of clay, its accessibility and geographic range have, over the ancient past greatly influenced the design and structural capabilities of buildings. The plastic qualities of clay has allowed architects and builders over the millennia to include this remarkable substance in nearly all aspects of construction; used in the manufacture of bricks, floor, roofing, wall tiles and surface renders.

One of the most common products of clay is brick. Brick comes in many shapes and sizes and there have been many attempts to create a uniform sized brick (depending on what part of the world the brick is made). Due to the various design concepts through the ages brick still remains a most durable, tactile and diverse product. In Britain during the 19th and 20th centuries over 5,000 brick manufactures was each producing distinctive localized and regional brick types, usually based on clay geology and firing temperatures.

The earliest brick use occurs in domestic buildings from around 8,500 BC in the Upper Tigris at the settlement of Çayönü and in south-east Anatolia at Çatalhöyük (Hodder [12]). The first bricks to be fired using kiln technology date from the third millennium BC. Prior to this important innovation, bricks were sun-dried and made from mud (with varying constituents of clay, sand and silt). As opposed to other building materials, ancient builders realised the thermal qualities of brick; in that they absorbed and stored the heat of the sun in the day and released latent heat in darkness hours. It is probably from these most ancient of times that brick making becomes a craft specialization, employing generations of specialist [technologists] as well as unskilled labour. Knowledge of clay consistency/plasticity, extraction, clay preparation, firing and post-firing techniques would have been essential constituents for the success of the community (e.g. Brunskill [4]). Based on these base constituents we now turn to the buildings themselves, focusing on the rural vernacular of Romania.

2 Local materials and local traditions

Result of a complex balance between material, shape and natural context, vernacular architecture is the most integrated architectural form in communion with the environment. As vernacular buildings are always realized with a direct participation of the first owner, they constitute the expression of practical and spiritual needs of each community, sharing same values systems. Synthesis of centuries of life experiences and building traditions, vernacular architecture is a synthetic and symbiotic harmony of individuals, community and the built environment, fig. 2.

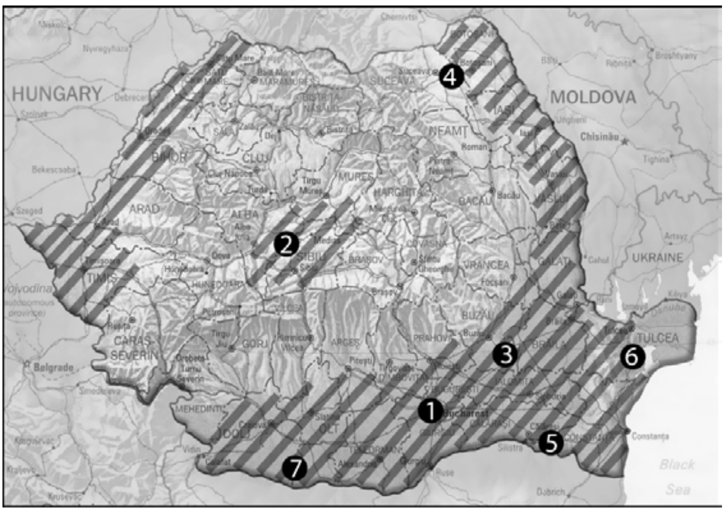

Figure 2: Map of Romania showing the areas with clay architecture and the sites cited in the text. 1 Bucharest, 2 Dumitra, 3 Rusetu, 4 Dumbraveni, 5 Ostrov, 6 Jurilovca, 7 Vadastra.

One of the most relevant values of the Romanian architectural heritage is, certainly, rural vernacular architecture. Characterized by an impressive unity in diversity, expressing a deep participation of the owners in the processes of creation, according materials and techniques to the needs for use and to the landscape, the richness and variety of rural vernacular heritage was the resource for a network of 17 open-air museums in Romania, realized in the last 70 years. Started in 1936, “Dimitrie Gusti” National Village Museum in Bucharest, the most frequented museum in Bucharest, receiving about 200,000 visitors by year, offers to its visitors 48 houses and farms, 4 churches, 20 technical installations brought from all districts of the country. The oldest monument dates from the 17th century, and the newest from the beginning of the 20th century.

Wooden architecture, earthen buildings, even one stone house - elements of Romania’s very rich vernacular and ethnologic heritage - are exposed in Village Museum’s open-air collection of monuments and constitutes a great architectural

Figure 3: “Dimitrie Gusti” National Village Museum general view.

resource. This visual expression of the vernacular is partly supported by its invaluable document archive and educational support for architects and other specialists in the field. Main building materials and techniques can become study-cases concerning experiences in transmitting ethnological heritage values, especially at a localized and regional level.

Used in the last 4-5 millennia in lessoid areas, earth buildings were the main vernacular architecture solution, covering about 25% of Romania’s surface. Five monuments of the “Dimitrie Gusti” National Village Museum (“DG”NVM), from Transylvania, Vallachia, Moldavia and Dobroudja, can be analyzed as examples of earthen structures (www.patrimoniu-etnologic.ro [27]), [29].

The Transylvanian house of Dumitra, Alba County, dating from the beginning of the 19th century is built on oak forks (interconnecting [structural] timber blades) out of wattle coated with clay and represents a single-storey rural dwelling, fig. 4. This building has a high pitched roofing frame covered by a straw thatch tied together by osier twigs. The pitch is considered steep in order that rainwater will not penetrate the roof or internal spaces. Similarly, the lower pitch of the roof overhangs the elevations in order to keep the elevations dry. The elevation stands on a stone plinth, again preventing moisture from penetrating the timber uprights, fig. 5.

The grange of Ruşeţu-Buzău County originates from a village lying in the north-eastern part of the highest plain in Romania and was built at the latter end of the 19th century. The primary building materials used was wattle and daub panelling that was supported by robinia forks stuck into the ground. The timber work comprised simple or double skeleton of laths nailed to posts, which are called “supports”, or to short wooden “studs”; these too were buried into the ground. The wooden structure is covered by clay render (mixed with water). One or two layers of bonded stone, forming a plinth were placed at the foundation level, fig. 6.

The County of Suceava lies in the north-eastern part of Moldavia and from this region is the house of Dumbrăveni originates, fig. 7. This building was built in the 19th century using the technique of the oak forks which support secondary timber framework, fig. 8. The external panels were infilled with

Figure 4: Horizontal wattle and timber, Dumitra.

Figure 5: House from Dumitra, Alba County in “DG”NVM.

Figure 6: Grange from Ruşețu Buzău County in “DG”NVM.

Figure 7: House from Dumbraveni Suceava County in “DG”NVM.

Figure 8: Vertical wattle and timber, Dumbrăveni.

Figure 9: The building of the roof, Dumbrăveni.

Figure 10: House from Ostrov, Constanta County in “DG”NVM.

Figure 11: Wattle and daub structure, Ostrov.

Figure 12: The annexes of the house, Jurilovca in “DG”NVM.

Figure 13: Detail of the house, Jurilovca.

wattle and daub (comprising clay and straw). The four-sided roof is covered in “jupchi”, overlapped sheaves of rye, fig. 9.

The house of Ostrov – Constanța County is typical of the old Romanian villages that contained granges, especially those sited along the River Danube, fig. 10.

Built of hornbeam oak forks and initially infilled with wattle and daub panelling, fig. 11, the elevation was coated in a clay render. The house has a roof with four gently sloping sides covered in tiles.

The grange of Jurilovca (near Razelm Lake, Tulcea County) was built in 1898. The house, and the annexes – the cave, the shed, the stable, the fish smoking house, fig. 12 – are all built of adobe, with pediments at both ends and reed covering, fig. 13.

As “Dimitrie Gusti” National Village Museum is an open-air collection of vernacular monuments, restoration activities constitute an essential field in transmitting traditional values. Conservation and restoration phases are realized by craftsmen invited from the same geographical area where the building originates, using natural materials and respecting traditional local and regional construction techniques. All activities on monuments are supervised by curators, conservators and architects. In addition, artisans and craft specialists are working, demonstrating and teaching, simultaneously to visitors and to students, architects, other specialists, the importance of regionality of Romania's building vernacular.

Special attention is given to educational partnerships with schools of architecture, which have every year use the museum resources for practical courses, interior design and the document archives. Starting with the first steps in architecture, student's activities, in particular vernacular values have a special place and are extended for those who are interested in elective courses or other activities; as witnessed with projects run by multi-disciplinary teams in several areas of the country; one of these areas of intensive and systematic research is Vadastra in the Olt region.

3 Age old methods, local contexts

The technique of using clay in the construction of dwellings (as rammed earth, adobe, and adobe brick) in villages of southern Romania began to be replaced with methods of construction of urbanism, commencing before World War II (Minoiu *et al.*: 161 ff. [20]). Using traditional materials such as clay and wood was thus restricted to household annexes, which were constructed in the wattle and daub technique, usually supported by timber-framing (Minoiu *et al.*: 108 ff., [20]).

Professor Dragos Gheorghiu conducted a study of the revitalization of the technological tradition of vernacular wattle and daub architecture in the village of Vadastra, southern Romania between 2003 and 2007. The study was possible due to a research project on the *traditional ecological habitat* (Gheorghiu [7–9]), funded by two grants from the Romanian Ministry of Education and Research (CNCSIS Grants 1612 & 945).

Beside the experimental research of the traditional constructions the project allowed the study of the way a contemporary rural community could return to the traditional ecological building techniques, using local [quarried] clay and other local material resources.

Vadastra village with its 1,643 inhabitants is situated in Olt County, in the southern Romanian Plain, on the loess northern terrace of the River Danube (Logofatu: 8 [16]). The entire wooded area of the south of this region has been largely cleared, wood being a very scarce commodity today. Bricks were produced by each family at the outskirts of the village with clay extracted from the local river terrace, and burned in pyrotechnic truncated pyramid [kiln] structures (Carlton: 22 [6]).

Today the architectural materials of the village comprises mainly of bricks and concrete, and no longer uses clay except for those households with annexes; though, a generation ago, most houses were made of timber, wattle and daub (Ghinoiu [10]), and only the Mayor's building was built of brick. Compared to the vernacular architecture of a century ago, the contemporary architecture of the village is made with materials that do not preserve any traditional or ecologic character, being only determined by the owner's exhibition of prestige; the vernacular of this region is thus somewhat lost.

In this context, the re-introduction of ecologic traditional technology using clay for the dwellings was primarily a problem of explaining the advantages of an ecologic architecture to the village population. The action began, indirectly, with an ethno-archaeological and experimental archaeology study of the dwelling process in this area in the past, which is summarized below.

Besides the experts and students participating in the experiment of construction, a group of villagers were involved. We considered this local input essential in understanding the seasonal needs and aspirations of a community governed by the importation of building materials and a potential lost generation of people who had largely forgotten the available resources such as the terrace clays.

During the three annual campaigns, three houses each measuring c. 3 x 8m and a semi-subterranean house of 2 x 5m were constructed, all being specific for this region and ranging in technological achievement from prehistoric to modern times.

All these buildings had a resistant acacia wood structure and wattle panelled walls, using twigs of mulberry and poplar, which are the only types of trees that still grow in this area.

The experiments started with the test of the foundation ditches, a construction method for earthen architecture used from prehistory to the modern age in the region of Oltenia (Minoiu *et al.*: 163 [20]). The ecological benefit of this type of structure in that it involves only local soil and organic materials, and preserves well over a long period, especially in wattle and daub buildings.

Following the erection of the timber frame and the wattle panelling, then began the operation of fixing the clay on the wattle walls, fig. 14, 15, which required three days of work for a group of 3-5 persons. The finished surfaces of the inside and outside walls and ceiling were left to dry for two days before the thatching of the roof using reed commenced. Numerous repair interventions were needed for correcting the cracks due to the shrinking of the clay that had been fixed to the various sections of the wooden structure. The final phase of work included the fixing of a thin layer of render made of clay mixed with cow dung which covered the elevations (McDermott: 303-4 [18]).

The first building was preserved in order to analyze the rate of denudation from weathering processes and human action. Our first ecological question was to find that if the walls were well compacted when fixing the structure of wood and straw and to see if their resistance was similar to that of brick structures. The continental climate of Vadastra region, with average summer temperatures of 25 ^{o} C, which can rise sometimes to 39 ^{o} C in August, and relatively low rainfall, favours wattle and daub architecture. Our experiments at Vadastra proved that the buildings were very cool inside during the summer.

All local materials of construction were collected from an area of 1 km square around the site, and the construction operations did not require specialized tools other than those used for gardening. The other houses, which were left to the

Figure 14: Pit for the preparation of adobe, Vădastra, 2005.

Figure 15: Wattle and daub house, Vădastra, 2003.

weathering process, have shown they were completely biodegradable following the recycling of their massive wooden frames.

The project undertaken in Vadastra village was arguably a process of cultural education held on two levels: as an ecological education, students and as a folk culture, convincing villagers that their local resources may allow the development of an ecological technology of construction by applying the methods used by previous generations of villagers.

As confirmed by the archeological and ethnographic data, clay alone or in combination with other building materials or substances, has been for almost 5 millennia the fundamental building material for the Romanian Plain area and for most of Europe. But, how can we explain this long-term persistence of a technological tradition? Besides the fact that it was the most easily suppliable material in lessoid soils areas (mainly in the warm climate areas), it had the following advantages: easy extraction, easy preparation, easy possibility of creating composite and reinforced materials, thermal efficiency, recyclability, biodegradability, resistance and sustainability under the action of natural factors, permissivity in developing repair or expansion operations of certain existing constructive elements (Minke [19]).

Considering the challenges of contemporary society, successfully passing the test of time, the qualities of clay as a building material may be ironically found in buildings that house most of the low-income population. These approaches of low-cost, low-energy materials such as clay surely meets the constraints that are firmly set within the raw material crisis, the energetics crisis and the fight against global warming and other ecological-related issues.

4 Earth architecture as ecological architecture

The extensive use of earth in various parts of the world (see Maniatidis and Walker [17]; Morton [21]), as well as in Romania, to create a sustainable architecture, is due to some qualities, which qualify it as the contextual building material.

We will present below a few of these qualities that demonstrate also its ecological character.

The first is the *total* recycling of the material, because the “waste by-products and defective products can be returned to the start of the production cycle and re-used” (Little and Morton [15]). When compared with the other building materials employed in contemporary architecture, earth produces the less pollution, when extracting, preparing and recycling.

Consequently, the second quality is that of a low carbon emission, earth dried bricks necessitating only 440 KWh/m^3, compared with ceramic bricks, which consume 1300 KWh/m^3 (Little and Morton [15]).

The third quality is the solar gain, obtained by orientation and thermal mass. These two ecological commandments were amply used in the Romanian vernacular earth architecture. Since the large majority of the houses were built with the main façade facing south, the new buildings replacing the old will not disturb the spatial orientation within the households. The intervention of contemporary architects could be to build a series of annex rooms on the northern facades to lower the thermal loss. A revival of the spirit of vernacular architecture would be the continuation of the tradition of the porch (Ro: *prispa, pridvor*) south oriented, whose roof protects the façade wall from the summer sun, but allowing the solar exposure in wintertime. By transforming this space into a sun lounge during the cold season one can maximize the glazing on the south façade. Such architectural solution was in fashion until the early 19th century in urban buildings inspired from folk architecture (Joja [13]), but was forgotten later.

The exploitation of the thermal mass in earth architecture is achievable by emphasizing the thickness of the walls, and by designing the shape of the roof covering the porch, in such way as to allow large areas of the south façade to be exposed to winter sunlight.

A fourth quality is the possibility to improve its properties by adding various binders.

To improve the technologies of building with earth (*i.e.* mud wall, rammed earth (Fr. *pisé*), earth bricks, compressed earth blocks, earth infill in timber frame construction, earth plasters, see Little and Morton [15]), one can utilize diverse organic or mineral additives (Minke: 41[19]; North [23]) to stabilise earth (see also Adam [1]; Sharif-Zami and Lee [25]).

All the additives or stabilisers, can increase the material durability and strength as well as the embodied energy (Little and Morton, [15]). However, some stabilisers like cement decrease the qualities of the prepared material, to cite the ability of acting as a humidity buffer of the stabilized earth (see North [23]).

This is the reason why we recommend using as additives the recycled sub-products of the local households or the sub-products of the local industries, all these possessing ecological qualities.

Tests demonstrate that the mix of cut straw fibres diminishes the compressive strength (see Minke: 47, Table 4.20 [19]), therefore rammed earth seems the best material to be used for earth buildings with more than one floor.

The fifth quality is the thermal performance of the earth; for example, a rammed earth wall without stabilizers equals the thermal performance of a solid ceramic brick wall (Minke: 31 [19]).

The sixth quality of earth compared with other building materials is the good absorption of humidity. When comparing the degree of humidity absorption of earth walls (300g/m^2 for a 1.5 cm mud layer; Minke: 16 [19]) with ceramic bricks (6 to 30 g/m^2) or plaster (26 to 76 g/m^2) one can observe the quality of the material to balance the humidity in a built space.

5 Concluding remarks: cultural modelling

What could be the conclusions of a project that considers returning to the use of earth in the Romanian village architecture?

As suggested above, there has been a millenary tradition in using this material that has survived through the modern age and is still working in certain peripheral areas of the country; our rural vernacular.

Our approach aims at promoting an **educational model** as well as a **cultural model,** fig. 16, 17.

We might demonstrate that in the case of a sustained social action, some mindsets may change and some village people might agree with an environmental-friendly design using earth in designing certain types of houses or figurative [principal] buildings, such as museums of the tradition or archaeo-parks. Romanian architects have already started to think about the concept of an ecological built heritage using earth and several of these include:

- project for the development of a traditional museum village in Radovanu commune, Ilfov County – author: Faculty of Architecture of Spiru Haret University

Figure 16: Students preparing the adobe, Vadastra 2003.

Figure 17: Villagers from Vadastra building an archaeo-park, Vadastra 2006.

- catalogue with projects of houses, and bed & breakfast facilities for the Danube Delta (protected area) – author: IGLOO ARCHITECTURE office.

In order to respond to expanding needs of specialists in conservation, as well as in multi-disciplinary planning practices, able to transmit the cultural values of good architecture, architectural education has to include modules that aim to teach and develop student's understanding of the value and complex potential of the inherited built environment.

Spiru Haret University, School of Architecture is the first private school of architecture in Romania, accredited by the Romanian Ministry of Education and Research. Its curricula include theoretic and practical courses for vernacular architecture, architecture and sustainable development, monument–restoration and the built heritage. Many of these courses, as well as drawing and perspective practical courses, interior design documentation, are using as documentary support the resources of the *Dimitrie Gusti* National Village Museum heritage. Students have to analyze the values and potential of the built heritage, in order to reflect on critical criteria and creative practices related to regeneration as essential component of sustainability. This internationally important museum site is really a starting point for any would-be architect from this part of Europe.

Romanian rural vernacular architecture is still, in the 21st century, a live element, which expresses, in a really complex way, the creativity and specificity of traditional building systems. The vernacular buildings that are in good state of preservation, dispersed all over the country, constitute the support of a really dynamic development of rural tourism, agri-tourism, eco-tourism, as sustainable tourism components. These forms of tourism can become alternatives for rural vernacular architecture preservation. In addition and in many ways extending beyond the constraints of tourism *per se*, the rural/traditional vernacular promotes an identity with the people who work and live within these sometimes ethnically diverse communities. Taking these points into consideration, we now briefly conclude with our vision for the future. At an educational level we have started the instruction of the student architects and designers in the spirit of understanding the ecological features that include a local tradition of vernacular architecture and of reintroducing the traditional materials in the architecture plan. Thus, the workshop themes for the 1st to the 4th years at the Faculty of Architecture, Spiru Haret University include elements of ecology, inspired by local/regional vernacular architecture.

The education of the young architects may enable the revitalization of the ecological spirit of local vernacular architecture and of the 3rd millennium AD architecture. Based on the ancient archaeological record, the historic record and the experimentation programme at Vadastra we are sure lessons can be learned.

References

[1] Adam, E.A., 2001, *Compressed Stabilised Earth Block Manufacture in Sudan*, unesdoc.unesco.org/images/0012/001282/128236e.pdf

[2] Becky L., and Morton, T., 2001, *Building with earth in Scotland: Innovative design and sustainability*, www.scotland.gov.uk/Resource/Doc/156686/0042109.pdf
[3] Bonner, R. 1984. *Better Burnt Bricks*, Action-Aid Kenia, Nairobi.
[4] Brunskill, R.W. 1990. *Brick Building in Britain.* Victoria Gollancz & Peter Crawley.
[5] Buchanan, W. 1985. *Labour Intensive and Small Scale Brickmaking*, UNIDO, Vienna.
[6] Carlton, R., 2002, Experimental open firing of locally sourced clays at Vadastra, South-East Romania, Gheorghiu, D. and Andrews, K (eds.), *Experimental Pyrotechnology Group Newsletter*, pp. 22-24.
[7] Gheorghiu, D., 2005, *The Archaeology of Dwelling. Theory and experiment*, Editura Universitatii Bucuresti, Bucharest.
[8] Gheorghiu, D., 2007, Material, spatiu, symbol. Note despre tehnologia de constructie si deconstructie a locuintelor Calcolitice din sud-estul Europei, *Anuarul Muzeului Etnografic al Transilvaniei*, pp.364-377.
[9] Gheorghiu, D., 2009, The Lower Danube Chalcolithic megaron house with internal column: The technology of building interpreted through experiments, pp. 1 –10. In Ayan, X., Manana, P. si Blanco, R. (eds.), *Archeotecture: Second floor. Papers from the archaeology of architecture at the EAA Meetings in St. Petersburg (2003) and Lyon (2004),* British Archaeological Reports, International Series 1971, Archaeopress, Oxford.
[10] Ghinoiu, I. (ed.), 2003, *Atlasul etnografic roman, Habitatul*, vol. 1, Editura Academiei Romane, Bucharest.
[11] Hodder, I. 1990. *The Domestication of Europe*. Blackwell Press, London.
[12] Hodder, I., 1998. Çatalhöyük, *Anatolian Archaeology*, 4, 8-10
[13] Joja C., *Sensuri şi valori regăsite*, Eminescu, Bucharest, 1981.
[14] Keddie, J. & Cleghorn, W. 1980. *Brlck Manufacture in Developing Countries*, Scottish Academic Press Ltd., Edinburgh
[15] Little, B., and Morton, T., 2001, *online*, *Building with earth in Scotland: Innovative design and sustainability*, www.scotland.gov.uk/Resource/Doc/156686/0042109.pdf
[16] Logofatu, C., 2007, *Monografia comunei Vadastra-Olt*, Arves.
[17] Maniatidis, V., and Walker, P., 2003, *A Review of Rammed Earth Construction for DTi Partners in Innovation Project 'Developing Rammed Earth for UK Housing'*, http://people.bath.ac.uk/abspw/rammedearth/review.pdf
[18] McDermott, D., 2007, Mud-plaster, pp.303-304. In Oliver, P. (ed.), *Vernacular architecture of the world*, Cambridge University Press, Cambridge.
[19] Minke, G., 2006, *Building with earth. Design and technology for a sustainable architecture*, Birkhäuser, Basel, Berlin, Boston.
[20] Minoiu, M.R., Ciobanel, A.I., and Budis, M., 2005, Locuinta, In Ghinoiu, I. (ed.), *Habitatul*, Vol. 1, Oltenia, Editura Etnologica, Bucharest.
[21] Morton, T., 2006, Feat of Clay. *Materials World*, pp 2-3.

[22] Nash, G.H. 2009. *Stewartby Brickworks, Bedfordshire Monitoring Programme for two Hoffman Kiln Buildings (CK1& CK3).* Report presented to English Heritage and Hanson Building Products UK. Report No. 402.0027.00177.
[23] North, G., [nd.], *Mud Brick and Cob - Natural Earth Building and Stabilisers,* www.ecodesign.co.nz/mudBrickCob&Stabilisers.shtml
[24] Parry, J. 1979. *Brickmaking in Developing Countries*, Review prepared for the Overseas Division, Building Research Establishment, Garston.
[25] Sharif-Zami, M., and Lee, A., [nd], *Contemporary earth construction in urban housing – stabilised or unstabilised*?, www.gla.ac.uk/media/media_129735_en.pdf
[26] Spence, R.J.S. & Cook, D.J. 1983. *Building Materials in Developing Countries*, John Wiley & Sons, Chichester.
[27] www.patrimoniu-etnologic.ro
[28] Zhang Kunyuan (ed.) 1988. *Technology Manual on Claybricks in China*, UNDP/ UNIDO Regional Network in Asia-Pacific for Low-Cost Building Materials Technologies and Construction Systems, Manila.
[29] xxx. *Locuința sătească din România.*1989, Studiu ICCPDC Bucharest.

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Digital-Green architecture: a new design process that integrates digital technology and sustainable concepts

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Abstract

The trend of digital freeform and the awareness of environmental issues have propelled architecture to a higher level by comprehensively merging new technologies and green concepts. These observations suggest that we need a new structure for understanding the design process that integrates digital technology and the sustainable concept. Instead of dealing with micro issues, the question is whether it should be more concerned with the comprehensive fusion of a new design processes and the overall interactions of digital technology and sustainability thinking. This could elevate the design process from a disconnected level to a more general and comprehensive level.
Keywords: Digital-Green, design process, digital technology, sustainable concept.

1 Introduction

With the advanced technological capacity of computing, calculation and simulation, the rationale of contemporary architecture should not be directed only towards the aesthetic and functional aspects, but more efforts should be invested in carrying out the concepts of habitability, self-sufficiency, and sustainability [1, 2]. With the improvement of technologies, architects and researchers such as Frank Gehry, Mark Burry, Larry Sass, Branko Kolarevic et al. recognized the progressive needs for new digital design process when using digital CAD/CAM technologies, Rapid Prototyping (RP) and Computer Numeric Control (CNC) as new design media [3–8]. By operating and applying new digital media in the design process in a more efficient way, one also needed to develop a new design and construction method to satiate the new needs.

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Therefore, the traditional design process - schematic design stage, design development stage, detail design stage and construction stage, evolved with the new structure of digital design process. The new four stages are broadly applied in the digital design process-computational concept design, analysis, manufacture and assembly method [9].

The development of the green concept has advanced from linear focus on energy saving to "non-linearity" [2, 10, 11]. Buildings need redesigning to be more self-sufficient and self-organized and to be generating renewable energy themselves. Technological development has raised the boundary and enriched the field with extraordinary knowledge and potential and this has made the impossible building become possible [12]. Traditional sustainable design process of site analysis/planning, building forming, envelope developing and Finishes/technical supports, also needs to advance in association with digital technology [13–16].

Over the past few decades, the approach of sustainability has shifted to include the integration of digital technologies and self-sufficient green thinking. While architecture has taken a leap into the digital age, research and the way architects approach sustainability, has also been transformed by the new technologies. In the 90s, Yeang [17] (1999) described an ecological building as 'a kind of living organism' responding to its surrounding environment. Some digital sustainable forerunners, such as Norman Foster with his Reichstag Dome, etc., were clearly aware of the significance of sustainability. Kolarevic [2] (2004) also suggested that curvilinear forms and the appreciation of sustainability are both important approaches. Peter Testa and Ove Arup's [18] Carbon Tower was presented as an energy saving example of digital technology. By transferring technology from the textile to the highly-compressed carbon fibre reinforcement of the external helix, the architects demonstrated that vertical columns between floors could be eliminated. Steven Holl's [19] (2005) Silver Water Drop revealed his ability to blend architecture and landscape while maintaining the digital freeform with recyclable and natural-finished stainless steel material that echo Yeang's [19] (1999) idea of convening a dialogue between a building and its environment. Also, the design of the rotating skyscraper, by David Fisher [20], introduced prefabricated floor components and a self-powered system using wind turbines. The architecture profoundly embodies the concept of digital motion in a building and advanced the application of technology and green thinking. Digital techniques, such as 3D computer modelling, CNC technology (Computer Numerical Control), and laser cutting, provide cost-effective production methods for architectural applications. These new methods allow the pre-assembly of building components saving waste and reducing building costs. Furthermore, the higher technologies allow architects and scientists to experiment with new materials during the design process that might better suit the sustainable needs. These observations suggest that we need a new structure for understanding the design process that integrates digital technology and sustainable concept in the Digital-Green era.

2 Problem and methodology

During the last ten years, architects started to design buildings with the integrated methods of new CAD/CAM technologies. The new analytical software with advanced computing, calculating and simulation capabilities is the backbone of the digital age. Some of them were also paying attention to the gradual progression of sufficiency and sustainability. It is time to examine if the merging of the new technologies and the green concept would redefine digital architecture in a comprehensive perspective. Nowadays, people have become more perceptive and aware of environmental issues and new design thinking needs to accommodate the need for both digital and energy savings. These trends lead researchers to face the new challenges of how digital architecture will deal with the issue of sustainable innovation. However, while digital technology increasingly incorporates green concepts in the design process, one aspect of much current digital sustainable architecture is still viewed as narrowed down to a one-sided technical green concept; a machinery add-on to a building or a hi-tech surface decoration [2, 21]. Digital sustainable architecture does not imply the combination of new technologies to sustain the building or the adoption of another technique to design projects, but the process and interaction between digital technology and the sustainable concept. The digital free-forms integrated with these technologies are often innovative and some appear as the direct answers and new approaches to digital sustainable design.

Given the project examples above, there are still certain levels of disconnected themes of the discussion pertaining to design process. Through the discussion of "digital and sustainable architecture," architectures have to re-evaluate the new structure of design process for broader sustainable needs. This could elevate the design process from a micro to macro level. The question is whether architects should be more concerned with the comprehensive fusion of a new design processes and the overall interactions of digital technology and sustainability thinking? What one needs to know is, should they be mere green building standards or expressions of freeform or true digital sustainable designs as perceptions of the merging of digital technologies with the new sustainable movement? The purpose of this paper is to shift perspective from the design of a digital sustainable object to the understanding on an extensive design process that integrates the digital technologies and green aspects. What is more important is to emphasize a broader range of issues in design process that intimately bonds digital architectural manipulation and sustainable expressions.

The main purpose of this research is to determine whether digital freeform, integrated with new technologies and new ecological needs, may contribute to the sustainable needs of New Digital-Green design process. By using case studies, the three steps to approach this research are: (1) to conduct a wide investigation of case studies to make a comprehensive evaluation of the new factors for the analysis of new design process; (2) to understand the logics and characteristics of a new digital-green design factor; (3) to analyze the basic design process in terms of from general, sustainable, digital and the preliminarily digital-sustainable architecture to obtain a new model of Digital-Green design process.

3 Examination of cases

The logic of choosing these ten cases is to explain the following principles. First, projects are selected from various countries based on an impartial perspective. The distributions of the locations range from Asia, Middle East, America, to Europe. Second, the structures embrace different architectural scales such as private residence and large-sized public stadium. Lastly, the chosen architects are sophisticated in experimenting with designing digital architecture with elements of sustainable issues. By analyzing the design processes that involve digital manipulation and sustainable design thinking, the examination of the ten cases aims to explore various characteristics of the architectures. From the ten projects, the relationship between digital technologies and sustainable characteristics plus the logic of design processes are explained with broader applications.

4 Factors for analysis design process

Based on the case study, the preliminary structure from digital or sustainable architecture might be insufficient for the needs of digital-green design process. It is necessary to apply new factors in generalizing the new design process to integrate both digital technology and sustainable concept. In creating the original design process, the knowledge of the five classic factors, detail/joint, material, object, structure, and construction, were categorized [22–29]. After rethinking the five classic factors, a set of seven factors: the joint, detail, material, object, structure, construction and interaction were proposed [30]. This redefined the classic elements with the backdrop of digital thinking. Through the digital design process with new methods of assembly, five digital factors were proposed including concept, manipulation, construction, form, and space [29]. In addition, four new digital factors are also sorted out which are motion, information, generation and fabrication [31].

Moreover, with the improvement of technology and the developing of green thinking, the use of computers and CAD/CAM technology in the design process transformed the expression of digital architecture into the combination of digital and sustainable operation. With the understanding of both set of basic factors, the commonality of those factors is analyzed through comparisons, which support the formation of a new design process skeleton. Considering the operation of sustainable factors, the study would address only the key areas based on structure, building form (envelope), electrical power, technical principles (ventilation, heating, cooling, lighting, etc.), environment (water, waste, energy, noise), site (microclimate, green space) and materials [13–15]. However, this analysis is not specifically concerned with the pure sustainable mechanical issue, but rather addresses the new design process that integrates digital technology and sustainable concept. By using the digital design manipulation technique merging with green thinking, the new method of design process is different from the original expression of digital architectural manipulation. Therefore, the new five Digital-green factors proposed in this paper are construction (structure), materials, object, interaction and form [22–31].

This research attempts to broaden the digital-green phenomenon from digital expression, therefore the five new factors are applied to analyze the cases.

The following definitions are of the five new factors applied in the research:

- Construction:

With the aid of computer technology and 3D modelling techniques, the original expression and definitions of structural appear to have changed dramatically not only with high-level technologies but also with energy-efficiency [14, 23].

- Materials

Based on the new construction methods of 3D modelling, animation, simulation and deformation, the selection of material has influenced its ability to fabricate the flowing surface and the application of specialized structural effects. The use of materials is mostly concentrated on looking for smoother textures and such aspects as transparency or metallic forms in the digital environment. When advanced to the digital-green period, the material selections for digital use may also have the duality of sustainable consideration [22, 32].

- Object

By making the architectural whole from architectural parts, those that were originally defined as columns, walls, slab, doors and roof…etc. were redefined by mixing the functions for both free-form and sustainable needs. Therefore, the parts free-formed with the aid of CAM/CAM technology, are also re-defined or reformed in an attempt to match the new needs of sustainability [15, 23].

- Interaction

The relationships between construction site and architecture, green space and architecture, and also with people and form are emphasized here [29].

- Form

With the new design thinking and process, concern for sustainable needs and computer-aided technology, the form of architecture, or the use of building envelops may be redefined in the digital-green environment. Walls, roofs, floors and other construction components are all effective in the transformation to the new spatial form [22, 29]. Through the assistance of green thinking and the new techniques, the form of the digital flowing surface may co-exist with sustainable needs.

5 Evolution of design process

5.1 Design processes

The factors of design process are analyzed by case studies during step 1 and 2 (Table 1). The design processes in Figure 1 [33] and 2 [6] show the change of

Table 1: Index of ten case studies.

Case #	Project Name	Architect(s)	Location	Year
1	Phare Tower	Morphosis	Paris	2012
2	The Dynamic Tower	David Fisher	Moscow	2010
3	Bird’s Nest	Herzog & de Meuron	Beijing	2008
4	Zaragoza Bridge Pavilion	Zaha Hadid	Spain	2008
5	Silver Drop	Steven Holl	Connecticut	2007
6	BMW WELT Munich	COOP Himmelb(L)au	Germany	2007
7	Carbon Tower	Peter Testa and Ove Arup	Dubai	2005
8	Yokohama Port Terminal	Foreign Office Architects	Japan	2002
9	Swiss Re Headquarters	Foster and Partners	London	1999
10	Reichstag Dome	Foster and Partners	Berlin	1999

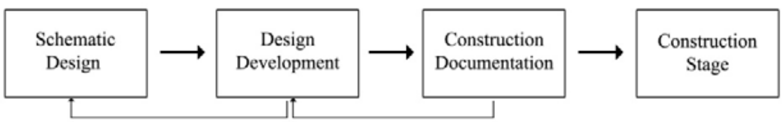


Figure 1: General design process [33].

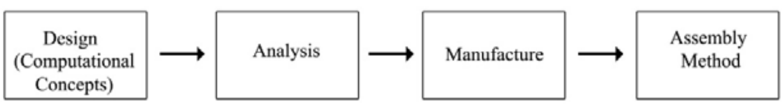


Figure 2: Digital design process [6].

design process from traditional to digital architecture field because of the different manipulations. It is also very important to explore the design process based on sustainable methods as shown in Figure 3 [34], which is almost parallel to either traditional or digital architecture in the past. Based on the analysis of the previous design processes and proportional information of the case-study factors, the design process of merging digital technology and green aspect is initiated. To maximize the capacity of a dynamic digital design process, the features of computational design media and digital graphics (topological surface, isomorphic field, etc.) allow architects to shape the form freely and create a more functional skin/envelope. Therefore, the emerging procedures of conceptual design, computational concept and envelope study provide new possibilities to the unexpected new forms and sustainable influence in the new Digital-Green design process in Figure 4. This new design process is anticipated to help designers to merge both digital and sustainable aspects in fashion during the design thinking and design process.

Site Analysis/ Site Planning → Building Form → Envelope → Finishes → Technical Principles

Figure 3: The sustainable design process [34].

a b

Figure 4: Case 4 (a) and Case 9 (b). Photo credit: Case 4 (a): Luke Hayes; Case 9 (b): Adrian Welch.

Figure 5: Case 4. Photo credit: Zaha Hadid Office.

5.2 Discussion of ten cases

5.2.1 Form

With the aim of technology and the development of green thinking, the form could be full of dynamic characteristics and at the same time work sustainably. In Case 1 and Case 4, the evolution of the freeform was determined by the consideration of responding in accordance to the path of the sun for the heat gain and glare. The curvilinear double skin on the south façade and the flat and clear-glazed north façade show its purposes of minimizing heat gain and maximizing interior exposures to natural daylight. Such as Case 2, each floor rotates independently with the power of wind turbines fitted between each floor, which not only provided effective power to the surrounding environment, but also allowed the free form to express itself with sustainable needs. Case 9 (Fig. 4) demonstrates how the spiralling form could be responsible for guiding the wind flow up the building for better ventilation. This helps to demonstrate how a digital architectural form full of expression is not limited in shape, but now has more capacity for the need to react with the environment.

5.2.2 Material

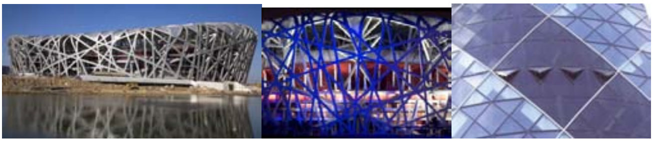
By using computer technology and simulation, designers could manipulate different kinds of materials to achieve the dynamic form one desires to approach but also have sustainable value for the environment. Case 4 shows the consideration of using new innovative sustainable triangular panels made of glass fibre concrete to envelop the outer skin of the building. Case 5 demonstrates how a digital freeform stainless steel building could also be sustainable with heat absorption reduction when the stainless steel improves to be recyclable and naturally-finished. By transferring weaving technology from the textile industry to architecture, the characteristics of the carbon fibre material were redefined to form the structural helix for the exterior surface of the Carbon Tower in Case 7. The use of mirrored cone shows how the project in Case 10 effectively decreased the carbon emissions of the building with the use of daylight on reflective material for heat gains. With the aid of computer simulation by CAD/CAM technology, this recycled/raw material made possible an increase in tensile strength that is up to five times that of steel. Considering that there is no need for columns between floors because of the extremely compressed characteristics of the material, this energy-saving advantage helps to explain the importance of using new sustainable materials with the aid of digital design processes to reconfigure traditional architectural elements.

5.2.3 Object

Based on the concern for both digital and green, one could see the definitions of basic architectural elements such as roof, façade, column or window becoming vague because of the comprehensive functions and roles. Such as Case 3, when the structure integrated the stairs, walls and roof all into one cohesive system, it also served as both structure and façade with its load bearing grid-like formation. The green features of the rainwater collection system also emphasize the dual functions of the roof in Case 3. To encourage the continuity of natural ventilation through the whole building in Case 6, the façade and the Double Cone column structure merge together with the roof with the solar modules integrated on the surface, the original architectural elements are replaced with the new forms and multiple functions. In Case 9, the functional parts such as the high performance solar glass façade, the ventilated floor plan, the air flow entrance and the lung-like light well demonstrate the multi-functions of the object, which offer a new reason to make an architectural whole, not only with high-level technique for its modern look but also to provide energy-efficiency.

5.2.4 Construction

The aim of computer technology and the needs of sustainable concern offer a completely new way to explore different possibilities in the areas of



a **b** **c**

Figure 6: Case 3 (a) (b) and Case 9 (c). Photo credit: Case 3 (a) (b): Ben McMillan; Case 9 (c): Luke Hayes.

construction. This feature is particularly evident in Case 2 when the whole skyscraper is to be built entirely from prefabricated parts that are made digitally for fast construction and energy saving. In Case 6, the project uses rectangular pipes to support the glass panes directly instead of traditional round pipes, which certainly reduces steel consumption in construction. Moreover, because of the new innovation of extremely compressed material by technologies, there is no need for columns between floors in Case 7. This helps to explain how merging digital technologies and sustainable concerns not only give us new ways of construction but also leads to new manipulations in design process and thinking.

5.2.5 Interaction

The project in Case 1 attempts to produce a close interaction between the environmental context and green space with the crown of wind turbines on the roof garden to grow the building's own ecosystem. One example is the shark scales envelope of Case 4, with its shingle's different ways of generation allowing for leading natural light and visual contact with the river, which demonstrate its relationship to the surrounding environment visually and sustainably. In Case 5, with the merging of high technology with green thinking, the ozonation bubbling system and green roof system on the rooftop brings natural light to the interior building and also corresponds to the surrounding site. From Case 8, one can observe how architecture and green space interact with each other. To express itself as an extension of the urban site, this linear structure puts the green roof of the building into a continuous relationship with the surrounding public park and waterfront, which connects the site to the rooftop green space, links the city to the sea, and also interweaves the interior and exterior. Hence, the interaction between this arrangement, green space and people, emphasizes how digital architecture produces more than just a fluid shape, but also interacts with the surroundings with environmental purpose.

a b

Figure 7: Case 4 (a) and Case 8 (b). Photo credit: Case 4 (a): Zaha Hadid Office; Case 8 (b): Mami Sayo.

6 Conclusion

This research has pointed out the need for a higher level interrelationship between digital design process and sustainable concept in the digital-green age. The recent digital sustainable architecture is more concerned with disconnected issues. The digital-green evolution in architectural design has been supplanted not only in the design manipulations, but also in the evolution of merging digital technology and sustainable aspects entirely. With such understanding, a new design process of merging digital technologies and sustainability through new factors are applied to the study (Fig. 8).

By merging the digital design manipulation technique and green thinking, the new method of design process differs from the original expression of digital architectural manipulation. It is essential to emphasize a broader range of issues in design process, bonding digital architectural applications and sustainable expressions. This could extend the design process from a disconnected level to a more general and comprehensive level. This might further lead to the establishment of a prototype or conceptual model created by computer simulations or modelling to test the potential of the new factors and the new design process for the further investigation. Through this process, we will have a closer understanding of the relationships between the new digital-green architecture with CAD/CAM technologies and the new green movement in future digital-green projects. By examining new design process as proposed in this research, future studies could have the direction for exploring diverse design media or manipulations for corresponding with digital and sustainable application. The result might influence the generation of future work and deliver some level of change through a freshly-integrated perception of new technology and sustainable design thinking.

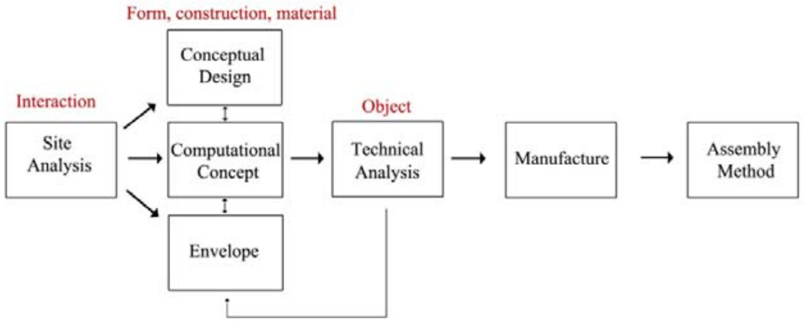


Figure 8: Digital-Green design process.

References

[1] McDonough, William & Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*, North Point Press, 2002.

[2] Koleravic, Branko. *Architecture in the digital age: Design and manufacturing.* Spon Press, 2004.

[3] Mitchell, W.J. *A Tale of Two cities:* Architecture and the digital *Revolution*, In Science, 1999.

[4] Ryder G., et al. *Rapid design and manufacture tools in architecture*, Automation in Construction, 2002.

[5] Burry, M. *Rapid prototyping, CAD/CAM and human factors,* Automation in Construction, 2002.
[6] Kolarevic, B. (ed.), *Architecture in the Digital Age: design and manufacturing*, Spon Press: New York, 2003.
[7] Lim, C.K. *A Revolution of the Design Process*, In Proceedings of Computer Aided Architectural Design in Asia (CAADRIA 2004), pp.571-583, Souel, 2004.
[8] Ali, A. & C. Brebbia. *Digital Architecture and Construction*, WIT Press, 2006.
[9] Kolarevic, Branko. *Digital architectures, eternity, infinity and virtuality in architecture*, pp. 251–256, 2000.
[10] Deleuze, Gilles. *A thousand plateaus: Capitalism and schizophrenia*, University of Minnesota Press, 1987.
[11] Delanda, Manuel. *A thousand years of nonlinear history*, Zone books, 2000.
[12] Mitchell, W.J. *Beyond productivity: information technology, innovation, and creativity,* The National Academies Press, 2003.
[13] Olgyay, V. *Solar Control and Shading Devices,* Princeton University Press: Princeton, 1957.
[14] Hancock, M. *Energy Efficient Building.* Blackwell Scientific Publications: Oxford, 1992.
[15] Slessor, C. *Eco-Tech: Sustainable Architecture and High Technology,* Thames & Hudson: London, 1997.
[16] Kolarevic, Branko & Malkawi, Ali. *Performative Architecture: Beyond Instrumentality,* Routledge, 2005.
[17] Yeang, K. *The Green Skyscraper: the Basis for Designing Sustainable Intensive Buildings*, Prestel: New York, 1999.
[18] Architectural Record Innovation, http://archrecord.construction.com/innovation/2_features/0310carbonfiber.asp
[19] Architectural Record, 2005 http://archrecord.construction.com/print.asp?REF=http://archrecord.construction.com/projects/portfolio/archives/0510whitney.asp
[20] Inhabitat: Design will save the world, Greener Gadgets, New York, http://www.inhabitat.com/2007/05/16/david-fishers-twirling-wind-power-tower/
[21] Foster, Norman. *The Third Industrial Revolution,* http://www.fosterandpartners.com/content/essays/The%20Third%20Industrial%20Revolution.pdf
[22] Semper, G. *The four elements of architecture and other writings,* Cambridge University Press, 1951.
[23] Botticher, K. *The tectonics of the Hellenes,* Postdam, 1852.
[24] Sekler, E.F., Structure *in art and in science,* George Braziller, 1965.
[25] Frascari, M. & V. Gregotti. *Theorizing a new agenda for architecture: an anthology of architecture theory 1965–1995.* Princeton Architectural Press, pp. 498–515, 1983.

[26] Gregotti, Vittorio & The Exercise of Detailing, In: Nesbitt, Kate (editor). *Theorizing a new agenda for architecture –an anthology of architectural theory 1965-1995,* Princeton Architectural Press: New York, pp.494-497, 1996
[27] Moneo, R. *The idea of lasting: a conversation with Rafael,* Perspecta, Vol 24. pp. 146–157, 1988.
[28] Frampton, K. *Rappel a l'ordre: the case for the tectonic,* Architectural Design Vol 60, pp. 19–25, 1990.
[29] Gao, W.P. *Proceedings of Computer Aided Architectural Design Research in Asia,* Yonsei University Press, pp 519–534, 2004.
[30] Liu, Y.T. & Lim, C.K. *New Tectonics Towards a New Theory of Digital Architecture: 7th Feidad Award,* Birkhauser, Boston, 2009.
[31] Liu, Y.T. & Lim, C.K. *New Tectonics: A Preliminary Framework Involving Classic and Digital Thinking,* Design Studies Vol.27: 267-307, 2006.
[32] Steele, James. *Sustainable Architecture: Principles, Paradigms, and Case Studies,* McGraw-Hill, 1997.
[33] Lawson, Bryan. *How designers think: The design process demystified,* The Architectural Press, 1997.
[34] Mendler, S. & W. Odell. *The HOK guidebook to sustainable design,* John Wiley & Sons, 2006.

Socio environmental impact in eco-architecture

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Abstract

The interest of this paper is to focus on the social community and its built environment as an important part of creating ecological design, satisfying the community's social culture needs and achieving eco-architecture. The social impact assessment (SIA) is an important indicator in the age of information, communication technologies and globalization that affects the future of architecture. The social environment is different to the natural environment because it reacts in anticipation of change, but can adapt in reasoned ways to changing circumstances if this is part of the planning process, and there is the opportunity to participate in designing our future. This paper addresses itself to that modified challenge to achieve eco architecture. Firstly it attempts to define and clarify the SIA as a framework for the comprehensive understanding of environmental experience, regarding its variables and how it could be different depending on social cultures. Secondly it applies this idea to architectural projects that have won prizes at the AGKA awards for sustainable projects in developing countries, adopting the concept of our need to preserve the balance of nature. We consider Masdar, the zero carbon city in the UAE, in our case study with attention being given to the important relationship between physical design and social behaviour regarding eco-architecture.
Keywords: social impact, environmental, sustainable, architecture.

1 Introduction

Eco-architecture is sustainable architecture that involves a combination of values: aesthetic, environmental, social, political, and moral. It is about using one's imagination and technical knowledge to engage in the central aspect of the practice, designing and building in harmony with our environment. The smart architect thinks rationally about a combination of issues, including sustainability, durability, longevity, appropriate materials, and sense of place [1]. The challenge

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is finding the balance between environmental considerations and economic constraints. Consideration must be given to the needs of our communities and the ecosystem that supports them, and here we should mention that the SIA as a very important indicator for eco-architecture.

2 Definition of eco-architecture

First we have to define Ecology as the science of the relationship and interaction of living organisms with their inanimate (e.g. climate, soil) and their animate environment, as well as the study of resource and energy management in the biosphere and its sub-categories, and the study of the detrimental effects of modern civilization on the environment, with a view toward prevention or reversal through conservation [2]. Second we define what we mean by ecological building: as a movement in contemporary architecture. This movement aims to create environmentally friendly, energy-efficient buildings and developments by effectively managing natural resources. This entails passively and actively harnessing solar energy and using materials which, in their manufacture, application, and disposal, do the least possible damage to the so-called 'free resources': water, ground, and air.

2.1 Eco-architecture principles

2.1.1 Understanding context

Sustainable design begins with an intimate understanding of place. If we are sensitive to the nuances of place, we can inhabit without destroying it. Understanding place helps determine design practices such as solar orientation of a building on the site, preservation of the natural environment, and access to public transportation [3].

2.1.2 Connecting with nature

Whether the design site is a building in the inner city or in a more natural setting, connecting with nature brings the designed environment back to life. Effective design helps inform us of our place within nature.

2.1.3 Understanding natural processes

In nature there is no waste. In other words, natural systems are made of closed loops by working with living processes: we respect the needs of all species. Engaging processes that regenerate rather than deplete, we become more alive. Making natural cycles and processes visible brings the designed environment back to life.

2.1.4 Understanding environmental impact

Sustainable design attempts to have an understanding of the environmental impact of the design by evaluating the site, the embodied energy and toxicity of the materials, and the energy efficiency of the design, materials and construction techniques. Negative environmental impact can be mitigated through use of sustainably harvested building materials and finishes, materials with low toxicity in manufacturing and installation, and recycling building materials while on the job site. Embracing co-creative design processes, sustainable designers are finding it is important to listen to every voice. Collaboration with systems consultants, engineers and other experts happens early in the design process, instead of an afterthought. Designers are also listening to the voices of local communities.

2.1.5 Understanding people

Sustainable design must take into consideration the wide range of cultures, races, religions and habits of the people who are going to be using and inhabiting the built environment. This requires sensitivity and empathy to the needs of the people and the community.

2.2 Environmental and social sustainable architecture

There are five principles of an environmental architecture (Fisher, AIA, November, 1992 [4]): the first is a healthful interior environment. All possible measures are to be taken to ensure that materials and building systems do not emit toxic substances and gasses into the interior atmosphere and additional measures are to be taken to clean and revitalize the interior air with filtration and plantings. The second principle is energy efficiency. All possible measures are to be taken to ensure that the building's use of energy is minimal, cooling, heating and lighting systems are to use methods and products that conserve or eliminate energy use. The third principle is the use of ecologically benign materials. All possible measures are to be taken to use building materials and products that minimize destruction of the global environment, wood is to be selected based on non destructive forestry practices and other materials and products are to be considered based on the toxic waste output of production. The fourth principle is Environmental Form. All possible measures are to be taken to relate the form and plan of the design to the site, the region and the climate and measures are to be taken to "heal" and augment the ecology of the site. Accommodations are to be made for recycling and energy efficiency and measures are to be taken to relate the form of building to a harmonious relationship between the inhabitants and nature. The fifth principle is good design. All possible measures are to be taken to achieve an efficient, long lasting and elegant relationship of use areas, circulation, building form, mechanical systems and construction technology, symbolic relationships with appropriate history, the earth and spiritual principles are to be searched for and expressed, and finished buildings shall be well built, easy to use and beautiful. Many definitions of a sustainable community have been put forward, but they all revolve around the interconnectedness of society, economy and environment; a sustainable community is one in which the economic, social and environmental systems that make up the community provide a healthy, productive, meaningful life for all community residents, present and future. Sustainable communities acknowledge that there are limits to the natural, social and built systems upon which we depend [5].

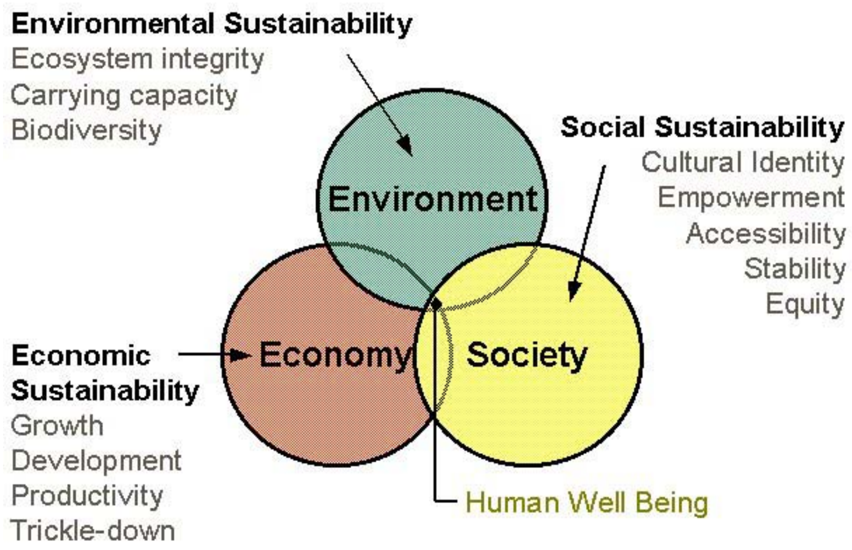

Figure 1: Three dimensions of sustainability.

In addition to social, economic, and environmental health, sustainable communities are about the participation of all elements of society in decision-making processes. Local governments can help their communities to become more sustainable, but they cannot do it without a mandate from, and the participation of the local community, according to the National Round Table on the Environment and the Economy. Sustainability must be community-led and consensus-based because the central issue is will, not expertise; only a community-based process can overcome the political, bureaucratic and psychological barriers to change. However, citizen-led processes must be complemented by top-down government support because it is still only governments that have the regulatory powers to secure the transition to sustainable development.

2.3 Model principles for sustainable communities

A sustainable community is one that recognizes that growth occurs within some limits and is ultimately limited by the carrying capacity of the environment. It values cultural diversity, has respect for other life forms and supports biodiversity and has shared values amongst the members of the community, (business and personal decision-making processes). The community makes decisions and plans in a balanced, open and flexible manner that includes perspectives from the social, health, economic and environmental sectors of the community. It makes best use of local efforts and resources (nurtures solutions at the local level) and uses renewable and reliable sources of energy. It minimizes harm to the natural environment, fosters activities that use materials in continuous cycles and, as a result, a sustainable community does not compromise the sustainability of other communities [6].

3 Social impact assessment methodology

The impacts of development interventions take different shapes. While significant benefits flow forth from different development actions, there is a need to also identify and evaluate the associated negative externalities. Social impacts are impacts of developmental interventions on human settlements; such impacts not only need to be identified and measured but also need to be managed in such a way that the positive externalities are magnified and the negative ones minimized. This document provides a realistic methodology for appraisal of possible social ramifications through active stakeholder participation and their effective mitigation.

3.1 Social impact assessment (SIA) definition

Social impact assessment (SIA) is the process of assessing and managing the impacts of a project, plan, program or policy on people. Although there has been some debate over the precise meanings of terms such as SIA, Social Analysis, Social Assessment, Social Appraisal, and even Social Soundness Analysis, most of the debate about these terms has had little bearing on the SIA discipline. Amongst the international professional community interested in SIA, although there is not a generally agreed definition, I will define that concept as: "Social impact assessment is the process of analysing and managing the intended and unintended consequences on the human environment of interventions (policies, plans, programs, projects and other social activities) and social change processes so as to create a more sustainable biophysical and human environment" [7].

3.2 SIA important features and variables

SIA is understood to include adaptive management of impacts, projects and policies and therefore needs to be involved (at least considered) in the planning of the project or policy from inception. The SIA process can be applied to a wide range of interventions, and undertaken at the behest of a wide range of actors, and not just within a regulatory framework; it is implicit that social and biophysical impacts are interconnected; and finally, the overall purpose of all impact assessment is to bring about a more sustainable world, and that issues of social sustainability and ecological sustainability need to be considered in partnership. SIA variables point to measurable change in human population, communities, and social relationships resulting from a development project or policy change. After research on local community change, rural industrialization, reservoir and highway development, natural resource development, and social change in general, we suggest a list of social variables under the general headings of: population characteristics, community and institutional structures, political and social resources, individual and family changes, and community resources [8].

4 Eco-architecture winning projects

The AKDN through its efforts gifts architectural awards for sustainable and eco-architectural projects that seek to identify and encourage building concepts that successfully address the needs and aspirations of societies in which Muslims have a significant presence. The selection process emphasizes architecture that not only provides for people's physical, social and economic needs, but that also stimulates and responds to their cultural and spiritual expectations. Particular attention is given to building schemes that use local resources and appropriate technology in an innovative way and to projects likely to inspire similar efforts elsewhere and this paper will analyze three of the winning projects for the 2007 cycle [9].

4.1 Royal Netherland Embassy, Addis Ababa, Ethiopia

The Royal Netherlands Embassy complex lies amidst the urban sprawl on the southern outskirts of Addis Ababa, enclosed within a dense eucalyptus grove. The architects' guiding principle was to preserve and respect the topography of the surrounding landscape while addressing the functional requirements of a working embassy. They took care to maintain existing contour lines and leave the vegetation and wildlife undisturbed. The main building, an elongated horizontal volume, cuts across the sloping terrain on an east-west axis. Walls, floors and ceilings are pigmented the same red-ochre as the Ethiopian earth and are uniformly composed of concrete, creating the effect of a cave-like space, reminiscent of the rock-hewn architecture of Ethiopia. By contrast, the roof garden with its network of shallow pools alludes to a Dutch water landscape. An unashamedly contemporary and simple organisation of spaces, the Dutch Embassy in Addis Ababa overcomes the complexities of security and surveillance normally associated with the design of embassy compounds. It is a quiet yet superbly imaginative intervention into the existing landscape, and the sensitivity to place and process is abundantly clear in this space of encounter between traditional Ethiopian architecture and Dutch cultural and architectural themes.

4.2 School in Rudrapur, Dinajpur, Bangladesh

This joyous and elegant two-storey primary school in rural Bangladesh has emerged from a deep understanding of local materials and a heart-felt connection

Figure 2: The Royal Netherland Embassy.

to the local community. Hand-built in four months by local craftsmen, pupils, parents and teachers together with experts from Germany and Austria, it uses traditional methods and materials of construction but adapts them in new ways to create light-filled beautiful, meaningful and humane collective spaces for learning. The school is part of the Modern Education and Training Institute (METI) of the Bangladeshi NGO Dipshikha, which places an emphasis on helping children develop their own potential and use it in a creative way. The building follows the same principles, bringing out the best in local materials by inventively combining them with improved construction techniques. Earthbound materials such as loam and straw are combined with lighter elements like bamboo sticks and nylon lashing to shape a built form that addresses sustainability in construction in an exemplary manner.

Figure 3: The Bangladesh school in Rudrapur.

4.3 University of Technology Petronas, Malaysia

The University of Technology Petronas' prototypical built configuration, consisting of an all-encompassing shaped canopy with functional boxes inserted underneath, is a contemporary reinterpretation of the classic metaphor for tropical architecture - an umbrella that offers protection from the sun and rain. It is a complex educational structure that links concept with expectation, its high-tech emblematic architecture appropriate for a large scientific university in a rapidly developing nation. At the same time, the design responds both to the physical landscape and to the weather patterns of the Malay peninsula. A soaring, crescent-form roof supported by steel columns winds around the edge of the site, covering pedestrian routes and providing a defined, shaded zone for social interaction and circulation. To preserve the natural topography, the core academic buildings are wrapped around the base of a series of knolls, and viewed from a distance, the university's canopy elevation echoes the tree canopy of the densely forested site. This is an exemplary use of a performance-based approach to architectural design that goes beyond the diagram. The design has been carried through to completion with meticulous detail, rigour and persistence, and marks a real collaboration between the two architectural practices, with an important transfer of knowledge, process and technology.

 

Figure 4: University of Technology, Malaysia.

5 Achieving eco-architecture building

An ecological approach to the built environment involves a holistic approach to the design of buildings. All the resources that go into a building are by materials, fuels or the contribution of the users need to be considered if a sustainable architecture is to be produced. Producing ecological buildings involves resolving many conflicting issues and requirements. Each design decision has environmental and social implications. Measures for ecological buildings can be divided into four areas, reducing energy in use, minimising external pollution and environmental damage reducing embodied energy and resource depletion, minimising internal pollution and damage to health. An ecological building places a high priority on health, environmental and resource conservation performance over its life-cycle. These new priorities expand and complement the classical building design concerns: economy, utility, durability, and delight. green design emphasizes a number of new environmental, resource and occupant health concerns, Reduce human exposure to noxious materials, conserve non-renewable energy and scarce materials, minimize life-cycle ecological impact of energy and materials used, use renewable energy and materials that are sustainably harvested, protect and restore local air, water, soils, flora and fauna, support pedestrians, bicycles, mass transit and other alternatives to fossil-fuelled vehicles. Most ecological buildings are high-quality buildings; they last longer, cost less to operate and maintain, and provide greater occupant satisfaction than standard developments. What surprises many people unfamiliar with this design movement is that good ecological buildings often cost little or no more to build than conventional designs. Commitment to better performance, close teamwork throughout the design process, openness to new approaches, and information on how these are best applied are more important than a large construction budget. Ecological building needs to fulfil the six issues mentioned table 1 [8].

Table 1: The six issues to be considered in eco-architecture.

Site	Energy	Water
Materials	Waste	Community

5.1 Site issues

Considering ecological building we have to mention the site issue that will contain landform and microclimate (topography, light-coloured surfacing, vegetative cooling, wind buffering and evaporative cooling), land-use (use density, use mix and activity concentration), site design (solar orientation, pedestrian orientation), infrastructure efficiency (water supply and use, waste water collection, storm drainage, street lighting and recycling facilities), and finally on-site energy resources.

5.2 Energy issues

The benefits from the energy-efficient siting and design of buildings are economic (saving money), social (reducing fuel poverty); and ecological (reducing resource exploitation and emissions). Every new development ideally should have an explicit energy strategy, setting out how these benefits are to be achieved.

5.3 Water issues

Water conservation methods: Toilets (Low flush toilets, dual flush toilets, vacuum or compressed air toilets cistern displacement devices, waterless toilets (composting toilets, incinerating toilets), wash hand basins (push taps, flow control, self closing, tap flow regulators), outside and garden.

5.4 Material issues

The energy input required to quarry, transport and manufacture building materials, plus the energy used in the construction process, can amount to a quarter of the 'lifetime' energy requirement of a very energy-efficient building. To reduce embodied energy, without compromising longevity or efficiency: re-use existing buildings and structures wherever possible (provided their energy costs in use can be reduced to an acceptable level), design buildings for long life, with ease of maintenance and adaptability to changing needs, construct buildings and infrastructure out of local and low- energy materials where possible, reduce the proportion of high rise, detached or single-storey developments, design layouts which minimise the extent to roadway and utility pipe work per dwelling.

5.5 Waste issues

Humans are the only species on Earth that produce waste which is not a raw material or nutrient for another species. We are the only species to produce wastes that can be broadly toxic and build up for long periods of time. As William McDonough, Dean of the University of Virginia School of Architecture, has said, a sustainable society would eliminate the concept of waste. Waste is not simply an unwanted and sometimes harmful by-product of life; it is a raw material out of place. Waste and pollution demonstrate gross inefficiency in the economic system since they represent resources that are no longer available for use and/or create harm in humans and other species [10].

5.6 Community issues

Many definitions of a sustainable community have been put forward, but they all revolve around the interconnectedness of society, economy and environment, a sustainable community is one in which the economic, social and environmental systems that make up the community provide a healthy, productive, meaningful life for all community residents, present and future. Sustainable communities acknowledge that there are limits to the natural, social and built systems upon which we depend. In addition to social, economic, and environmental health, sustainable communities are about the participation of all elements of society in decision-making processes. Local governments can help their communities to become more sustainable, but they cannot do it without a mandate from, and the participation of the local community.

6 Conclusion

Eco-architecture must be community-led and consensus-based because the central issue is will, not expertise; only a community-based process can overcome the political, bureaucratic and psychological barriers to change. However, citizen-led processes must be complemented by top-down government support because it is still only governments that have the regulatory powers to secure the transition to sustainable development, and here is the role of social impact assessment which is predicated on the notion that decision-makers should understand the consequences of their decisions before they act, and that the people affected will not only be apprised of the effects, but have the opportunity to participate in designing their future.

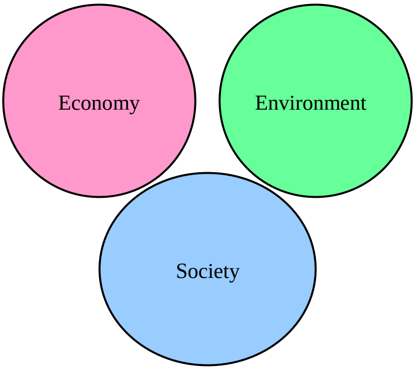

Figure 5: A view of community as three separate, unrelated parts: an economic part, a social part and an environmental part. Traditional quality of life indicators tend to measure these three parts separately.

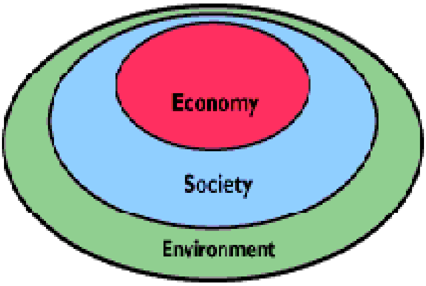

Figure 6: A view of community as three concentric circles: the economy exists within society, and both the economy and society exist within the environment. Sustainability indicators attempt to measure the extent to which these boundaries are respected.

References

[1] F. J. Soria López, Architecture and nature at the end of the 20th century: towards a dialogical approach for sustainable design in architecture. Proc. of the 1st Int. Conf. On Harmonisation between Architecture and Nature, G. Broadbent, New Forest, UK, pp.24-28, 2006.
[2] Wikipedia encyclopaedia web site, http://en.wikipedia.org/wiki/Sustainable_architecture#Sustainable_building_materials
[3] Building Energy Efficiency Research web site, http://www.arch.hku.hk/research/beer/sustain.htm#1.1
[4] Sustainable Buildings, Low Energy Housing. The European Sustainable Energy Systems in Advanced Cities (SESAC) web site, http://www.concerto-sesac.eu/spip.php?rubrique81
[5] Foster, Norman, *The Economy of Architecture, in Back from Utopia: The Challenge of the Modern Movement.* Rotterdam: 010 Publishers, pp. 26-37, 2002.
[6] Markiewiscz, Evan, Architecture, Society and Social Change, in ArcCA: the journal of the American Institute of Architects, California Council, no. 2, pp. 42-45, 2003.
[7] Taylor CN, Bryan CH, Goodrich CG, *Social Assessment: theory, process and techniques*, Middleton, WI: The Social Ecology Press, pp.15-22, 2004.
[8] Global Sustainability Concepts: Capital & Subsidies. UNCED and Rio web site, http://darwin.bio.uci.edu/~sustain/state/chapter1.htm
[9] Aga Khan Award for Architecture web site: http://78.136.16.169/pages/p03124.html
[10] Dennis A. Rondinelli & Michael A. Berry, Environmental citizenship in multinational corporations: social responsibility and sustainable development, European Management Journal, volume 18, Issue 1, pp. 70-84, 2000.

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Integrating aspects of cultural and environmental sensitivities into affordable housing in the Arab Gulf region

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Abstract

Supported by strong oil-based economies, governments in several Gulf Arab states are committed to providing their citizens with free or highly subsidized housing. These are typically offered in the form of three or four bedroomed, single or double storey villas built on a freely provided piece of land. Thousands of these units are constructed every year to satisfy the growing population in these states. Unfortunately, the designs for most of these units follow ubiquitous design guidelines that do not fit well with a variety of cultural requirements for housing in the region. In addition, these designs are not sensitive with regards to the climate in which they are built. Consequently, both house owners and responsible government agents have begun to express their dissatisfaction with these designs. The lack of cultural sensitivity relating to the need for high levels of privacy has forced many owners to make costly modifications, and often limits their use and enjoyment of their property. The lack of environmental sensitivity has resulted in inflated government budgets that are needed to supply subsidized electricity and water to these houses. As a result, both owners and government agents now demand better designs, ones that are sensitive to the culture as well as the environment. This paper provides a different design approach that aims to satisfy these demands by integrating both cultural and environmental requirements. The paper investigates these requirements, shows a proposed architectural design, and critically reviews the design identifying its abilities and failures to satisfy and integrate these requirements.
Keywords: architectural sustainable design, cultural sensitivity, housing, Arab Gulf, courtyard houses.

1 Introduction

This paper aims to put forward for discussion a design approach that intends to integrate both environmental and cultural aspects of the architectural design for private houses. Such integration aspires to achieve sustainability not only in aspects such as energy and water but also extends to covering the sustainability of human cultures. The Arabian Gulf region was selected as the context for this discussion because of its unique culture that is being threatened by the very large percentage of expatriates (which can exceed 80 percent of the population), and the rapid change in lifestyle which includes, among other things, the expectations for private houses.

With strong economies supported by oil revenues, governments in these countries provide their less fortunate citizens with free economy housing. Thousands of such units are constructed annually in the region. Traditionally, the housing unit will be a villa with four to five bedrooms on a piece of land that measures about 800 square meters. While these specifications are considered luxurious in many parts of the world, they are seen as economical for citizens (natives) of the region due to large family sizes and high per capita incomes. Energy and water are typically provided at highly subsidized prices. Figure 1 shows a sample of the provided house.

However, several factors are now beginning to make such model of provision unsustainable. One factor is the rapid increase in the number of marriage-age citizens, which has enlarged the demand for such housing. The other important factor is the construction boom in the region. This has sharply inflated not only the cost of providing the houses, but more critically the cost of the infrastructure needed to provide subsidized water and energy. As these countries hardly have a system of taxation, the economic boom did not necessarily increase the pool of money allocated to provide the needed infrastructure. Shortages in electricity and water supplies have started to appear. The provision of highly subsidized water and energy puts pressure neither on the designers of the free housing to design sustainable buildings, nor on the users to invest in modifying their existing energy and water consumption patterns.

Figure 1: Sample of a free economic house.

Increasing the price to cost level is seen as a destabilizing action and is not considered a viable option. The only feasible economic solution is clearly to make more effort to provide environmentally sensitive designs that consume less, and hopefully at the same time help users change their consumption patterns.

But the economic aspect is not the only force able to reduce energy and water consumption. In a region which has a hot climate and a very small industrial base, it is estimated that 70% of generated energy is used for the air conditioning of buildings. This energy is mainly generated by burning oil, thereby adding more CO_2 in the atmosphere. In a desert region, the supply of water also requires the burning of oil to desalinate sea water. As there is hardly any agricultural activity, most desalinated water is used in buildings. The desalination process not only results in an increase in Co_2 emissions but also affects the marine environment by depositing warm and highly saline water in the Arabian Gulf. As such, the need for environmentally sensitive buildings is increasingly recognized in the region. This is particularly the case with freely provided residences, as their design typically receives less attention and they are built in large numbers.

However, these buildings have additional problematic aspects. Designed by expatriates following standard international regulations that combine with a poor understanding of local culture, these residences do not adequately satisfy the needs of their occupants. As will be shown, privacy, the ability to receive guests with segregation of the genders, and the use of domestic servants, are among the important components in the cultural fabric of the region. The inability to address these components makes the users of these residences uncomfortable in their own homes, and gradually forces them to change their cherished traditions.

The paper shows an approach towards addressing some of the above mentioned challenges through a design approach that tries to integrate environmental and cultural requirements. The paper starts by investigating these requirements, and then demonstrates the proposed design approach in contrast to the traditional one. Finally, a sample design that is based on the proposed approach is shown and analyzed critically against both the cultural and environmental requirements. The author hopes that the proposed approach will trigger more discussion and investigation among academic and professional communities for the integration of cultural and environmental aspects of architectural design to achieve sustainability in both of these aspects.

2 Investigating environmental requirements

The Gulf Arab region is located on the western shore of the Arabian (Persian) Gulf. While its macro environment is that of a dry desert, the micro climate varies slightly due to factors such as the effect of the water in coastal areas and the effect of height on mountain areas. Therefore, we will assume a particular part of the region for which the reported study was developed. This part is the flat coastal area of the United Arab Emirates, which includes Abu Dhabi, Dubai, and Sharjah as its major cities. The two psychometric charts (Figures 2 and 3)

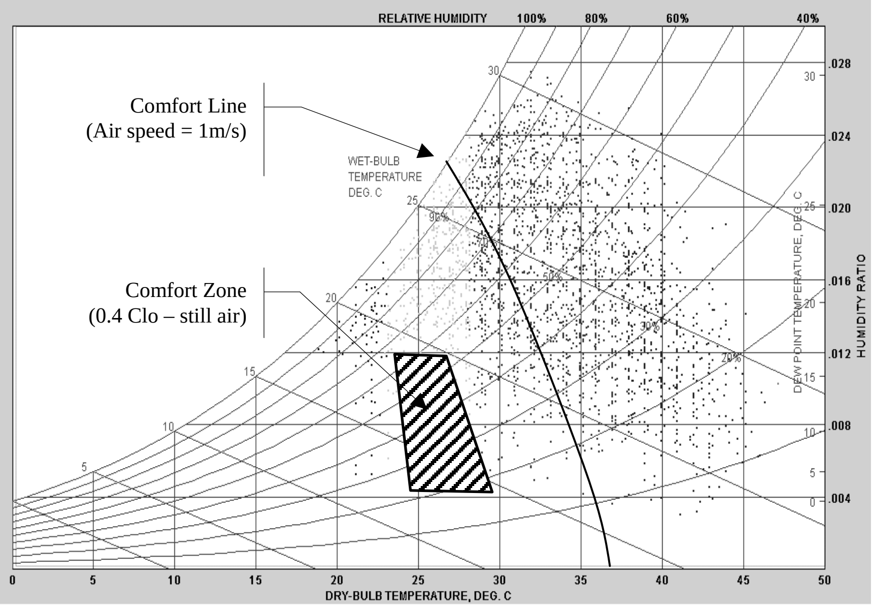

Figure 2: Abu Dhabi data during the hot season (June to October).

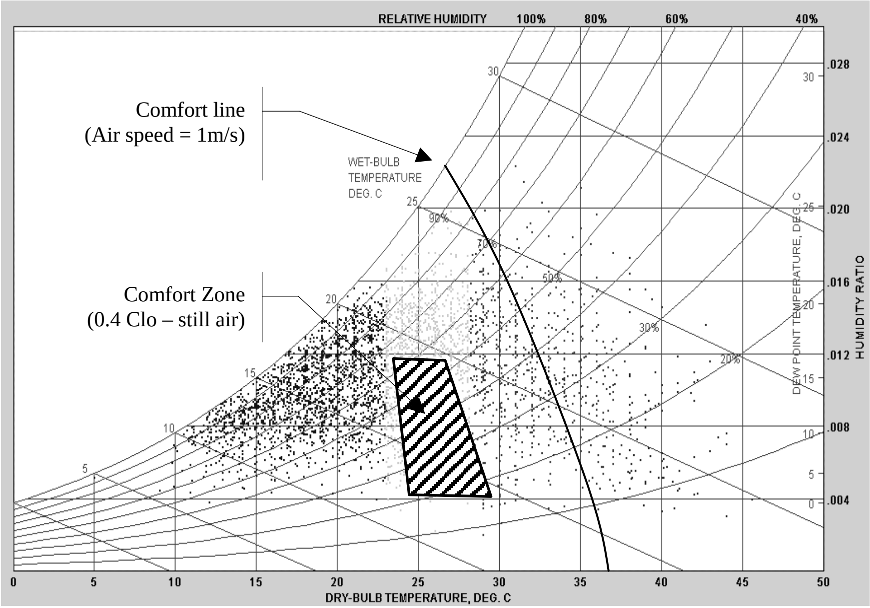

Figure 3: Abu Dhabi data during the temperate season (November to May).

show the two main climatic seasons in this part of the world; a hot and humid climate for almost six months, tempered to a warm climate for the rest of the year. The climate data on the psychometric charts are for the city of Abu Dhabi and are shown using the software Climate Consultant [1]. Some of the preferred conditions for human thermal comfort are superimposed on the charts. The hatched zones indicate the comfort conditions for a typical sedentary person wearing light clothes when the air around the person is still. The curved line shows the possibility for the typical sedentary person to tolerate warmer and more humid conditions when the air speed moves up to 1m/s (3.6 km/h).

The data on the two charts shows the possibility of using air movement (natural ventilation) during most of the temperate season to achieve human thermal comfort and without the need for mechanical air conditioning. It also shows that air conditioning is required during most of the hot and humid season. Figure 4 shows the wind speed and direction for Abu Dhabi during the temperate season, using the software Climate Consultant. The data shows a wind speed of average 4 m/s with dominant wind direction on the axis of North-West South-East. The shown wind speeds are measured at the airport at a typical height of 10m. With standard calculations, this wind speed can be translated to 2 m/s at a height of 3 meters in a suburban area. Such a wind speed can be used for natural ventilation and can result in an average air velocity of 1m/s inside a building.

Other environmental data (not shown here) indicate abundance of solar radiation through most of the year. This indicates the need to provide shading to reduce solar heat gain. It also shows the potential of using solar energy to run air conditioning, provide domestic hot water, and generate some of the required electrical energy.

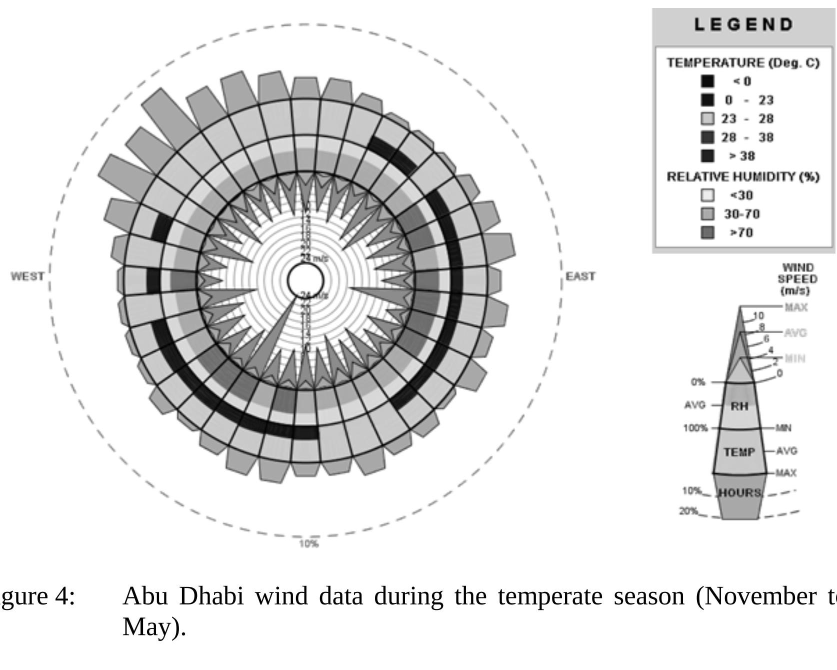

Figure 4: Abu Dhabi wind data during the temperate season (November to May).

3 Investigating cultural requirements

The Arabian Gulf region has some particular cultural requirements that have been shaped by many factors, including religion, history and the natural environment. Anecdotal data collected by many discussions with the citizens (natives) of the region suggest the following cultural issues as being critical to the design of houses.

3.1 Privacy

Excluding immediate circle of family members, both males and females keep a very high level of privacy. If seen by outsiders, they need to wear clothes that cover almost all of the female body and most of the male body. As such, house design needs to ensure that people such as neighbors and passersby will not be able to see inside the house and view the residents wearing their relaxed house cloths. Failure to provide this privacy in current designs had resulted in residents being unable to use the house in comfort. It has also resulted in environmental implications as to be shown later.

3.2 Guest segregation

Historically, the natives to the region lived in isolated villages in the desert. Due to the harshness of the environment, travelers and guests were received with generosity to provide them with support. This generosity remains in the culture of the society and one or more spaces in a house are dedicated to the reception of guests. However, male guests sit with male family members while female guests sit with female family members in segregated spaces. Typically the space allocated to male guests is accessible from outside the house so that normal household activities are not interrupted. Female guests are typically invited into the living room inside the house if the male space is occupied. Food is typically served to the guests in these spaces; normally on the floor. Occasionally, some guests may need to sleep overnight. The guest bedroom needs to be isolated so it does not interrupt the privacy of the occupants.

3.3 Domestic servants

The relatively low cost of hiring domestic servants (maids and drivers) in the region makes their employment a standard practice. Domestic servants have their own rooms. The rooms of maids (typically female) should be apart from those of drivers (typically male). Preferably, domestic servants' rooms function independently of the rest of the house in the event that the owners are travelling and leaving behind some domestic servants.

3.4 Kitchen extensions

Because of the relatively large number of members in a family and the high frequency of guest visits, there is a need for large kitchens which are isolated from the rest of the house and have outdoor extensions. However, privacy needs to be ensured when cooking is performed outdoors.

4 Design approaches

The current approach for private residences in the region is locating a building in the middle of the allocated lot (Figure 5(a)). The author makes the case that this approach - which is common in many parts of the world - affects not only the social behavior of occupants but also their energy and water consumption, hence impacting both cultural and environmental sustainability in the region.

Because of the very high concern regarding privacy, residents of houses designed using the current approach are unable to use their outdoor spaces comfortably because their neighbors can see them; this means that they need to be wearing certain clothes. This factor impacts the quality of life, as residents cannot enjoy fresh air, nor gather outdoors, nor practice gardening, nor use a swimming pool. But the problem of privacy extends beyond this. Windows cannot be left open and need to be covered by curtains or have reflective glass that ensures privacy inside the house. The difficulty relating to the opening of windows makes cross ventilation an avoided solution, even when the weather would allow it. Hence, air conditioning is used continuously throughout the year to compensate for the lack of natural cooling. Daylight is also affected by the use of curtains and reflective glass. This results in greater use of artificial lighting. The impact of cultural issue on energy consumption needs to be recognized and integrated into the design.

In their attempts to achieve privacy, residents build walls around their houses (see Figure 1). This has become a standard requirement with the current approach. A typical wall will have reinforced concrete columns that are four meters apart. Each column has its own foundation and reinforced concrete tie beams that link these columns and carry masonry walls that extend between the columns. The materials used to build the walls can be as much as that needed to build the structure of the house itself. This results not only in cost increase but also in the consumption of materials that have large embedded energy and water.

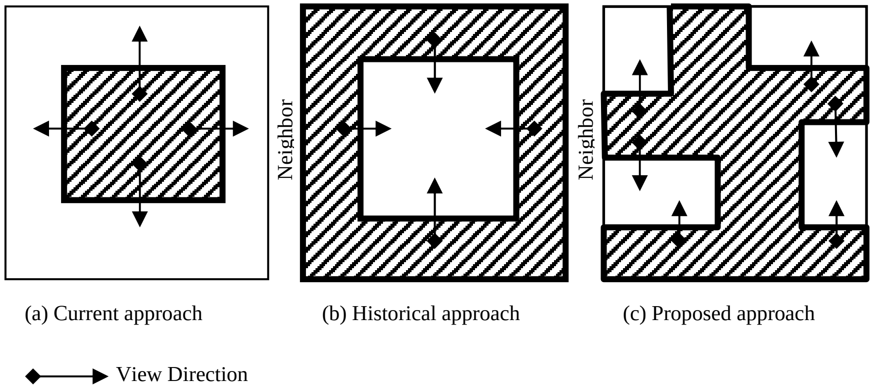

Figure 5: Three design approaches for locating the residence mass on site.

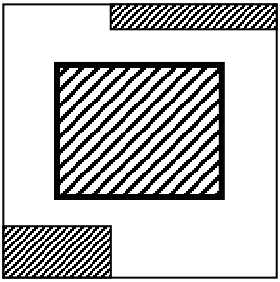

Figure 6: Typical location of the guests, kitchen, and utilities annexes.

The need for these walls can be evaded if the design approach integrates the cultural need for privacy.

While surrounding walls may help provide privacy from passers-by at ground level, it helps little in protecting upper floors, where bedrooms are typically located. Some occupants tend to use dense-leaved trees to secure some privacy for the upper floors. In a region where it hardly rains, this results in significant use of desalinated water to grow and maintain these trees.

The need to host guests in a space separate from the house is typically translated - with the current design approach - into an annex, as shown in Figure 6. Similarly, the kitchen and maids' rooms are treated as an annex. This lack of integration of these elements with the residence design contributes not only to the inability to use the outdoor spaces but also to the increase in energy consumption. These separate annexes are exposed to the sun with large roof areas relative to their volumes. This is particularly critical during the summer when the sun is almost perpendicular to the roofs.

A possible solution to the above-mentioned problems is to return to the historically used single courtyard approach (Figure 5(b)). This approach provides privacy through having most spaces looking inwards to the central courtyard. Guest rooms here need to look outwards so that guests do not violate the privacy of the courtyard. However, there are some issues with this approach. Cross ventilation is difficult to achieve for spaces that are sharing a wall with a neighbor. Circulation can be an issue, particularly during the summer. The single courtyard is typically used as the circulation space between the spaces around it. When air conditioning is used during the summer, residents need to circulate around the courtyard to move between the spaces. The courtyard needs to be closed in to enable the air conditioning of the circulation corridors around it. As some of the spaces have the courtyard as their only source of natural light, closing in the courtyard for the needs of air conditioning affects the natural light in these spaces. The historically used single courtyard approach does not fit well with current life styles where people of different ages and both genders are enjoying different types of activities (both indoors and outdoors) and where movement is very frequent between the different zones of the house. The approach put all these activities into a single space.

The proposed design approach aims to avoid the problems of both approaches. As shown in Figure 5(c), it includes several courtyards within a mass that fills the whole site. The outdoor spaces are integrated into the mass and are not treated as leftovers. These external spaces serve both environmental and cultural roles in an integrated fashion.

From the environmental perspective, these outdoor spaces enable cross-ventilation through all the main indoor spaces during temperate weather. During summer, the proportion of these small courtyards (width to height) results in the shading of many of the external walls as well as the courtyard grounds. Limited numbers of native palm trees can provide further shading during times where the sun is at its peak angle in the sky.

From the cultural point of view, the windows of the surrounding spaces are oriented to open to the courtyards but in a parallel direction to the wall of the bordering neighbor. Minor treatment for these windows prevents neighbors from seeing each others' courtyard areas. Privacy can be easily secured and residences can enjoy using open spaces. The different courtyards can be assigned as private (seen and used by the family members only) and semi-private (seen and used by guests). Private ones can be further divided to accommodate a variety of activities by family members of different ages and genders.

5 Proposed architectural design

This section provides a sample design that uses the proposed approach in trying to integrate both cultural and environmental aspects. The design is developed under the guidance of the author by a student of the Architecture program at the American University of Sharjah. In the authors' opinion, the design addresses and integrates successfully most - but not all - the environmental and cultural concerns.

As shown in Figures 7 and 8, the design has two floors and includes four courtyards (C1 to C4). The courtyards have relatively small dimensions in plan. Their widths relative to their heights provide adequate shading and hence minimize the sun's effect on the vertical elements of the envelope. However, the environmentally-useful small dimensions for the courtyards do not allow the violation of the residents' privacy due to the appropriate allocation of the functions of the spaces around these courtyards. At ground floor level, the outdoor space (C2) is semi-private and is viewed by guests who occupy the guest room (5). The outdoor spaces (C1) and (C2) are typically private. However, if female guests are using the living spaces (9), they become semi-private. When the living spaces are used by guests, they do not violate the privacy of other parts of the residence. The swimming pool is located so that neighbors cannot view its users. The logia (8) location makes this possible (the plan is mirrored for the neighbor). The outdoor space (C3) is private and allows for an outdoor extension of the kitchen where residents can wear comfortable clothes while preparing food and are without fear of being viewed by neighbors, via minor window treatments to the proposed design.

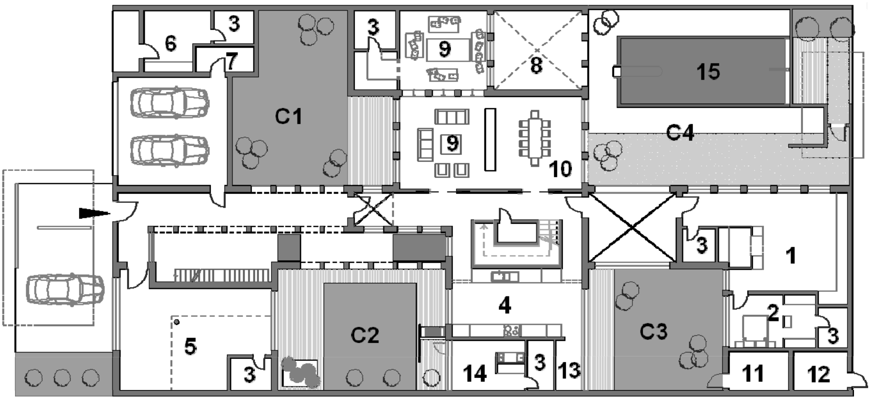

Figure 7: Ground floor plan of the proposed design.

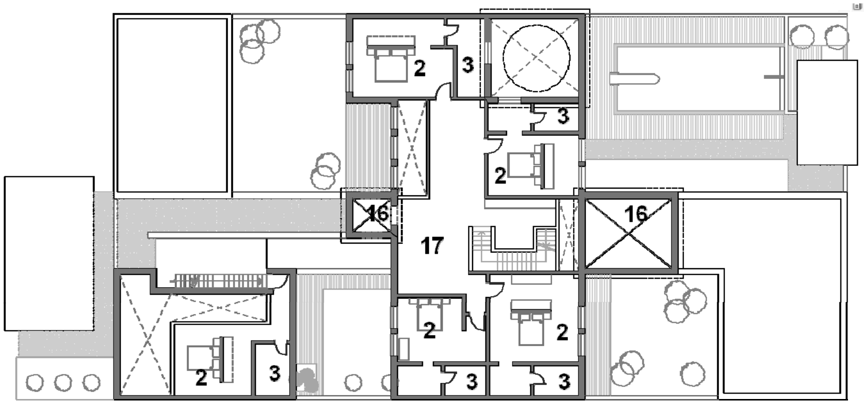

Figure 8: First floor plan of the proposed design.

Key to spaces:

1	Family	9	Living
2	Bedroom	10	Dining
3	W.C.	11	Storage
4	Kitchen	12	Chiller
5	Majlis (guest room)	13	Laundry
6	Driver	14	Maid
7	Tools	15	Pool
8	Logia	16	Wind tower

With the multi-courtyard approach, almost all spaces can be naturally ventilated through cross ventilation. All upper floor bedroom windows open on to the different courtyards, but are parallel to the border with the neighbor. Hence, privacy is provided for bedrooms as well as for the neighbors' courtyards

(Note: the design assumes a front road and back pedestrian road. These roads make the distance to the back neighbors far enough to secure privacy. Minor window treatment is certainly needed)

All roofs are covered with vacuum tube solar collectors (not shown in the drawings) that heat water used to run an absorption chiller (12) that air conditions the residence during the hot season. Locating the solar collectors on the roof not only provides shading to the roof during the summer (environmental control issue) but also makes the roof non-usable and hence secures privacy for the neighbors (cultural issue).

Guest room (5), kitchen (4) and domestic servant rooms (14 and 6) are integrated into the design and are not annexes as in the current design approach. This makes these spaces less exposed to direct sun and hence reduces the amount of energy needed to cool them. Yet the guest room and guest bedroom represent a separate air conditioning zone, making it possible to save energy by switching off air conditioning when the zone is not in use.

As the proposed design is expected to be repeated, various orientations for the windows and courtyards are expected. Wind directions may not be facing the windows' orientation for some units. Two wind towers (16) are therefore provided to capture the wind from any direction and encourage natural ventilation during the temperate season. The location of the towers requires further study to make sure they can actually function as expected. The wind tower, however, has other cultural function as it emotionally links the natives of the region to their historical roots where wind towers were typically used.

6 Conclusion

This paper discussed a design approach and a design example that applies this approach for the integration of both cultural and environmental requirements to achieve multi-dimensional sustainability in affordable housing projects in the Gulf Arab region. The paper investigated these two types of requirements, explained the proposed design approach in contrast to the current and the historically used approaches, and critically analyzed a design example that used the proposed approach.

Acknowledgement

The author acknowledges Ms. Noura Omaira, a native of the United Arab Emirates and an alumnus of the American University of Sharjah for her effort in developing the design example. Ms. Omaira developed the design under the authors' guidance during her final design project as an architecture student at the university.

Reference

[1] Climate Consultant, UCLA Energy Design Tool Group, http://www.aud.ucla.edu/energy-design-tools

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The analysis and design of urban wetland: the Water Garden in Portland and Living Water Park in Chengdu as case studies

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Abstract

Problems caused by urbanization, such as inadequate water content in the urban foundation, ecological imbalance in the soil and the heat island effect, have become issues that people pay a great amount of attention to. Two projects, cited as being successful in integrating urban landscape planning and wetland ecology, are the Water Garden in Portland, USA, and the Living Water Garden in Chengdu, China. An artificial wetland is effective in establishing urban ecology. It may not only solve the problem of the urban water crisis, but also brings a series of good eco-environmental effects, such as the conservation of groundwater, regulation of climate, extending green areas, purifying the air, beautifying a city, and even effectively controlling flood damage, etc.
Keywords: rainwater infiltration, artificial wetland, city ecology.

1 Introduction

With the over exploitation of soil resources in urban development, the length and breadth of land that was utilized for agricultural or forestry purposes or as natural habitats of animals or plants, has been unearthed by architectural changes in many landscape areas. Industrial land, traffic sites and large numbers of concrete buildings, as well as other sorts of land impervious to water, have taken the place of the original land to become the main part of the urban foundation.

This phenomenon seriously affects the natural infiltration of precipitation and causes surface runoff to collect relatively together, which may result in urban floods, serious water shortage in urban foundations and disturb the balance of the soil, thus cutting off the natural cycle in an urban environment. Meanwhile, a fog is formed by exhaust gases that cover the city and traps radiation heat in the air,

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which cause higher temperatures in the city and leads to the formation of an urban heat island. Moreover, the hardening of the urban land leads to ecological imbalance and pollution. All of the above factors focus on what occurs daily.

2 Wetland and water gardens

Lately, in the process of urbanization, wetland resources have become more and more relevant to the city, not only because of their site but also in view of social, economic, and ecological reasons. As a result, the existence of wetland faces great challenges. It warns us to re-explore and re-consider the relationship between humans and nature in the urban development process.

Wetland as a special ecotype first came into research in the 1970s. To be brief, wetland is an ecotype between land and water. The conception of a Wetland Park is similar to that of a small protection zone, yet somewhat different from the general sense of natural protection areas and parks. According to the recent trend of domestic and foreign wetland protection and management, wetlands involve species and habitats protection and ecotourism, as well as environmental education under the entitlement of a Wetland Park.

A Wetland Park can prosper a local economy and offer a site for citizens to recreate and enjoy wetland sceneries. What's more, a Wetland Park may become a special area for local residents to protect their culture formed in the long-term process of living around wetland; it might even become an important element and component of a city's features, distributing benefits to various communities.

3 Water garden, Portland, Oregon, USA

About ten years ago, a water infiltration experiment was conducted in Portland, Oregon, concerning the annual months of almost continuous rain that brought people to conceptualize their original solution that is spreading and being

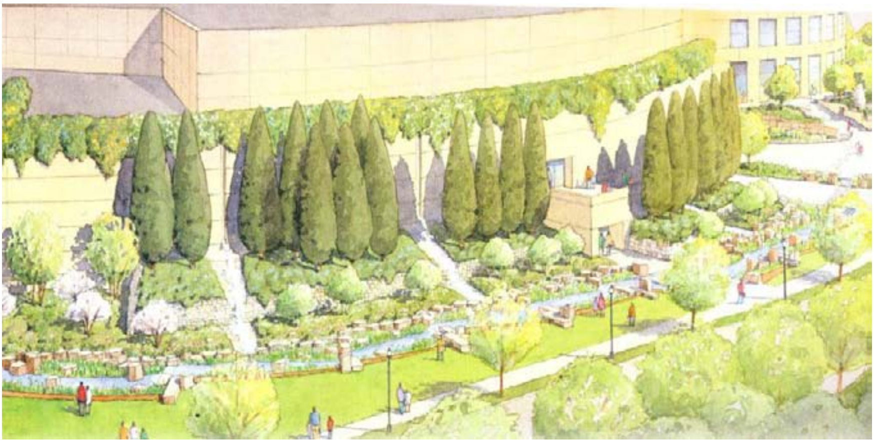

Figure 1: Water garden of Portland.

imitated throughout Portland. In this experiment, Murase, a Portland landscape designer, with his cooperators designed the rain garden, pervious to most or all of the runoff from the parking lot.

This extraordinary rain park, designed by Reed Meyer Architect, can infiltrate water from the roof of the Oregon Convention Center, with the East Bank building being the largest of the tested buildings. In this project, rainwater is collected in the 33.38-acre roof, delivered to the garden through tubes on the conference centre’s south side and then seeps into the ground.

In many parts of Portland, prevention of rainwater problems caused by drainage overload shall be listed as a principal issue. However, this is not the case here. With the Huila River flowing ten meters away, rainwater can be discharged into the river smoothly. The designers’ main goal is to improve water quality by absorbing rainwater and filtrating micro-organisms inhabiting plants,

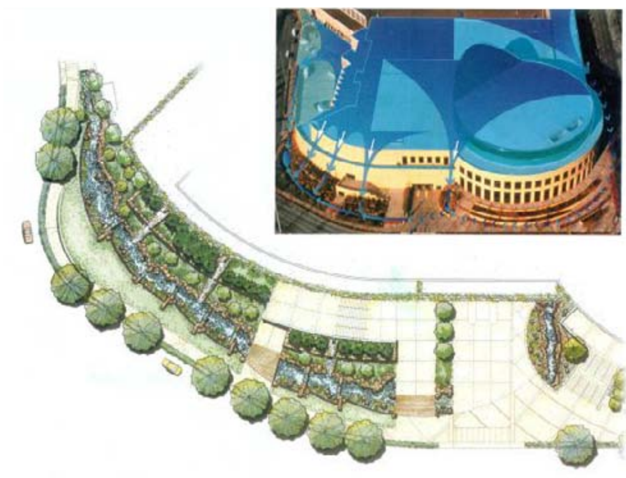

Figure 2: Plan of water garden.

Figure 3: The pool system.

roots, and the soil (the majority of the micro-organisms are motes in vehicle exhaust gases).

The Portland Garden contains the following systems.

3.1 Pool system

Rain garden, through a series of shallow, small waterfalls as well as series-wound pools separated by basalt weirs, slows down the speed of the water flow. When each pool is filled to capacity, the rain water then overflows falling 46 centimetres to the next pool and leaving sediments stably in the primary one. The whole artificial ditch is 969 meters long and 1.8 meter wide on the average. In this way, the pools slow down the speed of water flow and not only save water but also provide sufficient time for water to infiltrate into the underground.

3.2 Stone system

The bottom of the ditch in the rain water park is mainly made up of pale green slate, allowing water to flow smoothly to the top. Meanwhile cobblestones on the edge of the ditch make way for water to infiltrate into the underground while rough basalts walling the ditch create an artless and natural atmosphere. All these vivid and dramatic details combining both the dynamic and the static embody the designer's profound understanding on the law of nature, penetrating discernment and high standard of design. Meyer Reed's design of the main ditch can be viewed as perfect in the composition of the Northwest Pacific stones, embodied in the following five aspects.

Figure 4: Stone system.

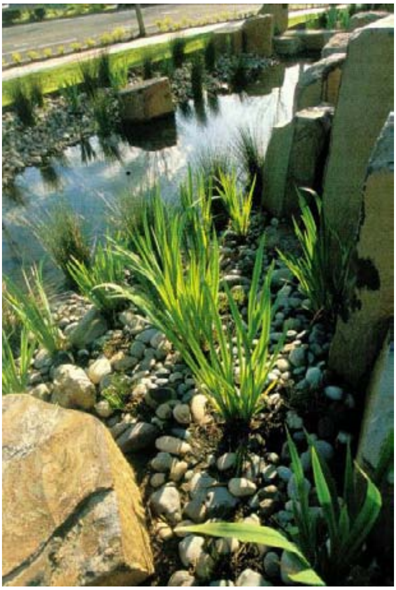

Figure 5: Plant system.

The bottom of the ditch made of hard slates produced in a quarry on the border of Washington and Idaho.

River stones utilized to fix the slope on the side of the whole system come from Montana's colourful quarry, with diameters varying between 2 centimetres and 10 centimetres.

In order to direct the spillway to spread along the length, the origin of the ditch uses a retaining wall, which is built up with solid stones from Montana. Vertical elements along the ditch's length are composed of cylindrical bronze basalts from the district of Moses Lake in Washington. The wide and dry wall as well as the eroding pool of the deposition pond on the building's south apply basalts outside of Camas, Washington.

3.3 Plant system

Lots of aquatic plants are planted on both sides of the drain to create natural ecological environment of artificial wetlands. These plants, growing up from gaps between pebbles and gravels, add a green colour to the rain garden and make it more vivid, lively and natural, but also play the role of a depurative agent, absorbing a variety of harmful pollutants, such as grease washed down from the adjacent roads. In addition, the plants and its root system can firmly fix gravel and sand to prevent against long-time water erosion.

Theoretically speaking, the systems mentioned above are proved to have the capability to allow plenty of water to infiltrate into the underground, especially during short continuous flurries. What is the rate of rain infiltrating into the soil during the heavy downpour? It is difficult to cite convincing data to answer this question, for in practice no one is there to inspect the performance of the system. However, Bill Cop, the project engineer, has introduced plenty of signs such as the phenomena that water does not stay in the pool for a long time, showing that lots of water is being absorbed. In a heavy rain, water overflowing the cascading pools finally influx into the lowest pool. Water runs over the lower pool through a siphon and flows into a 76 centimetre public drainage pipe.

Generally speaking, the rain garden in the extension of the Oregon Convention Center deals with the storm water issue very successfully. It won the annual award for the best water conservation in Portland. As a project combining water, supervision, and celebration; the rain garden deserves wide dissemination as a model.

4 Living water garden, Chengdu, Sichuan province, China

The garden, an appealing urban park that grew out of a larger project to improve the water quality of the Fu-Nan River, covering six acres along the banks of the Fu-Nan River near the centre of the city of Chengdu in western China, is an elegant example of environmental education [2].

Figure 6: Plan of the living water garden.

Figure 7: Anaerobic settling tank.

Figure 8: Anaerobic settling tank.

4.1 Overview

Living Water Park is China's first water theme park of the city's ecological landscape. Water is collected from the polluted Fu-Nan River, and flows through the park's wetland purification system, and finally returns into the river. Battersea Damon, an American artist and water protector, first proposed the conception of the living water garden and won Chengdu's government support. She organized artists as well as water conservancy, city planning and landscape engineers from China, America, and South Korea to design and construct the garden, which covers an area of 2.4 hectares and has great cultural, artistic, and ecological significance.

4.2 The water-treatment system

Wetland Park covers an area of 0.2 hectares, and the capacity of sewage purification is 200 cubic meters each day. It removes bacterial pollutants and heavy metals in the water and returns it to the river. Contaminated water (usually equal to or lower than the water quality GB3838V) is pumped into anaerobic sedimentation tanks from the Fu-Nan River where anaerobic micro-organisms decomposition occurs in physical sedimentation.

The process allows most of the solid matter in the water to accumulate at the bottom or float on the surface, in which part of the solvable organic matter will be broken down into CO2, CH4, H2O and N2 while some of the simple organic matters will be degraded. Water coming out from the anaerobic pond flows through sculptures and into the oxygen tanks, and gets degraded once more by aerobic micro-organisms and then flows into two sets of plant-ponds and plant-bed treatment system. This system is composed of five lively pond plants and 12 plant-beds. Water pollutants, when flowing through the whole system, experience adsorption, filtration, oxidation, revivification, decomposition and gradually degrade into nutrients available for flora and fauna. Water coming from the treatment system flows through several water sculptures and goes into three fish ponds successfully. To ensure that dissolved oxygen in the water meets the needs of the growth of fish, two circumfluence items of equipment are used to return part of the water into the plant pond to increase dissolved oxygen and up-grade the water quality to meet GB3838--88III. Part of the water from the fish pond can be pumped back into the park for landscape use while the rest inflows Paddling Pool and back to Fu-Nan River. Every day up to 200 cubic meters of water flows through the water park. Although this is not enough to change the quality of water in Fu-Nan River, it does allow visitors to see the process in which "dead water" is gradually activated, purified, and finally flows as clean water.

Figure 9: Living water.

Figure 10: Sculpture of living water.

4.3 The art of the garden

The living water park's core park, the plant river as well as the plant-bed group are located in the fish stomach. This shape imitates Huanglong travertine pool group on Sichuan. Wooden trestles set up between ponds are in a rural style. Three fish ponds and fountains as well as paddling ponds show at the tail of the fish. Plant blocks, plant-bed groups, planted duckweed, water hyacinth, pond lilies, etc. which are tested out to have strong water purification capacity, adaptability and visual value, park slopes imitating Emeishan Mountain's micro-climatic and natural vegetation, plant pond, raised beds and restocking of fish ponds with ornamental fish and frog, etc. all form a symbiotic system of the fauna and flora in the water environment. Visitors can see the water treating process and the phenomena that the quality of water upstream is poor which accommodates sparsely any life, for example, no fish but only few duckweed algae and very few plants exist in the anaerobic pool and oxygen tank. With step by step purification, the higher the grade of the flora and fauna, the better the growth of plants, indicating that life and water are interdependent with each other. As the garden provides a living environmental education classroom, it attracts groups of teachers and students. Some parents take their children to gather around the pool for an "eco-environmental class" experience. Some middle school students even apply to participate in water analysis and protection. The living water garden is not the one and only public facility for education on water purification. Water labouring park designed by Lorna Jordan (referring to "the art of cleaning", Landscape

Architecture, Jan. 1997) as well as College Padillas Elementary in L.A. designed by Campbell Okuma Perkins associates, play a similar role to that of the living water garden in Washington and New Mexico. There are also some public facilities on water purification education, such as Wuhan hydrobiology institute.

However, the living water garden wins special achievements since it is located in the centre of the city and has strong affinities. Other projects locating remotely, for example, the municipal waste water factory, cannot provide as sites for everyday entertainment and relaxation while the living water garden can. Water purification details inspire people's instinctive curiosity towards science and natural environment. Sculptures, platforms as well as all other sorts of design elements can be appreciated just for their beauty. Paths in the woods, verdant plants and lawn offer a perfect place for recreation in the city. This park is designed to upgrade citizens' organization to protect the environment. As a result, designers did not try to reforge a natural environment. Visitors clearly know the fact that they are in the artificial water park environment. The conception of the park is close to public art rather than natural protection in most artists' eyes.

Both the rain water park and the living water park are achievements with efforts of landscape designers, biologists, as well as architects. Designers integrate water bodies, introduce favourable elements to the parks, and pay adequate attention to the park's merits and demerits, both allowing plants, soil, as well as water to function properly in urban space. Both parks are upgraded rather than harm the living environment of the districts they're located in. Soil, water, and plants stay in harmony with the people in the city space.

5 The ecological significance of urban wetland

5.1 Wetland increases the capacity of water storage and purification and the water content of the city foundation

Many problems exist in city foundations, such as too much hard ground and serious water loss. As a result, it is difficult for rain to return to earth, causing serious damage to the capacity of natural water retention and resulting in shallow underground water that quickly dries out. Rain gardens and living water gardens can solve this problem effectively: on rainy days, the living water garden and rain garden can store water. They slow down the speed of water with shoals, small waterfalls, and series-wound pools. Moreover, they can accommodate plenty of water that infiltrates into the underground. Water superfluously flows through open ditches and into public drainage pipes, releasing much pressure on the public drainage systems and other municipal facilities.

5.2 Vegetation's role with regards to regulating climate leads to reducing pollution and controlling the urban heat island effect

Because of the impelling force produced by photosynthesis, plant pump can transport most of the water from the roots to the leaves, as water evaporates into the air and takes the heat away. There are sharp differences of temperature between each side of the leaves and the plant pump consumes a lot of heat in the process of transporting water from roots to leaves, enabling effective absorption of large amounts of radiation and heat in cities, as well as regulation of air, temperature, and humidity.

The photosynthesis of plants and its features such as the capacity to store and filtrate water, ability to regulate temperature, radiation, air humidity, as well as its cleansing ability makes an impact on urban management and digestion of city noises which all perform to improve eco-city micro-environment.

As far as the green house effect caused by compaction of urban space, vegetation photosynthesis is effective to regulate concentration of carbon gases and produce oxygen in the centre of cities. Furthermore, vegetation can absorb urban radiation, regulate air temperature and humidity, and improve urban climate.

What's more, vegetation in wetland park has adsorption and absorption capacities and can degrade air pollutants and partly absorb the air and rainwater contaminants containing nitrates or other harmful substances. Vegetation growth which consumes a lot of carbon and releases oxygen, improve urban air quality. And vegetation can effectively muffle noise and reduce the impact of noises on citizens' life. Contaminants adsorbed and clotted can be utilized and absorbed as nourishment.

5.3 The role of biodiversity conservation

A vegetation corridor and an urban water system can be combined as the "urban ecological corridor" of the urban structure. Urban ecological corridor and urban cold bridge coexist and provide fresh air for cities, reducing the impact imposed on cities by urban heat island effect and restoring urban ecological chain which has been destroyed.

Plants and waters in the living water park and the rain garden provide a site for birds and insects unusual in cities to habitat, and extend as ecological corridors. The scene that children kneel, sit, or lie beside water, observing insects and fish living and existing in every wetland park, promoting children's instinct to be curious, though nowadays not many cities offer a water park that satisfies the longing to observe nature directly.

5.4 The educational value of the ecological environment

The water purification system of the living water garden is not aimed at great improvement in water quality. Take the Fu-Nan River for example; the water quality can be greatly improved only by reducing the amount of discharged pollutants. Actually, the living water garden is designed to help Chengdu citizens to realize that the progress of their environmental awareness along with a sense of pride for their city can inspire them to protect the environment and improve it.
In many aspects both of the gardens located in China and the U.S interpret the environmental theme. They are successful and can be viewed as integrated and vivid examples of urban ecological wetland design and have profound influence on people's environmental sense.

6 Conclusion

Urbanization is progressing with accelerated rate in China. In this process, outskirt wetlands such as lakes, rivers, pools and swamps are resources irreproducible once they are destroyed. The protection and utilization of wetland resources, such as to reconstruct them into urban wetland parks or urban ecological parks or other sorts of public green spaces, are favourable for the formation of a city's characteristics.

The living water garden as well as the rain garden in the city can effectively protect, clean-up, and beautify nature and offer citizens a chance to get close to it. They create a good ecological environment for various urban species with comfortable, healthy, safe and nice living conditions for residents. Of course, the anfractuous and ever-changing urban environmental issues are impossible to be accomplished in an action. Final settlement of the problems of cities depends on humanity's reflection and the development of science and technology to the comprehension management of urban environment, recovery and regeneration of the urban eco-virtuous circle. Yet in any case, living water park and rain water garden provide as important examples in the field of creating urban ecological spaces, proving that people can effectively regulate and improve urban development through design as well as by utilizing landscape conception and urban ecological engineering principals. In this way, people can restore satisfying urban environment and living space. Living water park and rain water garden are fruits of the combination of biological science and landscape architecture. They start a revolution in the process of urbanism in "landscape, biological science, and architecture", and provide an effective way in creating urban ecology.

Acknowledgement

I would like to thank Mr. Xingliang Zhang for his company when I visited the living water garden.

References

[1] J, William, Thompson. 2004, 9. Landscape architecture.
[2] Mari, Padova. 2004, 9. Landscape architecture.
[3] H. Takabayashi, M. Moriyama, Urban heat island phenomena influence by sea breeze, AIJ. Technol. Des.No.21, 2005.6

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Floating houses – chances and problems

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Abstract

Floating architecture could be a resolution in the future for current problems in many districts, cities and landscapes. Such problems can be seen particularly in the need for additional housing areas and construction grounds in some countries in Europe and Asia as a result of the growing population and/or the slowly rising sea level in context with the worldwide climate change. Another example for problems of current interest is the use of alternative energies. The water areas of channels and closed down harbours offer good opportunities to create new water landscapes with modern marinas consisting of floating houses and other floating architecture. As this paper will show, this is achieved in the same way that brownfields, such as the pits of former opencast lignite mines, are appropriated for such modern marinas after their transformation into post-mining lakes. Thereby, the possible use of water as an alternative energy source is demonstrated too.

On the other hand there are a lot of new problems with regard to the physical and chemical effects of water on the constructions of floating architecture. New materials and structures must be developed in order to withstand the attacks of waves, sea climate, salts and ph-values. The harmonisation between architecture and nature is to be discussed. Moreover, there are questions about energy and water supply, waste disposal and safety. Three years ago a new project was started with regard to these topics. The first results of the investigations supported by experiments and numerical simulations are presented in the paper.
Keywords: floating architecture, floating houses, post-mining lakes.

1 Introduction

Floating architecture is gaining significance in the wake of increasing public awareness for the new development of bank areas. Rehabilitation of brownfields,

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particularly those of former lignite mine pits, is an expensive undertaking and requires not only technical solutions, but also the generation and involvement of new ideas.

Floating architecture is a possibility for redevelopment after the closure of opencast lignite mines. It can give impulses for regional development instead of pure rehabilitation of a culture landscape. Moreover it offers opportunities for a renewable energy source: water.

Yet there are a lot of additional problems due to the special climate boundary conditions, including wind waves and chemical components of the water in the case of post-mining lakes. There is a need for studying and solving these problems to avoid damage in the future. The paper demonstrates the effect of the corrosion of steel concrete by an unusual environment. Direct attacks of the climate components solar radiation and wind, owing to a lack of neighbouring buildings or trees on the one side and modern glass architecture on the other side, cause an uncomfortable room climate in summertime. The management of energy and water supply and waste disposal must be resolved. The safety of children or animals is also to be discussed. In districts with a cold wintertime the attacks of ice on the pontoons and the safety of walking on footbridges must be considered.

2 History of floating architecture

The global history of floating houses is very complex [1]. The technique and architecture of these buildings all over the world depend on the climate boundary conditions, the culture and the raw materials that were available at the different local places. In Europe the historical situation is relatively simple: At the beginning there were houseboats, which in many cases were originally used as barges. Asia has a much longer history of floating architecture. Yet owing to

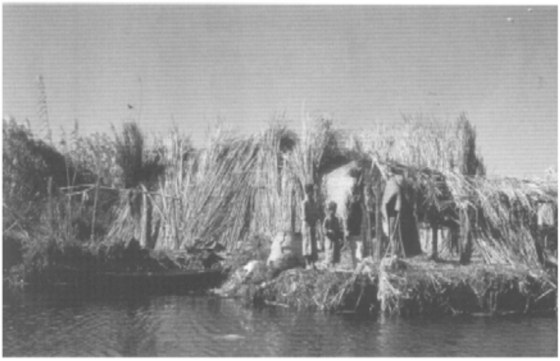


Figure 1: Floating houses and islands of the former “Madan – culture” using reed material.

the Asian mentality, the documentation is very meagre and the records are only rarely available. Figures 1 and 2 show examples of floating architecture from the past and present.

3 Chances

The development of life has taken place likely in the environment of water. There was and still is a fairly affection of human beings for water areas. Now it is possible – and in some cases it even seems to be a necessity – to return to the water places. Nowadays techniques are available to use the properties of water in our favour; this means to use the possibilities of the mobility of floating architecture and the energy resources of the surrounding water areas.

In the following some prospects in context with floating architecture are briefly presented.

3.1 Use of alternative energy resources

The surrounding water can be used for heating and cooling throughout the year. For this we can utilise the techniques of evaporation, heat pipes or running water through the building envelopes by using the buoyancy and minimized pumps that are available, see the sketch in figure 3.

Figure 2: Floating house erected in 2009 at a post-mining lake.

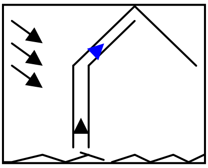


Figure 3: Moving water in the envelope parts of floating houses by means of the difference in density of water caused by the different solar radiation on the facades.

3.2 A new feeling

The direct experience with the natural environment of water is the base for an attractive property. Many people would like to spend their life in a floating house.

3.3 Additional construction ground

Floating architecture will be a resolution for the future lack of construction ground as a result of the growing and expanding population of the world. In addition, in context with the rising sea level, the marinas of floating houses could be an alternative construction ground, e.g. in The Netherlands and some countries in Asia.

3.4 New materials and innovative construction

The construction and materials of floating architecture are subjected to attacks of water and climate components, such as wind waves, salts, solar radiation, humidity and so on. In the sense of sustainability, new materials and composites of them with innovative properties are to be developed and tested.

3.5 Mobility

One advantage of floating architecture over usual buildings is its mobility in view of changing positions or local places. By this the owner can look for other places as desired and to his liking. Besides the subjective component, the mobility is an advantageous property with regard to supply and waste disposal and regarding the optimization of the solar energy inputs.

3.6 Revaluation of brownfields

The use of floating architecture in the areas of old docks and post-mining lakes revalue the cities and landscapes in numerous towns and districts all over the world. The flooding of a post-mining lake is a long-term and complicated process.

Figure 4: Marina animation of so-called gothic floating houses at the lake of Geierswalde in the Lusatian Lakeland near to the border of Poland, Germany.

Figure 5: Revaluation of former opencast mining landscapes in Lusatia, Germany: initiated by the international building exhibition IBA “Fürst Pückler Land”.

(a) (b)

Figure 6: Floating bridges of the diving school on lake “Gräbendorfer See” during wintertime. German district Lusatia, near the border with Poland.

4 Problems and risks

On the other hand there are a lot of problems due to the special environment of water and its physical and chemical properties. Some problems of floating houses and their swimming bridges are given below.

4.1 Local climate

The construction is subjected to stronger external loadings due to the increased attacks of wind, wind waves, driving rain, ice and solar radiation. Floating houses should be reached safely in winter time too, figures 6, 7.

Figure 7: Frozen lake “Partwitzer See” in the German district Lusatia.

Figure 8: “Ar-che” design with a comprehensive glass architecture [2], animation of the floating house according to figure 2.

4.2 Indoor climate

There is no problem to improve the heat insulation in the cold season in case of strong winter climate e.g. by an increased intensity of wind. But during summertime innovative solutions are necessary in order to guarantee a moderate indoor climate. Users demand a comfortable atmosphere in spite of more and more glass architecture (figure 8), no plants and neighbouring buildings, reflected radiation and difficulties with use of blinds caused by more and intense wind.

4.3 Corrosion of materials

The additional attacks by chemical and physical components of salts, ph-values, ions etc. and the special components of the local outdoor climate effect an intense corrosion of materials. Figure 9 represents the damage at a concrete, which set in already two years after its installation at the lake “Partwitzer See”.

Figure 9: Concrete corrosion at the floating bridge of the floating house according to figure 14.

4.4 Algae determination

The microbiological growth of surfaces is a topic worldwide [3, 4]. Owing to the improved thermal insulation of envelope parts of buildings the external surfaces tend to a natural state. Currently and in context with the investigation of floating houses by the authors the systematic measurements of algae are underway.

4.5 Energy and drinking water supply, waste disposal

The supply of a floating house with drinking water and energy by electricity, gas or district heating as well as the disposal of the property are possible both by decentralized and by centralized systems (e.g. see table 1). They have to comply with the current environmental law and building guidelines.

5 Selected examples

5.1 Alternative energies

5.1.1 Use of the heat pipe principle

In different versions it is possible to use the phase change energy for the transfer of heat energy. For instance figure 10 demonstrates the heat pipe as a protector against attacks of ice loading in wintertime.

5.1.2 Envelopes with flowing water

With regard to the sketch in figure 3 the graphs in figure 11 show the difference of pressure caused by the difference of temperature between the facades.

5.2 Mobility of floating houses

The advantages of a mobile building have a subjective side (everybody can choose a place according to his desires, ideas and technical references) and an objective side (by means of the possible position changes a maximum input of

Table 1: Comparison of different sanitation options.

	catch basin onboard	**small absorption bed onboard**	wastewater treatment plant near the water at the bank (semi centralized connection)	**central connection**
technical requirements				
plant construction flexible connectors	-	-	●	●
weatherproof	-	-	●	●
antifreeze/ heating	-	-	●	●
anti-abrasion-material inside outside	●	●	● ●	● ●
UV- protection	-	-	●	●
heat resistant material	●	●	●	●
corrosion protected	-	-	●	●
leak warning system double-wall system	 ●	 ●	●	●
noise insulation	-	●	(●)	(●)
appendix connections outside the building	●	●	(●)	(●)
fail safe system	-	●	-	-
system level security	●	●	-	-
continuous operation necessary	-	●	-	-
multiple usage of the treated sewage	○	(●)	○	○
weight raising of the pontoon	●	●	○	○

Assessment:
● : yes
(●): yes, under certain preconditions or restrictions
○ : no
- : not necessary

Figure 10: Test stand for the dolphin model, constructed as a heat pipe.

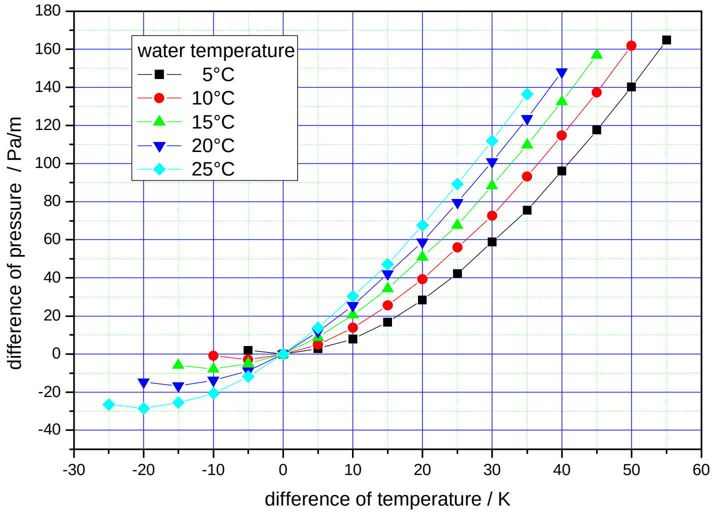


Figure 11: Differences of pressure between facades of one building with and without solar radiation.

solar energy can be reached). A concentration of the infrastructure on one centralized location in a large district of several lakes connected through so-called channels reduces the costs of supply and waste disposal [5].

5.3 Materials

5.3.1 Reinforced concrete pontoon

Figure 14 shows the attacks by wind-waves to a floating house on a post-mining lake flooded with water almost completely.

(a) (b)

Figure 12: Fitting of heat exchanger in the pontoons for cooling and heating of the floating house according to figure 2.

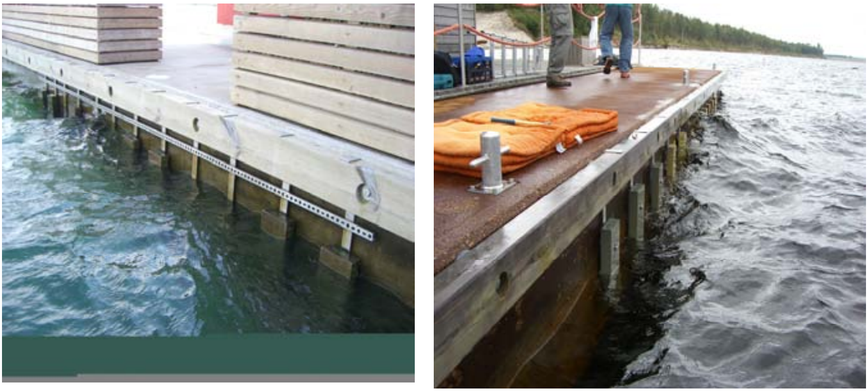
Figure 13: Map of connected lakes in the so-called Lusatian Lakeland.

Yet the dynamic loading of the concrete is not the only. reason for the damage. Above all things a low level of the ph-value causes a strong corrosion (see figure 16). Investigations for new concrete formulations and innovative composition of concrete are underway.

5.3.2 Steel pontoon

Steel pontoons must be overcoated with an additional surfacing of a high quality. Of course this is necessary if it is planned to put the pontoons into post-mining lakes with a ph-value measured according to figure 16.

Figure 14: Waves at the lake “Partwitzer See” – a former opencast lignite mine in the Lusatian Lakeland.



(a) (b)

Figure 15: Investigation of concrete samples subjected to different areas (water, air and fluctuating zone between water and air).

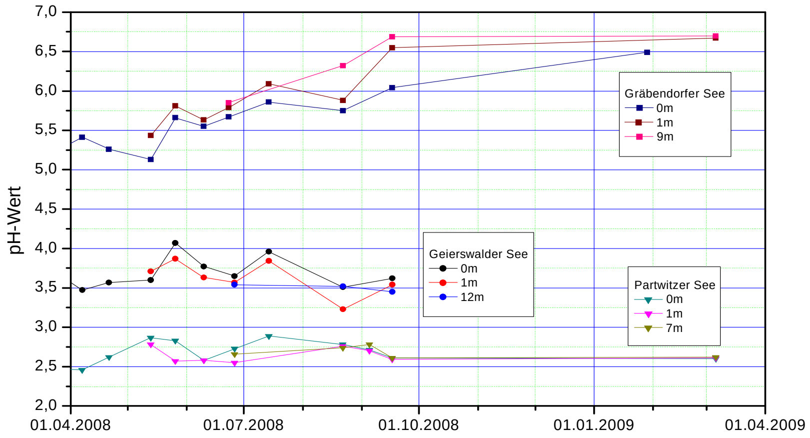


Figure 16: Course of the ph-value of different lakes in the Lusatian Lakeland.

5.4 Room climate in the warm season

Figure 17 shows the issue with regard to human thermal comfort [6].

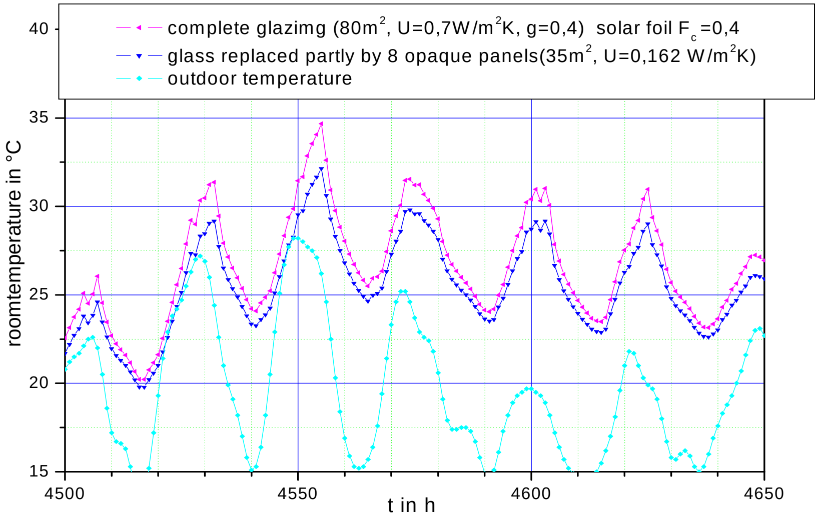


Figure 17: Course of the room temperature of a floating house according to figure 8.

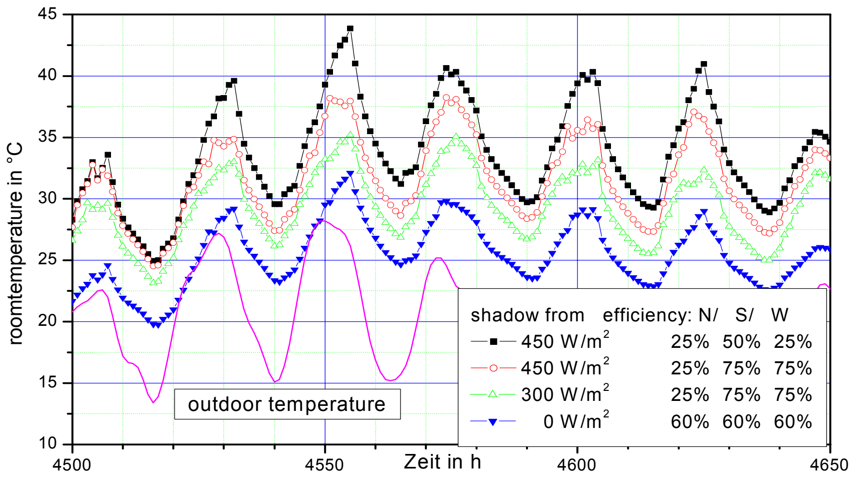


Figure 18: Floating house according to figure 8, glazing replaced partly by 8 opaque panels shaded by 25% bright curtain, 50% indoor blind, 75% outdoor blind and 60% solarfoil applied to the interior surface of the window glass.

References

[1] Giebler, S.: Master Thesis "Schwimmende Architektur: Bauweisen und Entwicklung", Brandenburgische Technische Universität, BTU 2007.

[2] Project: Wil/Design K. Wilde; concept: steeltec37 T. Wilde; manufacturer: Wilde Metallbau GmbH, Germany

[3] Stopp, H. Strangfeld, P. et al: Algen auf Fassaden, Bauphysikkalender, pp. 561-644, Verlag Ernst & Sohn, Berlin, Germany 2004.

[4] Stopp, H; Strangfeld, P.: Energy saving and the hygrothermal performance of buildings. Conference proceedings, III. Latin American Conference on Comfort and Energy Efficiency in Buildings, Curitiba, Brazil, November 2003.

[5] Floating Mobile Architecture, documentary of the international competition 2008, Internationale Bauausstellung (IBA) Fürst-Pückler-Land 2000-2010.

[6] Stopp, H; Strangfeld, P.: "The hygrothermal effects of external and internal wall surfaces", 4th IBPC, Istanbul, August 2008.

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Educational ecological architecture

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Abstract

"Sustainability," being the buzzword of the 21st century, is particularly challenging to the current generation, now in their early teens, which grew up with a childhood of lackadaisical use of fossil energy. This generation, which will soon be leading the world, has been inappropriately labelled the "generation me" and is expected to prove its successful transitioning into "generation p [ostfossil]." If the young emerging architectural professionals choose, they can be the mission group in helping reduce the overall fossil footprint that buildings contribute to the world by 40%. The young professionals, however, must be proactive because developers and contractors increasingly target low or no emission structures. While their energy performance is undoubted, their architectural performance is questionable. An architecture student at the University of British Columbia recently and most appropriately addressed this dilemma in a much more unplugged way, "...you guys screwed up everything and we are supposed to fix it...." This paper investigates two major missions: first, and most important, how to get the upcoming architectural generation p(ostfossil) excited about the topic of bioclimatic design, and second, where to begin in the future to create a sensitive and intuitive understanding for both the poetics and pragmatics of eco- and archi-friendly architectural design.

Keywords: K12 design, bioclimatic educational design, developing aid design, generation (p ostfossil), brettstapelbauweise, timber modification technology.

1 Introduction and analysis

As an international collaborative and cross-cultural study, authors Dr. Sandra Costa Santos, Gerold Klein, and Associate Professor Martin Despang have identified “human event and activity in space” to have potential for an improved sustainable life to be built from the bottom up. By exposing young people as early as possible to a living in balance with nature and the elements in decency and style, a solid societal basis for bioclimatic regeneration of the built world is achievable.

The architectural building type of educational design serves as a vehicle to transport the eco- and archi- friendly value system, and becomes a means to widely distribute and deeply anchor these values in society from an early age.

The synergistic and effective method to achieve the injection of values into society can be seen in the immediacy of architectural design: building carbon neutral kindergartens and schools, as well as using the academic freedom to push the architectural and environmental bar as high as possible. By utilizing this creative knowledge to consult and coach young architecture students to design these facilities, the students are then considered to be the best experts, as they employ sensitivity or the essentiality of bioclimatic spaces and places as early as possible in their careers. This paper uses both academic and professional case studies to illustrate this pedagogical method. Dr. Costa Santos will explain her internationally respected pedagogies, along with her recent third year studio design probe of a local school in La Coruna/Spain.

Following, the paper will cover DLR / Omaha, Nebraska, as the leading designers of schools in the USA, and their collaboration with Professor Despang’s University of Nebraska – Lincoln’s students’, for the design of a School in Gulu, Uganda. The paper concludes with a critical assessment of the ILMASI school for mentally disabled children in Garbsen / Germany, designed by Despang Architekten, which utilizes innovative, typological, technological and tectonic strategies relating to solid wood and thermally modified timber, which have been critically reflected on and researched by Dr. Costa Santos.

2 Educational case study: CESUGA Spain

The primary school is the first major design project that third year students have to tackle in the School of Architecture in CESUGA [2]. The school follows University College Dublin’s program of studies with some variations required by the Spanish government. This is a five-year academic course, with a completion of a bachelor degree after the third year. Therefore, the third year is an important milestone for the architecture students to prove a certain level of competence and expertise. The school’s culture is strongly studio-based, understanding the studio not just as a place for design, but as a place for comprehensive design where much of the knowledge learned by the students through the lecture series has to be applied, tested, and explored through their own projects. The lecture series covers building technology, structural design, building services, architectural ecology and conservation, and history and theory of architecture. The third year studio program brings students closer to the architectural character and representation of institutions and collective and civic architecture by managing issues of scale, landscape, territory and graduation from private to public space in society. The students have to develop the ability to consider the needs of the individual and those of the collective and have to recognize the expressive public nature of collective buildings by representing in the city the values and ideals of the community. Following our school's ethos, the design studio program is strongly based on the idea that structures, building technique, ecology and understanding of materials are part of the design process. The students are asked to use a broad range of skills and techniques, including hand and computer drawing, model making, and other means to make legible their design approaches.

Over the course of seven weeks during the 2008-2009 term, the students had to think, explore, and investigate to design a primary school in Ourense. Ourense has a population of over 107,000 inhabitants and is located in Galicia along the river Minho valley in northwest Spain. Considering the huge amount of gold that the valley used to have, it was called Auriense, meaning "the gold city", by the Romans who built a bridge over the Minho (this was later rebuilt in the 12th century). Thus Ourense became an important city of Hispania until the shortage of gold in the river. Due to its strategic position, this bridge held a lot of traffic during the Middle Ages. When the railway came to Ourense in the 19th century, the development of the city would point towards retail and administration. After the Spanish Civil War from 1936-1939, Ourense's growth admitted strong immigration from rural areas. Today, the city remains as an administration and trade centre. Its local microclimate offers humid, cold winters and humid, hot summers. The site for the primary school was located along the Minho River, between the Roman bridge and the contemporary Millennium Bridge. During the duration of this exercise, the pedagogies applied by the tutors pursued a series of objectives including the understanding of place, spatial ambition through the development of the architectural program, and the integration of structures, construction, and ecology. The methodology used in the studio offers the

(a) (b) (c)

Figure 1: (a) Ourense primary school; (b) organization in plans; and (c) sections.

students some indication of direction, leaving students to find their own solution based on group and individual work, group reviews, precedent studies, discussions with school teachers, and critiques with invited professors. Associate Professor Martin Despang kindly offered his experienced views on schools and joined in the studio tutorials in January 2009.

The first step the students are asked to take is the site analysis. The site analysis runs along seminars on Ourense within the history lecture series. The students begin with a site visit that allows them to take data such as photographs, notes, sketches, survey elevations, plans and sections. This analysis is followed by various studies that aim towards grasping the site's morphology, the way it is influenced by (and influences) its environment, its role within the community's activities, and its needs and values. This step should naturally lead the student to propose a site strategy.

Once they have analyzed the site, they study precedents and visit schools, where they have the chance to hear from the teachers how schools work or should work. By this point, they should be in a position to work with the program they were given. Working with the program involves a degree of critical thinking since the question is not as much meeting a required accommodation as it is achieving a good and inspiring environment for the children and the community in which they belong. Third year students are expected to translate a given brief into added value for the school users. Understanding the brief allows the students to develop their site strategy into a building strategy or conceptual design.

During the following weeks, the students are asked to develop their project through several scale jumps and assess it during interdisciplinary studio seminars (structures, construction and ecology). At the end of this process, a successful student project will offer an architectural educational space based on a sensitive understanding of construction, structures and ecology. The methodology used in the studio proves that students asked to "work with and for" the site from an early stage helps deliver sensible spatial solutions in terms of community interaction, resources, and construction. Integrating technology and ecology within the overall project strategy not only adds spatial value (making the whole proposal more sound), but can also increase energy efficiency

Figure 2: Versions and options of eco-tonics.

(enhancing good natural lighting, helping crossed natural ventilation and using materials with thermal mass, for instance). Educating young architects-to-be at an early stage on taking responsible bioclimatic decisions can prove vital to preserve our environment.

3 Educational case study: Jesuit School/Gulu Uganda Africa

Through DLR Group's [3] relationship with Creighton Prep, a rapport was developed with Father Tony Wach. As a result, DLR´s passion for K-12 design and the intrigue of an unfamiliar culture and environment was revealed. A team was formed to pursue Father Tony's vision of providing educational opportunities for the youth in northern Uganda/Africa in form of a school to be located in the southeastern part of the country, four miles east of the city of Gulu.

3.1 Society of Jesus (Jesuits)

The tradition and mission of the Society of Jesus (Jesuits) is "to be in solidarity" with suffering brothers and sisters, particularly through prayer and spiritual ministries, advocacy, and financial assistance. In the northern region of Uganda, 20 years of terrible insecurity has broken down the culture, family life, morale, health, economy and education. In accordance with their mission, the Jesuits plan to construct a boarding school to accommodate 1,200 boys and girls. The curriculum will consist of liberal arts and vocational schooling, working towards repairing the broken way of life in the area. Given the remote location, the campus will use sustainable strategies such as on site brick production, solar energy and water harvesting for farming or gardening, all together maintaining the quality of life for its residents.

UNL strives to find studio projects that are relevant to the global condition, along with working with firms to expose the students to architectural practice.

The Project was welcomed by the University of Nebraska-Lincoln's College of Architecture [1] Dean Drummond and embraced by Professor Despang who, in his home country of Germany, is a registered architect and partner of Despang

(a) (b) (c)

Figure 3: (a) Andy's socializing; and (b) private spaces; (c) Kelly's arboretum.

Architekten [4]. Despang Architekten, located in Hannover, Dresden and Munich, Germany, is renowned as an innovator in K-12 and sustainable design, thus making Professor Despang a good partner with DLR Group. The studio culture instilled by Professor Despang and Professor Erhard Schütz is one of a lab environment focusing on the exploration of new technologies and materials. Given DLR Group's expertise and experience, they were teamed together, incredibly excited about the possible learning opportunity.

DLR, the leader in K-12 designs in the USA and an emerging innovator in sustainability, wished to share their expertise with future architects at an academic level. DLR Group principal and Representative Gerold Klein worked side by side with Professor Despang in guiding the students through their individual research and design process. The interaction showed the students that design could be their future in a way to make a difference in the world. Klein's vast experience with DLR Group showed to be very beneficial to the students during the exploratory process, especially since he was making them aware of the pragmatic as well as poetic aspects of design, encouraging them to design in synergy of both.

The fundamental challenge and experience of the studio for all participates, mentees, and mentors was to step out of their cultural comfort zones, from the point of view of comfortable developing countries and cultures with amenities and comfort, down to an opposite environment which lacks the basics of human existence. It became an investigation of the "essentials", questioning how much an individual and its solidifying communal entity absolutely needed to provide decency and spatial dignity. In the region of Gulu, this primarily meant shelter from the harsh extremes of the elements of sun and rain. Each student had to take into consideration the culture, climate, typology, vernacular, and materiality. The ultimate goal was then to select tectonics and materials that were plausible for either being locally available or brought in with careful consideration of the appropriateness in terms of effort, cost, and carbon footprint. The students and instructors, coming from a culture of "plenty", struggled with this and were quickly aware of their thoughtlessness in their own capitalistically driven context, where the way they build is not driven by logical and resource related

(a) (b) (c)

Figure 4: (a) Chris's canopies; (b) Sara's mounts, (c) Nate's communities.

conscious parameters, but rather the forces of unrestricted markets. These markets then sell products like natural stone, for example, an attractive but yet cheap building cladding material; the natural stone, however, comes with the high price of being carved out of the earth by child labour in underdeveloped countries and the price of shipment with extreme carbon footprints. This case is similar to privileged people buying new laptops, their old one being shipped to Africa where underprivileged, young children burn them under the open sky to extract the metal parts and sell them back to the developed world, wasting their health and drastically shortening their life expectations during the process.

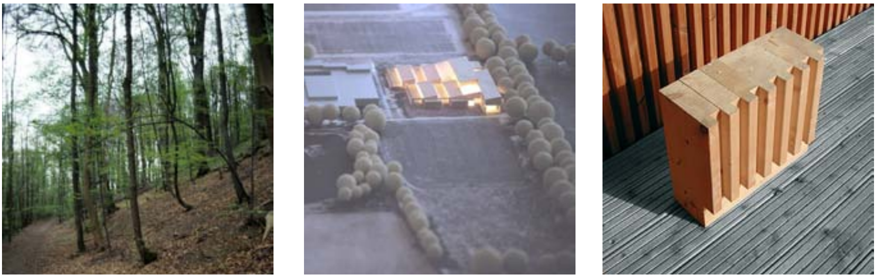
The studio therefore began to realize that thoughtful design for the minimum demand with the minimum means could be a method that could possibly be meaningful beyond the Gulu School. This realization would be an educational impact for all of the students.

All of the designs for the Gulu School provided sun and rain protected spaces as well as the incorporation of thermal mass. This combination can provide the decent physical background to allow the users to be intellectually and spiritually challenged to become better-educated citizens who continuously use their improved skills to elevate the societal quality of life. The school design to this broadened extent has the power to fundamentally change society for the better.

By the end of the studio, the students left with a new appreciation for the profession’s potential for intercultural, ethical, and humanitarian responsibility as well as the architects role to help by sharing the excellence of their own culture while at the same time respecting and interpreting the local culture. The project was a great learning opportunity for both academia and the professionals.

4 Professional case study ILMASI School/Garbsen Germany

The ILMASI School [5] by Despang Architekten can be seen as an assessment control application of the pedagogical and societal goals of the academic methodologies at CESUGA and UNL/DLR in Gulu. The task was to design a built environment that is responsive to the needs of a just begun post fossil 21st century in making it as bioclimatic in its broadest possible way of life cycle consideration. At the same time it aimed to achieve the highest building culture

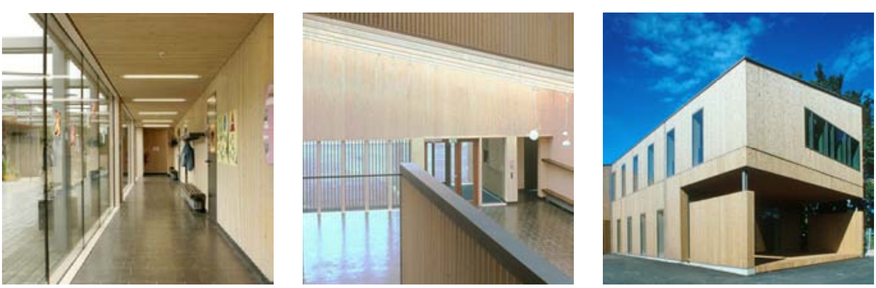


(a) (b) (c)

Figure 5: (a) Concept nature; (b) concept macro; (c) concept micro.

achievements, which seek synergy of environmental and architectural excellence. In terms of its social responsibility, as much as the school near Gulu provides decent space for the poorest and most underprivileged, the ILMASI does this for an equal group of people in the developed country of Germany who need the most and special care, as these are mentally disabled children.

ILMASI stands for “integrated learning with all senses”, which describes the pedagogical idea to stimulate these children in a multi-sensatory way, in direct response to their needs to be addressed beyond the visual sense—which is what school design and architecture conventionally does in contemporary educational design. Design decisions regarding the structural, mechanic, tectonical and materiality choices in K12 design are supposedly made by parameters of efficiency and effectiveness, which usually leads to the most streamlined results without addressing multi sensitivity but rather a “value engineering” in bringing the down to the profit driven basics as opposed to the essentials of complex simplicity. Although under a conventional capped budget for this civic building type, the search, in a way very similar to the Gulu School, went for a system with one essential, locally available material which could do it all, including catering to the 5 senses and assuring a very practicable low maintenance and utility cost reducing building at the same time. The idea was born out of the analytical question presented to the school board asking what the ideal place for the children to be in was. Their quick response was a forest, because of the variety within a systematic structure and the ability to soothe air and soul. The architectural abstraction became a structural system of surface notched wooden boards nailed together to structural slabs, which were anonymously applied to walls and ceilings in a seamless manner to create the inner surface.
In terms of the multi sensitivity, sound is absorbed by the louvered texture, whereas light and shade play with the eyes. Walking by and touching the thermal mass balancing wood resonates in the fingers and the humidity absorbing nature provides a gentle smell and occasionally occurring resin can even be tasted.



(a) (b) (c)

Figure 6: (a) Walk in the woods; and (b) internal clearings; (c) architecturalized.

Against prejudice, using wood in an intensive way is sustainable because, as a local renewable resource, it encourages the replanting of trees and forests, which helps convert carbon dioxide into oxygen.

In terms of the embodied “evidence base design” factors most valuable trait is that at the recent fifth anniversary a significantly improved physical and psychological/spiritual health improvement of the children was confirmed. This can be credited to the inclusive tectonic system in collaboration with the systematic layout that maximizes exposure to daylight and sun in parts through UV admitting ETFE roofs and the injection of outdoor courtyard spaces with fresh air exposure.

The client, being the Regional Municipality of Hannover, also reported that the utility cost of the building was significantly low due to the thermal properties of the wood and the extra insulation behind a maintenance free rain screen of TMT (Thermally Modified Timber), which keeps the energy inside through closed north facades and increases passive solar gain with optimized southern solar exposure. To the long-term surprise of the client, the exposed, solid wood wall surfaces have shown a significantly lower maintenance demand than the conventional intent of efficiency and effectiveness of the selected plastered walls. The multi-sensual qualities have also more than outperformed common brick and CMU wall systems. Although the building costs have been in the same range as the comparable solid, stereotomic buildings, the maintenance costs have been significantly lower and the comfort and appreciation level exponentially higher.

The ILMASI School has proven itself to be unconventional and nontraditional with cutting-edge conceptual and materialized design strategies, customized to the specificity of the educational clients needs as a valid design method in the field of educational facilities. The project’s wide recognition and reception by an international research community, kindly including Dr. Costa Santos with relevance of typological wood technology with application of her PhD, had motivated Despang Architekten to continue to work likewise with a variety of following projects: an all day school addition in exosceletonic concrete, a kindergarten in cellulose insulated light weight wood, and a currently under construction thermal massing, earth burned concrete kindergarten for Germany’s oldest University of Göttingen.

5 Conclusion

Educational architecture is the very best investment for the future because of the sensitization by young people for both ecologically and architecturally performing spaces and places having the potential to be an essential impact on the global environment.

Educational facilities, besides dwellings, are most personal and emotional in terms of occupational intensity, providing them with the most power to positively influence people’s attitude towards bioclimatic principles. Whereas dwelling types exclusively reach the individual only, educational facilities typology inclusively addresses many members of society and has a tremendous potential of pedagogical capability in terms of their way of teaching about post fossil living through the way the buildings are conceptualized. The method to let the youngest generation of terrestrials grow up in built environments with the lowest carbon and largest architectural values possible leads to a natural positive bioclimatic conditioning, which enables them to intuitively operate on an environmentally progressive basis.

Strategically speaking, the most effective ideal is to have the current generation of young architects in training engage in the typology of education design, so that their future children can grow up in bioclimatic environments, widely spreading this progressive post fossil lifestyle. The necessary motivational means to get them excited to look back that early into their lives at their just escaped childhood is to allow and encourage the design of educational buildings to be more critically cutting-edge and as fun as other building typologies.

Maybe then the synthesis of the education of ecological architecture through the foundation of ecological educational topology will have a multiplying effect of the soon to be disciplinary generation p[ostfossil] in charge, taking effective and joyful responsible leadership for their millennium.

References

[1] University of Nebraska College of Architecture, http://archweb.unl.edu
[2] CESUGA - University College Dublin, www.cesuga.com
[3] DLR Group, www.dlrgroup.com
[4] Despang Architekten, www.despangarchitekten.de
[5] www.imagineschooldesign.org
[6] Institut für Holztechnologie Dresden/Institute for Wood Technology Dresden, www.tmt.ihd-dresden.de

Sustainable development and heritage: "trabocchi" and the rules for building on the coast

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Abstract

The purpose of this study is to promote tourism as a basis for the sustainable development of the territory, in particular of the Teatina coast in the province of Chieti – Abruzzi. This study is focused on the maintenance and recovery of the "trabocchi" (ancient wooden fishing huts built on stilts) which are paradigmatic instances of the building praxis of the "genius loci". The study is aimed at pointing out the role played by these constructions in determining conditions for sustainable development in relation to bathing facilities. We must consider that the elements on which tourist promotion of the territory is based can be easily put aside in a project which is not understood in all its implications and aspects. In these highly vulnerable areas, tourism has an impact on both physical and image development and might be relevant in causing strong anthropic pressure on the natural environment. The improper use of the territory can quickly cancel cultural memory and threaten one's sense of history, giving space to a landscape which is homologated or even alienated from the false icons of local material culture. The study we present here is the result of a commission of the Province of Chieti to carry out an integrated project where each action (exploitation of nature, bathing facilities, link with the urban and inland agricultural, recovery and re-use of emerging manufactured products for services, sustainable alternate mobility) is strongly connected to the others, and each choice has to be valued according to the results in the other sectors.

The first part of this work involves formulating rules to build new "trabocchi" and determine the elements needed to define the required surroundings. In short, these new constructions must be located within acceptable "scenery" that reflect

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their traditional types of natural location, and therefore provide the basis of a new pattern of tourism and the individuation of sustainable indicators to set compatible facilities on the above mentioned coast.

Keywords: sustainable development, coastal environment, trabocchi, heritage.

1 Introduction

Starting from the recovery of a typical structure constituted by original, manufactured products, the aim of delineating the parameters that must be set for the sustainable development of a specific territory necessitates a brief report on these products, as well as a critical overview of the state of the art. The *trabocchi* are constructions for inshore fishing which could have taken origin in the XIII century, surely attested in the XVII century; they represent a demonstration of genius loci which make full use of local material resources and encouraged the "transfer" of technologies in an appropriate way; this is the reason why they will be considered a useful instance of "sustainable practice" for the building of manufactured products on the sea. The Teatine coast is characterized by the presence of a remarkable number of *trabocchi*. A structural analysis of them shows the elements which compose the system (footbridge, flat of fishing, stabilizing grid, fishing device, functional equipment); furthermore, it is possible to recognize the evolutionary process which constitutes one of the characteristics of such manufactured products. One especially refers to the changes due to the transfer of technologies (for instance the one that happened in concomitance with the railway building) and the modifications due to the change of use, now acting, ranging from fishing to "service" of the bathing tourism system; in the first case, mutations prevalently regarded the technical-constructive device, in the second case they take into account the dimensional morphological system for reasons connected to the possible widened fruition and, therefore, to the necessary security.

Until the 1970s, the interventions of maintenance, made by the same men working on the *trabocchi,* did not determine, on the whole, relevant changes in the system arrangement. The documentation of those years still shows the *trabocchi* as "emanations" of a place sufficiently uncontaminated from strong urbanization. Their anthropological context was mainly limited to rare

Figure 1: Images of the trabocchi along the Teatine coast.

settlements, little villages and isolated villas which progressively had been integrated into a natural and agricultural landscape without producing a break with tradition; the railway itself had been "overwhelmed" by the surrounding landscape, thanks also to some literary narrations (See G. D'Annunzio, *Trionfo della morte*, 1894) which also contributed to a representation of the railway as a "character" of the landscape itself. Conversely, in the following years the socio-economic evolution has showed its negative aspects also in this territory: a sudden urban growth was being achieved without considering any environmental consequences; the choice of technologies and building materials extraneous to the local culture; the progressive shift to a mass tourism which is unlikely to be supported by such a "fragile" natural environment as the territory above mentioned, in terms of the configuration of its landscape, as well as of its geological consistency. It is, in particular, little more than 20 kilometres of high coast with high hydro-geological risk for a particular vulnerable cliff. During this time of rapid growth and transformation, the *trabocchi* were prevalently abandoned, the people leaving to seek more profitable work.

In more recent times a politics based on specific local interventions has allowed a recovery process of this characteristic architectonic-cultural inheritance so as to induce various territorial corporations to develop appropriate projects; the Abruzzi area, in particular, enacted two laws to establish proper safeguards for the property established by the so-called "spontaneous architecture" promoting, for instance, the recovery and the increase in value of the *trabocchi* (Regional Law of December 1994, n.93: "Arrangement for the recover and increase in value of the *trabocchi* of the Teatine coast"). But if on the one hand local institutions have confirmed their role as guarantors of the cultural property value represented by the "Genius loci", on the other they have not yet devoted all their resources to promote the image of this area with an advertising campaign that would present the "coast of *trabocchi*" as a "recognizable mark". The project of the shifting of the railway line constituted the further reason of the rediscovery and reutilization of this property. This is because, until now, the railway which ran along the waterline has preserved this portion of coast from the savage tourist colonization impeding the use of the coastal zone.

2 The knowledge of *trabocchi* and of their environment

It is necessary to know this heritage in order to take a census that will help to individuate any manufactured product in its context. However, the general knowledge of the construction is crucially important to identify all the significant documentation relevant to the realization of the interventions. For every overflow, "specific registry cards" were then set up, with the aim of starting" reflections founded on the destiny of the property.

Three specific objects are defined:

- the conservation of the "local" insertion identity; in this sense, the enrichment of the identification data with information of geological type (sea bottom) and climatic-environmental (currents and waves) turns out to be important in explaining the conditions in which buildings are placed with the aim of noticing the role in the breakdown determination and the corrective clause; for instance, to improve the foundation systems and choose the materials more appropriate to the solicitations of the sea climate; the conservation of the local constructive identity implied in the recurring geometries, the typologies and the dimensions; while registering information on the recurring dimensional data of the covered surface (with the relative orientation) and the configured data and typological (with a summary of the minimum and maximum dimensions of the manufactured products and the constituent spaces which are normally used to meet the demands of

Table 1: Survey schedule.

<table>
<tr><td>Progressive number</td><td colspan="3">Modelling of the sequence of trabocchi</td></tr>
<tr><td colspan="4">Territorial collocation and address</td></tr>
<tr><td>The place “geographical location identification”</td><td>Image of the environmental contest and access to the trabocco [extract of the Chart a 1:5000 of the surrounding with evidence of the road and access infrastructures]</td><td>Geological support:
• emergent sector
• submerged sector
Climatic conditions
• predominant winds
• prevalent current</td><td>Schematic planimetry with reference to the orientation of the winds and of the sea currents</td></tr>
<tr><td>The system “constitutive-dimensional identification”</td><td>Image of the trabocco [general photograph of the system]</td><td>Installing typology
• pier/cliff subsystems
• footbridge (distance from the coast)
• fishing plan (dimension and height on the sea)
• fishing device
• stabilizing grillwork
• bathing hut
• equipment</td><td>Schematic planimetry with the general dimensions of the handmade product

(the measures are those denounced for the licence; then there are those result of the image from the satellite, even if only indicative)</td></tr>
<tr><td>The memory “cultural and historical identification”</td><td colspan="2">Historical notices and chronicles.</td><td>Essential data:
• epoch
• constructor
• owner
• bounds
• utilization of the L.R. n.93 of 14th December 1994</td></tr>
</table>

environmental and technical matters) one aims at constituting a first data package, graphical-constituent, provided to show the first results on the validity/possibility for the recovery and reuse of the handworks;
- the conservation of "memory", at last, undoubtedly essential constitutes an essential element not only for the physical recovery of the handworks, but also for a sense of belonging to a place and a culture.

In short, the objective of the census was to provide more detailed information about the relative situation, number and state of the systems "*trabocco*" and simultaneously, also of the environmental context situation in which such manufactured products are located. Notably, if the result of this work leads to the maintenance of the environmental stability it will not be able to expand the tourist flow to the coastline. Specific and accurate data regarding not only the manufactured products but also significant built and natural features of the surrounding context must be recorded. Furthermore, it will be pointed out those artificial (manufactured products and infrastructures) and natural (beaches and cliffs) "emergencies" that could have a primary role in the proposal of a new model of tourist fruition of the system connected to the *trabocchi. Trabocchi* will furthermore be able to set up the reference archetype for the bathing facility design, figuratively appropriated to the place and eco-sustainable.

3 From the recovery to the regulations for the new construction of trabocchi

The rehabilitation and revaluation of *Trabocco Turchinio* (planning and works direction by architect M. Borrone), located at Punta del Turchinio in the municipality of San Vito Chietino were executed in about 13 months (works started in June 2004 and were over in July 2005) as a result of the violent sea-storm of the first days of the year 2003, numerous and immense structural damages occurred, which compromised the function and stability of the building. This experience became the bench test of the various compatible assumptions and above all the moment for the preservation of the constructive practises that now result in alienation. The planning action was inspired by the "Paper of Amsterdam" (1975), in which the principle of the "integrated conservation" is established; it associates the two concepts of the conservation/restoration and of the attribution of an appropriate use. In fact, the sense of this intervention has been directed to the impediment of actions which could have altered the authenticity of the recent past of the "fishing machines", involving all the actors who were aware of the complex, as well as fragile, heritage on which to operate. This environmental awareness has placed firm limits on the overall project of restoration and redestination of the object. The restoration took into account the need to provide the *Trabocco Turchinio*, (the only one public property named by Gabriele D'Annunzio in *Triumph of the Death*), with a function compatible with its nature, also through the functional coming up of materials within the bounds of their endurance, coming from the neighbouring areas, a function which did not involve violent modifications. Hence the idea to convert this structure into a place for didactic, scientific and cultural activities, also because history shows that the survival of *trabocchi* is tightly connected to their utilization. An awareness linked to the expectation that the evocative capacity of suggestion of these places can represent also a potentially important tourist attraction as is shown by the cultural and scientific interest of such areas, inducing us to think how their conservation is not only a cultural duty, but it may be also understood as the economic presupposition for a rearrangement compatible with their survival. The phases of the restoration work were carried out making a systematic disassembling of the *trabocco* and, more accurately, determining all the categories of technical elements (composing the technological units and the categories of technological units). This comes from a reading of the subsystems constituting the manufactured product in object: the footbridge, the flat of fishing, the fishing device, the bathing hut. Since we did not work on an ex-novo building but based our intervention on the existing one and above all considering the characteristics of the location of both Turchinio and *trabocco* on the rock more generally, it was impossible to operate, intervening on each technological unit one by one, or in other words according to a pre-arranged program which was meant for operations on all parts of the same unity.

This condition has induced us to repair a portion of the system at a time, for in this way only few elements belong to various technological units. So it has been possible to reduce the difficulties linked to the necessity to work on the water. In fact, the work conducted in movement by the shore allowed a portion of the system “renewed” to function as a framework for acting on the adjacent portion till reaching the elements located closer and closer to the open sea (where water reaches a depth of about 6 metres). The execution of these operations, perhaps the only ones we could realize, implies the use of these procedures adopting the most ancient method practiced in traditional maintenance architecture, such as the utilization of special materials and elements. In this respect, it is useful to underline some important aspects and to make explicit some properties that cannot be inferred from the reading of the written schedules.

The first technical elements object of the intervention have been those composing the structures of foundation and of vertical elevation; in the works of balancing and replacement of these elements materials similar to the original ones have been used, except for the elements of collection (originally made with threaded bars and iron bolts), which for the first time have been made with threaded bars and steel bolts to avoid the formation of rust. Monitoring on the acting and on the state of the just finished structure has revealed a very important datum which has not been assumed a priori: because of the movements due to the sea and wind actions, the steel bolts slowly unscrew themselves making the whole building unstable. Therefore, in the structure of *trabocchi* the rust also has a fundamental role which consists in creating the right friction and the necessary cohesion in the nuts between the wooden elements. In the light of this observation, the steel bolts have been substituted with new iron bolts similar to the original ones, while monitoring the structure and screwing the bolts several times until the action of the sea has not given up a fairly regular degree of rusting of the nuts retaining their full functionality. The peculiar aspect described above concerns even more the links between the elements of the structure of vertical elevation and those of the structure of horizontal elevation, as well as the links between the longitudinal and transversal elements of the structure of horizontal elevation. In particular, as regards the *trabocco Turchinio*, no alteration was made in the typologies of the structures of vertical and horizontal elevation which have remained those traditional and more ancient (the vertical structure defined only by one pole- till the level of pounding of the footbridge- and by two strips of poles slightly inclined at V – with the function of supporting for the cables constituting the parapet – and the horizontal structure defined by crossing elements of connection between the vertical pole and the longitudinal girders) in contrast with the alternative technologies used in the course of the years (see the vertical supports made with two crossing elements instead of only one pole).

The objective of not modifying the characteristics of the structures *trabocco* led to an intervention which has respected as far as possible the materials and the traditional constructive techniques (in the structures of elevation, in the closing, in the partitions and in the functional equipment). With reference to this aspect, it is significant to point out the characteristic and "strategic" arrangement of the cables constituting the stabilizing system of connection between the antennae, the little antennae, the antenna poles and the poles of the hoist. The system of cables supporting the antennae and suspended to the antenna poles is fixed also to the hoist poles in a criss-cross way with respect to the fishing plan, that is the

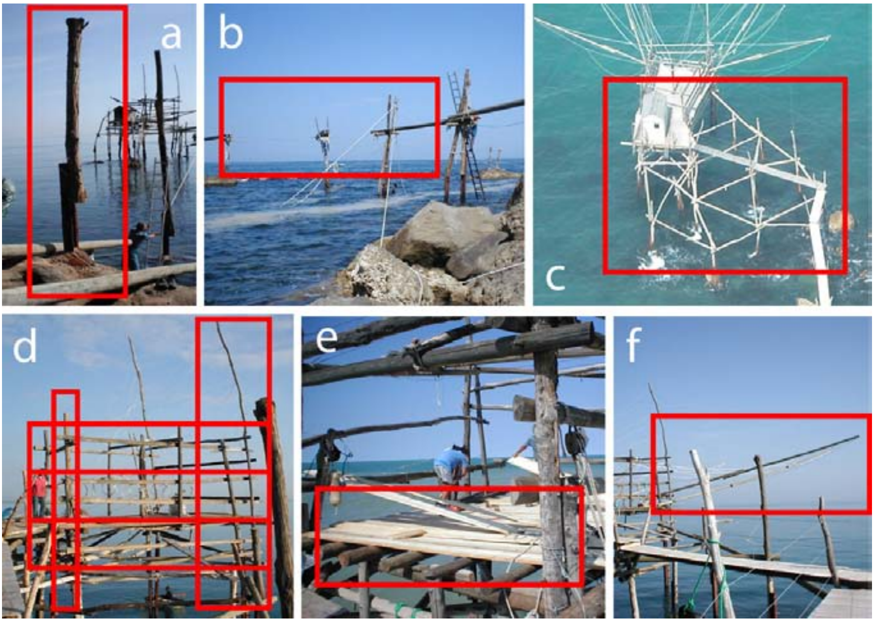

Figure 2: Images of the rehabilitation process: a) foundations and vertical elements of the footbridge; b) horizontal structure of the footbridge; c) stabilization structures; d) vertical and horizontal structures of the fishing plan; e) fishing plan partition elements; f) structures of the fishing device.

tie-beams of the antenna and of the antenna pole on the right, connect to the pole of the hoist of left and vice versa for the left antenna. While the tension rods which support the little antennae are still attached to the antennae and hoist poles, but follow a different path: cables of the little left antenna connect before to the left antenna pole then to that of right and at last the hoist pole, always on the right (never crossing on the fishing plan); the same happens for the tension rods of the little right antenna. This tension rod arrangement defines a system of cables which, following various directions, stiffens the whole system supplying with constraints the vertical and horizontal displacements of the structural parts. This stiffening is implemented by the link elements between the antennae and the little antennae. The intervention made on the *Trabocco Turchinio* represents an important and useful experience to organize an appropriate, ordinary and continuative activity of maintenance and balancing of the *trabocco*. This intervention provides precious advices to complete the theoretical indications with precautions for practical applications.

3.1 First conclusions about the construction of new trabocchi

The most important "conclusions" drawn from the experience of the realization of this intervention (and which can be considered in any future works) are essentially related to the peculiarities of the kind of construction in object and to its installing conditions (in other words from the need to bring and assemble, following particular procedures, the constructive elements in the sea) and concern:

- reaching the shipyards;
- the problems of security in the shipyards;
- the peculiar constructive models;
- the peculiarities linked to the originality of each structure *trabocco* and its installing conditions.

The aspects mentioned above are to be considered not as problems to overcome but as bonds to respect. In this attempt to respect the environmental characteristics of the places, the way to the shipyards can at most be ameliorated (by cleaning the uncultivated vegetation, for instance) but not certainly make it easier (by twisting the hills sloping down the sea with roads). Moreover, the problems related to the security of workers and to the peculiar constructive models have to be tackled considering the characteristics of the situation without modifying the traditional technical solutions.

In short, in order to control by regulations the recovering of the *trabocchi*, we shall state our impossibility to generalize rules, as well as the necessity of leaving a border of flexibility for each case which depends on the originality of each single structure and on its installing conditions. The control system of the more important aspects of planning can foresee a comparison with various qualifying aspects as: **morphological quality** – the whole typological and morphological conditions of a building or installing organism which guarantee the safeguard and the increasing in value of the context and satisfying qualitative levels in terms of architectonic, relational and perceptive relations; **eco-systemic**

quality – the systemic praxis to realize and guarantee conditions for wellbeing with respect to the pre-existing ecosystems along with a rational employment of the natural resources available; **useful quality** – the whole conditions which guarantee a suitable utilization of the building organism or of the installing complex by the consumers, with particular attention to the questions concerning the elimination and the overcoming of the architectonic barriers, the security of utilization and in general the needs of the new model of life referred to the weaker social users; **system quality (process and product)** – the organizing structure, responsibility, procedures, acting, techniques and operating activities put in action to satisfy the properties and the characteristics of a product which permit to respond to implicit or expressed needs.

The comparison between the project and the various performances can be disciplined by a control model of the single interventions synthesized in a project schedule where the following issues are scrutinized: the collocation suitable to the context, where the historic places of location and the distance between the different settlings are to be considered; the morphological and dimensional features of the manufactured product mentioned above, where the proportions of the subsystem (footbridge, fishing device and bathing hut) and the extensions of the relative spaces are to be considered; the definition of a suitable structural system, where the referring typology (in particular for the subsystem footbridge) and the geo-compatibility of the foundations are controlled; the choice of an appropriate constructive system, guaranteed from the responsible selection of materials and assembling techniques and also verified in its endurance, maintenance and functionality; the configuration of a complete organization of the spaces and of the surrounding environment, in order to evaluate the possibilities of fruition and adaptability of the spaces.

4 The model of tourist fruition and defining sustainability indicators for equipment on the coast

The promotion of good quality tourism, referred to a sustainable territory development in the specific case of the Theatine coast, needs to begin with the maintenance of the *trabocco* and the recovery of the constructive lesson of the "genius loci". It results from the recognition of the role these manufactured products could play on the level of landscape image as well as their function in suggesting conditions for areas specially equipped for bathing. In short, it is a question of remembering that the elements, especially the fragile ones, on which the promotion of the territory is based, risk to be penalized in a project which is not evaluated in all its implications. In these territories of extreme vulnerability, from the physical point of view and of their image, tourism can be configured as a risk for the environmental deterioration (intending for this not only the physical environment but also the social and economic one): the anthropological pressure, the congestion, can contribute to a sudden disqualification of the environment; the "savage" and inappropriate utilization of the territory, and also the construction of other *trabocchi* with inadequate technologies and materials can, in a short time, cancel the historic-cultural memory of the place, to give space to an homologate landscape or alienated by false icons of the local material culture. This is the case also for the isolated architectonic manufactured products and for the little and characteristic built-up areas which cover the coast; without an organic and common "plan", the interventions of both recovering and renewing, but more importantly the new constructions can alienate the peculiarity of the place and destroy those points of strength which today represent a possible alternative to the existing tourist offer, promoting eco-cultural activities. The increase in value of the system of naturalization, the model of bathing coast equipment, the relationship with the hinterland anthropological products (urban and agricultural), the recovery and the reuse of manufactured products emergent as reference in a service system, the proposal of an alternative and sustainable mobility system all are part of a unique, complex and integrated project where every action is strictly connected to the other ones and every choice must be evaluated with respect to the results in the other sectors. Choosing the *trabocchi* as "Manifesto" for the future development of the Theatine coastal territory means giving an objective where the choice evaluation and the balance between the options is the leading reason of the political and planning actions. There is no doubt that the knowledge of the trabocchi has been critical for an appropriate proposal for such a project, providing in parallel the guidelines for the construction of new buildings of the same kind. Moreover, it has made possible the identification of the elements necessary to the definition of a "surrounding" and to the increase in value. It will at last make it possible to make reflections on the sustainability indicator identification for the compatible equipment on the coast in object.

4.1 Tutelage and increase in value of the natural property

The coastal territory characterized by the presence of *trabocchi* shows environmental resources, and natural and anthropological-cultural property of remarkable interest. With the aim of promoting a sustainable tourist development, eco-cultural, we should put in evidence a few elements with a high power of attraction, that are central crux of the matter (functional to the definition of an organic arrangement of the entire area). The point of strength of these ambits is given by the character of the naturalization, still quite integral, that connects them; there are, however, territories not able to support this, for their scarcity on one side, and their geological consistency on the other, a solid tourist load. Hence, the weakness of a mass tourism characterized by residences on the coast and "heavy" and permanent bathing facilities. The naturalization, element of attraction, would be briefly destroyed with consequent decay of the tourist demands. The cataloguing of the specific ambits will contain the description of the "place" particularly for the safeguard of the environment in connection with the geological characteristics of the cliff and those hydro-geological of the waterline. The objective tends to guarantee the harmonization of each action-intervention with the characteristics of the place; the specific qualifications consist of the project of landscape integration. The indicator of control is given by the presence and the maintenance of the characteristics of the context to verify through the relief, ante and post intervention, and by the permanence of the perceptive peculiarities of the place itself.

4.2 Recovery and reuse of the property of the old hill top villages by the coast and the agricultural industry

In these territories the proposal of a sustainable development means an offer of various tourism segments such as historical, cultural, environmental, eno-gastronomic routes which are particularly useful for redistributing, in a more balanced way, functions and attractions. The same territory places itself with those elements suitable for supporting such offers and producing, therefore, a readjustment of the internal, often abandoned and underestimated areas, as regards the inhabited centres, and for the agricultural areas. The tourist request for residence, for instance, can be widely met with the presence of the heavy property in the old city centres and in the rural areas, as well as in the diffuse settlements; in such a way that there will be a more interesting offer which includes other attractive factors related to history and local culture, all the while respecting the new tourist building. The recovery and the reuse of big manufactured products which have been cast off, such as the railway stations, the workshops and other systems placed in strategic points on the territory, constitute further resources not to be alienated but to recover appropriately also considering in addition the role of land deterioration. The idea begins to take root as “a building constitutes a supply of invested natural capital, and that could be maintained during the time” (R. M. Pulselli, E. Tiezzi, *Città fuori dal caos, la sostenibilità dei sistemi urbani,* Donzelli Editore, Roma 2008. p.133) just through actions privileging interventions on the built products rather than on new ones and that, as consequence of it, introduce even the city and the building in a new cyclical process.

4.3 New mobility

For the bathing areas, the dismantling of the railway provides a “network” which would be able to determine a truly integrated bathing system of articulated served and serving spatial units as well as to unify the access to the *trabocchi* and the relevant and adjacent little beaches. The tunnel system utilization, once reinserted in the unity of the way, besides allowing the trial course of the whole path, will be able to supply a service system. The proposed mobility system will have to be verified on the base of energy systems put in action and of relating emissions.

4.4 Conclusions: for a sustainable model of stretch of stand equipment

The by now consolidated image of the *trabocco,* which is evocative of the Theatine coast, functions as the most appropriate “morpho-technological” pattern for this scenario, but also as a transferable model to other contexts characterized by similar physical-territorial connotations. In other words, the planning of the bathing facilities can adopt the lesson of *trabocchi* as a fundamental strategy and refer:

- to the **well-established image** of the system as light, fairly good and "transparent", demountable and reconstructable manufactured product;
- to the **installing typology**, the pile-dwelling, as a system that "conquers" the sea where there is scarcity of earth, and consequently, to the "measured" dimensions and consistency with respect to the place characteristics and the vulnerability of the geological support. It comes out a planning attitude in which the interventions assume a shape in a way inversely proportional to the place vulnerability and make reference, for instance, to a system of eco-planning based on a modular system able to be suited, (diversifying the offer and the elements, to the place demands);
- to **appropriate technologies** with the utilization of materials connoted from a high sustainability level (renewable origin, recycling easiness, in short subordinated to LCA/life cycle assessment) and with simple and feasible techniques, to a constructive and maintaining level, by a not skilled labour, above all in relation to the dismounting and seasonal remounting, matter of primary importance for the maintenance of the total environmental quality.

The specifications may define in particular the aspect of the manufactured products - which is shaped according to the parameters of sustainability - and privilege the reference to local material culture; it is preliminary, then, the study of the material culture and the recovery of the local constructive traditions. The specific objective is in this case the safeguard of the local constructive traditions. In short, it is requested a specific tutelage for the local material, constructive and technological characters. The strategies to act, at both planning and technological levels, refer to the adaptability of the manufactured products to the morphological characteristics of the sites; to the usage of local materials and techniques; to the reinterpretation of the constructive systems and to the morphological constructive techniques of less impact on the ground and more efficient from the energy and transports point of view. The control indicator used will consist in the verification of the presence or compatibility or comparison of the technical-constructive peculiarities and of the planning materials with the context in which the intervention is introduced. The necessary instruments will lead to the repertory evaluation of chosen materials and to the proposed techniques in relation to evaluations with LCA methodologies and of "ecological mark". Visual simulation of the intervention will be used for the evaluation of the correct installing.

References

[1] Forlani M.C., (2005). *I trabocchi, archetipi costruttivi della leggerezza. Il Progetto Sostenibile.* vol. 08, pp. 20-29 Edicom Edizioni

[2] Forlani M.C., (2005). *El conocimiento de la tradicion constructiva local de los Abruzos (trabocchi, pinciaie, caciare) para una nueva sustentabilidad proyectual*. (vol. I, pp. 395-406). in S. Huerta (a cargo di), *Historia de la construccion*, Actas del Cuarto Congreso Nacional, EFCA, Torrejon de Ardoz (Madrid).

[3] Forlani M.C., (2005). *Una proposta di attrezzature eco-compatibili per il turismo balneare.* (vol. 1, pp. 175-183) in A. Passaro, a cura di, *Attrezzature temporanee ecocompatibili per il turismo nelle aree costiere,* Atti del convegno internazionale "Abitare verde", Luciano Editore, Napoli
[4] Forlani M.C., Radogna D. (2004). *Trabocchi: a Sustainable Technology for Marine Environment*. (vol. III, pp. 269-274) In 8° World Conference on Timber Engineering. Proceedings of the WCTE 2004, Helsinki

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Section 3
Design by passive systems

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The use of green walls in sustainable urban context: with reference to Dubai, UAE

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Abstract

The impact of urban development on the natural environment generates unique challenges to architects and engineers seeking passive design strategies in hot and humid climates such as those in Dubai. They are collaborating to design new buildings that are energy efficient, environmentally friendly, and architecturally significant. Passive cooling design techniques, which are recognized mainly in the old Dubai, are energy efficient and can be considered as a good alternative to mechanical cooling systems. Green roofs and façades are passive techniques and add more benefits not only for reducing the energy demand of buildings, but also for providing environmental benefits, including visual relief, accessible green space, and improving air quality. In recent years, greening systems have been practised in many hot cities, including greening directly on to roofs and walls, greening the cavity between walls, and incorporating greening systems within the construction of the wall. Green roofs are frequently used in cities like Dubai; however, practising green wall technology is still new despite its great benefits.

Based on the climatic condition of Dubai, this paper attempts to reduce energy consumption in buildings by adopting passive cooling strategies in the sustainable urban context of Dubai. The growing interest in incorporating vegetated green walls into sustainable building is highlighted. To achieve the aim of the study, the following objectives have been covered: to investigate the use of passive cooling strategies in Dubai; to enhance the energy performance by reducing the cooling loads and therefore identifying the optimal parameters for building skins; and to draw guidelines for architects, planners and developers to demonstrate the potential benefits of green wall technology. In this context various issues, including the urban development of Dubai, sustainability, passive cooling techniques, and the performance of green walls, are to be considered.
Keywords: Dubai, energy efficiency, green walls, passive design, sustainability.

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1 Introduction

Recent ongoing developments in Dubai have consequences on the urban environment. Minimizing the negative impact of the construction boom on the natural environment and the trend to improve the ecological performance of buildings are the main concerns of the sustainable practices in the city. These ideologies have been acknowledged by architectural firms designing and constructing sustainable projects that are energy efficient. Architects and developers, such as Creative Kingdom and Mirage Mille, have incorporated ecological and sustainable approaches in their designs. Various concepts and techniques have been used to develop energy-efficient buildings and cooling load avoidance. The use of natural ventilation, thermal mass, shading devices, vegetation, landscaping, and the double skin façades have been adopted. In recent years, green roofs and façades have been rarely practised despite their wide range of positive effects for buildings, inhabitants, and the environment.

The study shows the environmental benefits achieved by adopting passive cooling strategies and integrating green walls in sustainable urban contents. The paper argues the value of integrating green wall technology into the double skin façades.

2 Urban development in Dubai

Dubai, the second largest of the seven emirates of the United Arab Emirates (UAE) after Abu Dhabi, has become one of the most modern cities in the world. The city started its urbanization process in the late 18th century with a small fishing and trading village in the Arabian Gulf. Nowadays, Dubai has the largest population in the UAE with about 1.5 million people, expected to be doubled in 2020 [1]. The demography of the city comprises a varied mix of nationalities and cultures. The strength of the Dubai economy is boosted mainly by the ports and national resources.

Dubai, with its hot climate, is situated 25 degrees north and 55 degrees east, within a sub-region of the northern desert belt. It is characterized by scarce rainfall and high levels for temperature, humidity and sunshine. In summer time, the weather is very hot and humid with daytime temperatures ranging from 35◦C to 49◦C. In winter, the daytime temperatures range from 25◦C to 35◦C, and sometimes falling to as low as 9◦C at night [2].

The architectural ideologies in Dubai have moved from a traditional vernacular style to modern planning ideologies. The traditional fabric reflects the climatic condition, the cultures of the residents, and the locally available building materials. This pattern is characterized by high-density buildings with narrow shaded alleys, tall wind-towers, and courtyards. The modern approach, which was established during the second half of the 19th century, was concerned with highly specialized building techniques. This modern style is highly recognized within the new central area of Dubai. A number of enormous mega-projects have been constructed, including the world's tallest tower (Burj Khalifa).

Shindagha Quarter [3] Narrow alleys, Bastikia Old Market

Figure 1: Architectural fabric of old Dubai.

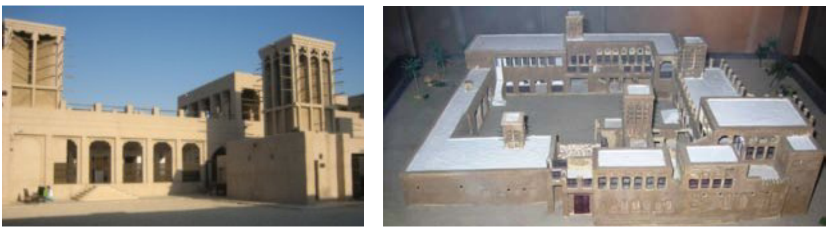

Figure 2: Sheik Saeed Al-Maktoum House, Shindagha, Dubai.

The architectural fabric of old Dubai provides natural cooling system to maintain a comfortable indoor temperature. Buildings tended to be very closely clustered together separated by narrow shaded alleys running from north to south to permit the prevailing winds to pass through. This fabric is well recognized in Shindagha and Bastikia Quarters (see figure 1).

Sheik Saeed Al-Maktoum House, built in 1896, is a typical example of the traditional architecture of Dubai (see figure 3). The living quarters of the house open on to the main courtyard to generate wind circulation around the rooms. Most of the rooms are provided with a shaded veranda overlooking the courtyard. Windows are mostly on the inside looking in towards the courtyard. Windows on the exterior walls are limited to narrow slits and semi-decorative openings that admit light and accelerate natural ventilation. The wooden ventilating screens (Mashrabbias) were also used to keep out the sun, and allow cool breezes. The wind-towers were the most distinctive architectural elements to trap the fresh cooling air and direct it to the indoor space below. The house was built from local high mass materials including coral stone, lime, plaster, and palm fronds. Such materials have adequate thermal storage which responds to the needs of the climate.

The trend of rapid urban development in Dubai has impacts on environmental aspects including environmental deterioration, high consumption of non-renewable resources, and high levels of air pollution. Minimizing this impact on the natural environment and efforts to improve the ecological performance of any project are the main concerns of sustainable building development during

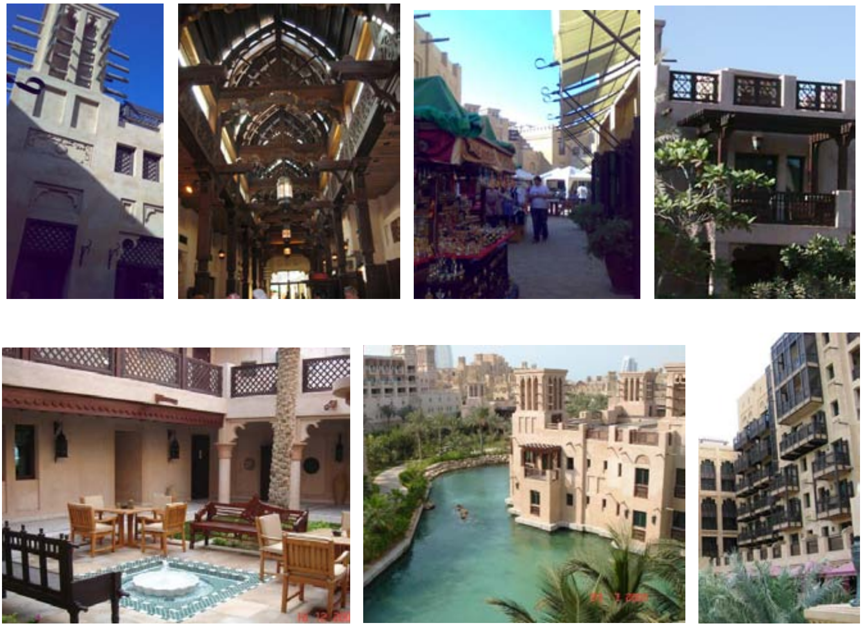

Figure 3: The use of passive strategies in a sustainable urban context, Madinat Jumeirah, Dubai (wind-towers, shading devises, courtyards, pools and canals, vegetation and landscape).

and after construction period [4]. Therefore, energy efficiency, a healthy environment, and protection of biodiversity are the key issues. It was indicated that buildings consume about 45% of total energy use; 25% of total water consumption; 70% of total electricity consumption, and about 40% of total carbon dioxide emissions [5]. These figures are even higher in Dubai and it has one of the highest per capita fossil fuel consumptions [6]. Therefore sustainable building practices, in term of energy consumption, are essential in cities like Dubai in order to adapt to sustainability.

3 The use of passive cooling strategies in a sustainable context

Sustainable development refers to a socio-ecological process characterized by the fulfilment of human needs while maintaining the quality of the natural environment [7]. Sustainable development could be achieved by architects, engineers, designers, town planners, and manufacturers of building products working cooperatively to produce green buildings that are designed, built, or operated in an ecological manner. Green Architecture is an approach that emphasizes the place of buildings within both local ecosystems and the global environment. Green building is the practice of increasing energy efficiency, while reducing building impact on human health and the environment. A green concept tends to focus on the use of natural materials, renewable recourses, and passive solar techniques [8]. Reducing energy loads is a main concern for green architecture. It is important to orient the building to take advantage of cooling breezes in a hot climate, and sunlight in a cold climate. To minimize the energy loads, passive solar design can be effective. Masonry building materials with high thermal mass are efficient. Many of these valuable passive strategies are employed in the traditional architecture of old Dubai. In Dubai's hot climate, where cooling is a primary concern, much can be done to capture natural breezes to keep buildings cool and comfortable. Courtyards, wind-towers, shading devices, thermal mass, insulations, deciduous vegetation, and green roofs and green walls can reduce energy loads for cooling.

The most important step in the passive design strategies is to develop an energy efficient building skin to minimize heat gains and catch cooling breezes. Depending on the climatic condition, passive design of the building skin might comprise the following concerns: orienting more windows to the north; incorporating adequate shading devices that prevent solar radiation; providing suitable insulation including vegetation; using high performance glazing that reduces heat gain and admit natural light. Landscape and outdoor spaces also play an important role in passive design strategies. The effective way to cool the building is to keep the heat from buildings. Specific strategies should be applied; including reflecting heat, blocking the heat, and removing built-up heat [8].

Shading, insulation, and vegetation are good strategies to block the heat and reduce the indoor temperature. Shading can reduce indoor temperatures by 10◦C. Effective shading can be provided by trees and shading devices. Vegetation provides a reliable heat buffer and can save up to 20% on energy use [9]. It also minimizes the heat island effect of the building. Moreover, the plants filter outdoor pollutants and improve air quality.

Natural ventilation helps remove heat and maintains indoor temperatures. In hot-humid climates, a building designed for passive cooling would be as open as possible to ensure the maximum possible cross ventilation. East and west walls should have a minimum of windows in order to exclude the low angle sun-rays. However, north and south walls should have enough windows to allow cross ventilation. Cross ventilation can also be enhanced by irregular-shaped, spread-out buildings. The wind-tower, which is the key element of the traditional architecture of Dubai, can also be used to ensure ventilation by using the cooling potential of the available breezes. The courtyard is another passive cooling device which may improve thermal comfort conditions in enclosed building spaces.

Architects and developers, like Creative Kingdom and Mirage Mille have incorporated ecological and sustainable approaches in their designs. Various concepts and techniques have been used to develop energy-efficient buildings and cooling load avoidance. The use of natural ventilation, thermal mass, shading devises, vegetations, landscaping, and the double skin façades have been adopted.

In the last few years, various passive design techniques have been applied to new large projects in Dubai, such as Madinat Jumeirah, the largest resort established in 2004. It reflects the rich cultural heritage of Dubai and resembles an ancient Arabian architectural style. The project was designed and built in an ecological and resource-efficient manner. As shown in figure 3, passive design elements such as courtyards, atriums, wind-towers, shading devises, vegetations, pools and canals have been integrated to create a pleasant outdoor environment and improve indoor comfort by achieving desirable thermal conditions. These strategies minimize the need for mechanical cooling systems and then reduce energy consumption.

External insulated, dense materials covered with vegetation have been used in passive design where the plants reduce overall temperatures of the building and minimize the heat gain. This strategy utilizes plants to increase energy efficiency by functioning as a natural shading system and reducing heat gain.

4 The use of green walls

Green walls, also known as vertical gardens have been successfully implemented in different climatic conditions. Green wall is used as a term for both living walls and green façades. Living walls, also known as bio-walls are composed of pre-vegetated panels or integrated fabric systems that are fixed vertically to a structural wall or frame [10].

Green façades are made up of climbing plants that growing directly on a wall or supporting structure. The plant grows up the wall while being rooted to the ground, in intermediate planters or on the rooftops. Rigid panels and cable systems can be used to hold vines off the wall surface.

Green walls provide a wide range of positive effects for buildings, inhabitants, and the environment. There are significant benefits resulting from the use of green walls.

4.1 Increasing energy efficiency in buildings

Green wall technology helps buildings become more energy efficient and helps to reduce the urban heat island effect, absorb storm-water, and leads to reduced carbon emissions. It acts as a protective barrier which provides better solar protections that can reduce the effect of the external load and the cooling need [10]. Previous observations indicated that green walls reduce the heat gain, and their surface temperature is lower than an exposed wall. Based on the analysis carried out by Green over Grey firm [11], studies have shown that the external surface of a green wall is up to 10°C cooler than an exposed wall; therefore the U-value for the green wall is usually lower and helps to reduce cooling loads. Previous studies demonstrated that non-vegetated areas could exceed temperatures of 50°C in July while vegetated areas remained at 25°C [12]. Interior green wall technology also helps to save energy. It can reduce the temperature of the room by 3 to 7°C, and can reduce the AC cost by up to 20% [11]. In winter, green wall techniques act as insulation layer by moving air between the plant and the wall and creating a buffer against the wind which reduces cool air coming in. The level of energy saving depends on many factors such as climate, building skin type, and density of plant coverage.

4.2 Sound insulation

In urban environments, plants and trees have been used as barriers against urban noise pollution. Plants, soil, and the trapped layer of air can absorb, reflect or deflect sound waves. Therefore, green walls have an acoustical insulation that is far better (up to 30 db) than that of exposed wall [13]. The degree of sound insulation provided by the green wall depends mainly on factors that influence noise reductions including depth of the growing media, type of plants, the materials used for the structural components of the living wall system, and the layer of air between the plants and the wall. In terms of sound control, the choice of the appropriate type of green wall technique depends mainly on the site conditions, climate conditions, and the function of the inner space.

4.3 Building surface protection

By reducing surface temperature of a building skin, and using appropriate techniques such as waterproof living wall panels separated by a layer of air; green wall technology can protect building surfaces and extend the lifespan of the building skin. This protection comes mainly from keeping rain off the building while allow moisture to escape, reducing the expansion and contraction of building materials, and protecting walls against wind and solar radiation which might affect the building materials.

4.4 Visual and air quality improvements

By bringing nature to the urban environment; green wall technology has a visual impact on the architectural fabric. The use of green walls as visual attractants increases the value of the building. Moreover, green walls can help to address the lack of green space in urban environments. Plants improve human health, capture airborne pollutions, and filter harmful gases. In addition to absorbing heat and increasing thermal performance, the green wall helps to filter the air moving across it. Green wall technology contributes directly to LEED credits (Leadership in Energy and Environmental Design) since it covers issues like sustainability, energy saving, air quality, water efficiency, wellness, and acoustics.

5 Integrating green wall techniques into the double skin façade

Architects and building engineers believe that the use of double skin façades (DSF) can provide better natural ventilations and thermal insulation, reduce cooling loads and energy consumption, facilitate daylight, and increase noise control [14]. It can provide about 30% reduction in energy consumption [15]. In summer, DSF can reduce heat gain and cooling loads while allowing in daylight and natural ventilation. Moreover, it can reduce heat loss in winter while still capturing solar gain. As shown in figure 4, DSF introduces two primary glazing layers separated by a cavity space that provides thermal insulation. This could be integrated with solar control systems, light reduction systems, and ventilation systems. The construction of the DSF usually provides better solar protection that can reduce the effect of the heat gain and the cooling need. The additional layer of glazing can reduce the insulation by about 10%. Further reduction could be achieved by placing shading devices in the cavity space [14].

Despite its advantages in terms of energy efficiency, the use of the DSF system is still limited in Dubai. The construction cost of the DSF is always higher than a single skin façade. However DSF may allow tradeoffs with building systems including cooling and heating systems. Previous studies indicated that the potential energy savings offered by the DSF can overcome the high construction cost and building performance can be maximized [14]. Based on a comparison analysis carried out by the author, the solar heat gain coefficient of DSF with shading devices was much lower (between 0.09 and 0.30 W/m2) than that of a double glazing single skin façade (between 0.30 and 0.40 W/m2). The U-value of the DSF vented with laminated shades within cavity space was between 0.9 and 1.4; while the U-value of double glazing single skin facade was between 1.1 and 1.5. It has also been indicated that DSF has an acoustical insulation that is far better than that of a conventional double glazing single-skin façade with difference of 10 dB [14].

To increase energy efficiency of the DSF, a vertically vegetation layer could be integrated into the cavity space of the DSF. This technique is known as vertically integrated greenhouse (VIG) [10]. The main idea of this system is that

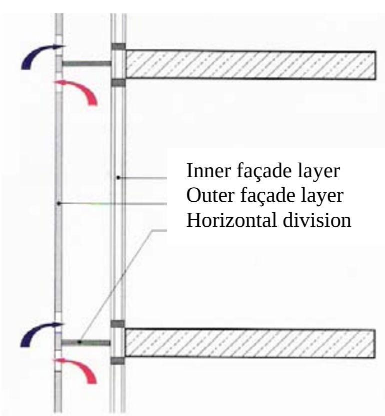

Figure 4: Section through DSF with ventilation system [16].

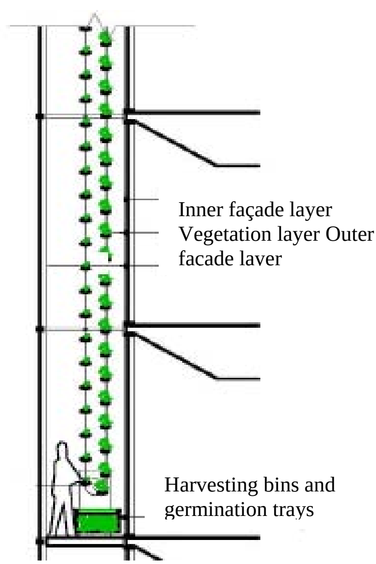

Figure 5: Vertically integrated greenhouse technique [10].

the installed plants can act as shading devices that help absorb heat and liberate it within the cavity (see figure 5). Moreover, installed plants increase sound insulation and improve air quality within the cavity space. Caplow et al identified the VIG concept as a highly productive, modular, and climatically responsive system for growing vegetables in a cavity space of a DSF [10]. By adding a commercial scale of vegetable production within a DSF, Caplow et al pointed out that the VIG technique helps to strengthen the economic justification of the DSF system and encourages architects and building engineers to adopt this technology.

6 Conclusions

Ongoing urban developments in Dubai have consequences on the environment. The trend to improve the ecological performance of buildings is the main concern of Dubai Municipality. Architects and developers have incorporated ecological and sustainable approaches in their design. Design strategies that minimize the need for mechanical cooling systems have been adapted in sustainable urban context. These strategies include proper shading, natural ventilation, thermal mass and good landscaping. Traditional architectural elements such as wind-towers, atriums and courtyards have been adapted in the new projects to enhance the stack effect and to speed the indoor air flow. Previous studies recommended that the use of dynamic double glass façades that accommodate change in the environment is highly appreciated for the fully glazed building in Dubai since it provides better solar protection that can reduce the effect of the heat gain and the cooling need.

The green wall is another environmentally friendly technique that helps buildings become more energy efficient and reduces the urban heat island effect. It provides better solar protection, sound insulation, surface protection to the building, and visual and air quality improvements. Integrating a vertical green screen into the double skin façade system (vertically integrated greenhouse) is recommended by many researches like Caplow, Nelkin, and others; since it acts as a shading device integrated within the cavity space of the DSF.

The use of green wall technology is still a new concept in Dubai, despite its great positive impacts. This technique requires extensive energy analysis and investigation in terms of thermal performance, sound control, and cooling load reduction. The study also recommends that an economic justification for adopting such technology is required.

References

[1] The United Arab Emirates Yearbook 2006.
[2] www.datadubai.com/technical-info.
[3] Kay, S and Zandi, D., *Architectural Heritage of the Gulf*, Philip Morris, 1995.
[4] Botta, M., *Towards Sustainable Renovation Three Research Projects. KTH*, Stockholm, 2005.

[5] Walters, L. et al, Miracle or Mirage: Is Development Sustainable in the United Arab Emirates? *Middle East Review of International Affair*, vol. 10, no. 3, 2006.

[6] Abou Alnaga, M. and Y. El-Sheshtawy, *Environmental Sustainability Assessment of Buildings in Hot Climates: The Case of the UAE*, Al-Ain, UAE, 2001.

[7] Rees, W. 1998, "Understanding Sustainable Development", *Sustainable Development and Future Cities*, Hamm, P. and P. Muttagi (eds), Intermediate Technology Publications, London.

[8] www.empowementzon.com

[9] Roehr, D. and J. Laurenz, Green Surfaces in the City Context, *Proceeding of The Ecocity World Summit*, San Francesco, USA, 2008.

[10] Caplow, T. et al., Vertically Integrated Greenhouse: Realizing the Ecological Benefits of Urban Food Production, *Proceeding of The Ecocity* World Summit, San Francesco, USA, 2008.

[11] Green over Grey - Living Walls and Design, www.greenovergrey.com

[12] Luvall, J., and H. Holbo, Measurements of short-term thermal responses of coniferous forest canopies using thermal scanner data. Remote Sensing of Environment, vol. 27:1-10, 1989.

[13] www.greenroofs.org/index.php/about-green-roofs/green-roof-benefits

[14] Haggag, M., Integrating Intelligent Glass Facades into Sustainable Buildings, Proceeding of the 2nd International Conference on Energy and Sustainability, Bologna, Italy. 2009.

[15] Oesterle et al, Double-Skin Facades, Prestel Verlag, London, 2001.

[16] Glicksman, L. et al, Double Skin, Airflow Façades. *Proceeding of the International Conference on Building Envelope Systems and Technologies*, Ottawa: Canada, Vol. 1, pp. 203-207, 2001.

The role of passive systems in providing comfort in traditional houses in Isfahan: a case study of the Karimi house

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Abstract

This paper concentrates on the passive systems of vernacular houses in Isfahan, using the Khaneh Karimi (Karimi House) as a case study. Passive systems may serve as a solution for the energy crisis in the world and the advantage of vernacular houses in Isfahan is the use of these systems. The high effective temperature caused by intensive radiation and the low level of moisture in the summer and cold weather in the winter are considered as critical climatic conditions in Isfahan; one of the solutions is to design vernacular houses. This paper aims at describing the role of each of the architectural elements, as passive systems, in making comfort in vernacular houses in Isfahan. In this case study of the Karimi House, elements such as a Badgir (wind catcher), a Hozkhaneh (basin room) and the use of air conditioning, a hoz (basin) and a baghche (small garden) in Hayat Markazi are considered as passive cooling systems for providing moisture and air ventilation in the summer and an Ivancheh (small veranda), using solar energy through Hayat Markazi and suitable materials for reserving heat in the winter, are considered as passive heating systems. Finally, the role of architectural design for creating passive systems in accordance with regional climatic conditions is manifested, using a qualitative method and the description of a sample in this paper.
Keywords: passive systems, heat comfort, critical climatic conditions, vernacular houses in Isfahan.

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1 Introduction

Any individual, even an employed one, spends at least one third of their day-night hours in their house and a human being relates closely to their house, more than any other architectural building, from the beginning of his/her lifespan to the end. Obviously, establishing climatic comfort within the framework of the residential unit is necessary. The vernacular architecture of Iran uses passive systems in compliance with climatic conditions for providing comfort, and employs nature for balance to create a microclimate within the framework of a house. In fact, the passive system is not anything but the building itself. The case study in this paper aims to survey the houses in Isfahan city, among which the Karimi House has been considered as a selected sample to be studied.

2 Introduction of Isfahan climate

The historical city of Isfahan is approximately 1590m above sea level in 32,37' North latitude and 51,40' East longitude in the heart of the Iranian plateau. As the Zayande-Roud River passes through Isfahan, it not only freshens the air by providing humidity and adjusts its climate, but also creates a mezoclimate in the Iranian plateau bed. This city is located in a climate with a hot-arid summer and cold winter (Kasmai [3]).

3 Introduction of Karimi house

Conformity of lifestyles with climatic conditions is a significant property of introverted houses in hot-arid climates, namely four season houses (Ghobadian [2]). This term is refers to a central courtyard surrounded by rooms and their application in accordance with the specific season of the year as required, according to the quality and the quantity of solar radiation. The application of spaces based on season and time schedule has led to internal space division into two categories of cold and hot and, also, the heat loss and the heating or cooling of the whole spaces are avoided in the comfort level. The Karimi house is a four seasons house, belonging to the contemporary Ghajar dynasty period of the 18^{th} and 19^{th} centuries.

Table 1: Isfahan climate characteristics.

The average maximum temperature	36-37
The average minimum temperature	-0.5
The highest daily temperature variation	18 Celsius degree corresponds to September
The maximum relative humidity	75 percent corresponds to December
The minimum relative humidity	19 percent corresponds to June
Mainly wind in spring and winter	west and southwest
Mainly wind in summer and fall	East, north, northeast and west

This house is comprised of an octagon yard and a large rectangular court and spaces in the northwest and northeast fronts of this large court, the important accumulation of house spaces, is found at its northwest front. It seems that the octagon yard plays the role of Birouni (exterior area, refers to a yard which is specified for men, outsiders and the professional affairs of the master of the house) and the rectangular one the role of Andarouni (the interior territory of the house, belongs to women and family members in general), respectively. This house is composed of spaces such as the entry, Hayat Markazi (central courtyard), Eyvancheh (small veranda), Talar (hall, a big room designed to serve guests, generally it is situated in the best place of the house), Sehdari (a room with three doors, connects to the yard with three big windows. This is the bedroom of the house.), Hozkhaneh (basin room), Badgir (wind catcher), etc.

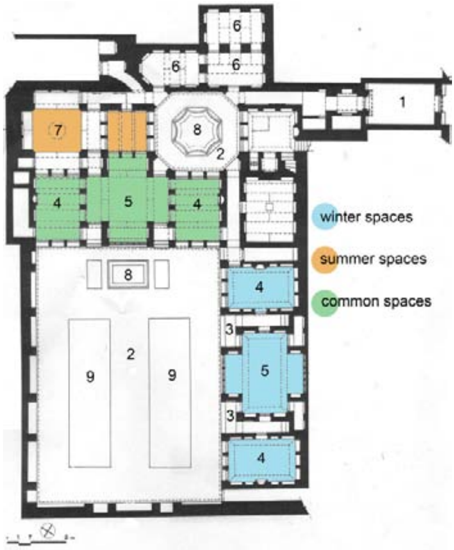
4 Hayat-e-Markazi (central courtyard)

In both hot-arid and hot-humid climates the central courtyard (Hayat-e-Markazi) is regarded as the heart of houses in terms of spatial, social and environmental considerations. The central courtyard is an element that is connected to the culture and climate of Iran. In this article only the climate is referred to. The comforts offered by a courtyard – privacy, security, and tranquillity – are properties nearly universally desired in human housing. Though the pattern of the central courtyard has resulted from the climatic conditions of the hot-arid region, the compatibility of this composition, caused by changes in interpolations, existing plant action, organizing screens, etc, with other climatic conditions in hot-humid, foot of the mountain, cold or even mild-humid regions can be noted too. The spaces of the central courtyard facilitate living for large scales of family members and, thus, to accommodate a kind of residential complex (Ahmadi [6]). The yard plays such great role in central courtyard houses that the number of yards increases depending on the households' financial power (Ghobadian [2]).

During the afternoons and evenings, upon irrigation of the parterre and sprinkling the yard with water, the yard is used as the family members' concourse and, also, it has an application for night sleeping. The dual function of the yard in providing comfort in summer and winter means that it not only receives solar radiation in winter but also it gets airflow with appropriate temperature and humidity in summer by means of the central courtyard.

5 Existing plant action and water in the central courtyard

The existing plant in the sense of parterre and water in the sense of pool, may supply humid and fresh, air as well as shade in the yard. All spaces approaching the courtyard can lead to their receiving this humid and delicate air. In an indoor shaped rectangular courtyard with dimensions of 19m x 14m, 2% of the surface area has been dedicated to the parterre and 2.3% to the pool. In the outdoor octagon courtyard approximately 50% of the surface area is dedicated to the



1) Entry
2) Hayat-e-Markazi (Central Courtyard)
3) Ivancheh (small veranda)
4) Sehdari
5) Talar (hall)
6) Otagh (room)
7) Hozkhaneh (basin room)
8) Hoz (basin)
9) Baghcheh (small garden)

Figure 1: Plan of the Karimi house.

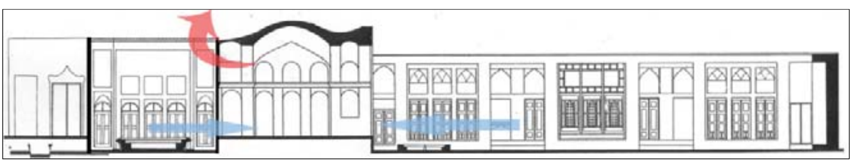


Figure 2: Existing wind in the central courtyard.

pool. Generally, in Isfahan, compared with other cities such as Yazd, the water pool is deeper. In conclusion, the central courtyard is an element made of space, which is limitedly involved in nature restoration (Ahmadi [6]).

6 Existing wind in the central courtyard

As a result of existing shade, the west facing indoor courtyards have a lower temperature in the summer afternoons, Due to it being expanded and lighter, less dense hot air indoor travels upward and, thus, it creates a pressure gradient between cool and hot air masses that allows air to escape out from both sides toward the sehdari and the hall located between these two structures. Upon its collision with the pool and the parterre, airflow becomes purified, cooled and humid and thereby natural ventilation is established in summer (particularly in the summer afternoons). Also, it is possible to make use of winds from the west and southwest in spring and summer by construction of a central courtyard.

Another remarkable thing to notice regarding the ventilation within this house is the utilization of a free plan in the design. The hall by the cross-shaped plan in the middle is in connection with sehdari-s rooms and hozkhaneh. The interconnection of these spaces is caused by sehdari which, when opened, would provide air convection toward every sector. Instead, it is also possible to close and separate these spaces by closing sehdari-s. This will be very effective in preventing heat loss in winter.

7 Existing light in the central courtyard

Considering the spaces formation around the central courtyard in four-seasons houses and their use in accordance with the required radiation and desired season, the spaces have been formed into northwest and northeast fronts in the Karimi house's yard. The northwest front privileges the utmost important position because of its benefiting from solar radiation and being magnificently glorious. In fact, the air equinox in Isfahan has decreased the importance of the nasard (shady sections, refers to the part of the building that is not exposed to the sun, this favours the southern section of the yard that receives the shade) sector of the house and the spaces of the north front have achieved a four-season function. Since Safavid's dynasty and king Abbass, the first Isfahan became the capital of Iran and the structure of Isfahan, Isfahani roon (roon refers to direction) changed to northwest-southeast, which corresponds to the climate conditions of the area. In fact, observing the climate axis has been so important that it became superior to the holy keblah axis. (Holy axis refers to the direction in which Muslims hold their prayers (kaba). This is the south western direction.) The use of northern west-southern east in the Karimi house provides the best condition to get sunshine in the winter and shade in the summer. Intense sun rays increase naturally with the widening of sun rays angles, which can be controlled by the tabesh band (vertical and horizontal curtains between doors). In Talars, also, white cotton cloth is used to protect the wood in front of oroses from the sun's rays as a movable curtain. The vegetation planted in parterres are deciduous and do not create unwanted shade in winter. Also, in summer the flower vases around the pool would prevent solar radiation from reflecting into water, which causes eye dazzling

8 Material of the central courtyard

Khesht (unbaked brick), as the main building material, has a high thermal capacity, i.e. it receives heat gains later during daytime and loses it later at night, Therefore, Khesht is able to adjust to the range of diurnal thermal changes. On the other hand, Khesht has a low thermal transmission and may be considered as good insulation. The tough and colourful texture of the Khesht makes the absorptions of the sun's rays limited and at the same time scatters the reflections of light. Because of the brightness of the external surfaces, and their great thickness, the use of carrier walls affects the increase of the minimum temperature of the building.

The wooden framework of the orosi and doors (especially those used in sash windows) is so constructed that apart from providing an ornamental (decorative) design for stained glass surfaces, it appreciably reduces the thermal exchange between the indoor and outdoor environment, without any noticeable decrease in lighting level (the function of wood as a heat insulator is also important). Orosi (sash window) is a netted window that goes up and down. It is ornamented with colourful glass and wood. Halls are usually covered with sash windows. Using small pieces of glass in the construction of sash windows is in accordance with the glass blowing industry of that era. The application of diverse colours altogether in an abstract form would turn the light entrance into a matter of religion.

9 Hozkhaneh

Hozkhaneh (basin room) is an elevated covered area enclosing a pool in its middle, which is usually connected with other spaces. In setting the spaces of the house, the corner spaces of the house are dedicated to secondary applications such as the kitchen, steps, etc., because of the lack of light from the yard. However, during the Ghajar dynasty, new solutions were found to use these spaces better. To solve this problem a skylight from the ceiling made the creation of new spaces possible. One of these spaces in the Karimi house is the hozkhaneh, creating a pleasant place for the summer. These climate-oriented thoughts show how these limitations were used to create new spaces according to the climate.

The hozkhaneh may be connected with the sehdari or hall and the hozkhaneh in the Karimi house with a cross-shaped plan and an octagon pool in the middle is also connected with its adjacent sehdari-s and hall. Light is allowed from reticular windows and colourful glasses into the roof, creating a fantastic reflection of light and colour playing on the water surface. The wind catcher also works over this space and in connection with the hozkhaneh it conducts the outdoor air into the hozkhaneh.

9.1 Summer daytime

During daytime the air above the hozkhaneh has a higher temperature than the air below it because of its adjacency to a hot mass of materials as well as its

Figure 3: Orosi and tabesh bands.

Figure 4: White movable curtain.

exposure to direct solar radiation. In general, hot air both from this sector and the whole house escapes by absorption through the window of the hozkhaneh or wind catcher along a path where there is no wind blowing. In addition, when the air enters from the hozkhaneh window or the wind catcher, it loses heat and becomes moist as it passes over the pool. Then, this cooled air is transmitted to different sectors.

9.2 Summer nighttime

At night, the air above the hozkhaneh is cooler than that below because of a thermal reflection with a high wavelength from the mass of roofing materials and existing cool air outside. Therefore, high dense cold air comes down and the lighter hot air moves upward and escapes out from the window of the hozkhaneh or wind catcher. This cold air and the air coming down from the wind catcher become wet when passing over the pool and, then, move to other sectors.

10 Badgir (wind catcher)

The Badgir (wind catcher) is a traditional architectural element that is an integrated part of residential houses of hot-arid and hot-humid regions of Iran (Mahmoudi [4]). The main function of the wind catcher is to receive and conduct airflow into the internal space and therefore it is referred to as the Badgir. Wind catchers are usually positioned in the summer-dwelling sector of houses and are connected to spaces such as the hall, hozkhaneh, basement (cellar) and yard, etc, and give natural cooling in these spaces by air convection and evaporative cooling. Dividing the Badgir's internal space by using separate blades results in simultaneous air entering and exiting through separate outlets into the space. Consequently among other functions of the wind catcher, one can mention hot air drawing out from inside of an edifice as a result of the chimney effect.

Susan Roaf has categorized the Badgir on the basis of a number of sides receiving wind in the wind catcher (Roaf [7]). According to Susan Roaf's categorization, the Badgir of the Karimi House is of a four-sided type that is in connection with spaces such as the hozkhaneh, sehdari and hall. With an approximate height of 4m from the roof surface, this wind catcher is placed at the four seasons front (north facing of yard) and contributes to passive cooling through air convection and evaporative cooling. It conducts the airflow into the indoor space in spring and summer. As the air passes over the hozkhaneh, due to its exposure to evaporative cooling, this airflow gets cool and humid and, thereafter, disperses within the space. The Badgir's opening is located within the indoor space to prevent hot air escaping from the wind catcher (chimney effect) in fall and winter. The existing wind catcher in the Karimi house allows the absorption of wind from the east, west and north in spring and summer for the four seasons sector of the house (north facing of the yard), which has access to west, east and southwest winds.

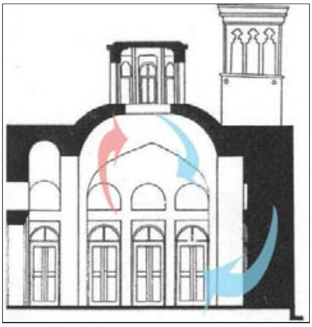


Figure 5: Summer daytime.

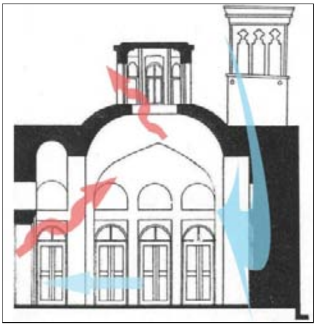


Figure 6: Summer nighttime.

Figure 7: Andarouni (the interior territory of the house).

11 Ivancheh

Ivancheh refers to half-open spaces that are shallow and roofed, limited from three points and open from one point. This half-open space acts as an obstacle for the reflection of the radiation. The other function of this indirect entrance is to reduce the ventilation of the weather from the inside and outside as a result of commuting in winter to these rooms. Ivanchehs are used in the Karimi house to enter sehdaris and the Talar in the east. Of course, the four seasons section Talar is connected to the yard by oroses, which can go up in summer to have access to the yard to use the air in the yard, hoz and the gardens.

12 Conclusion

The facts that are expressed about Isfahan climates by figures and diagrams, revealing this city's climatic crises and facilities, are reflected in the architecture of traditional houses, which can provide a solution for the crises. In Isfahan, thanks to the present moderate climate, it is not necessary to expend costs and supply materials to build summer-dwellings (as a demonstration of sustainable traditional architecture), unless they are specifically required where the land dimensions demand it. Therefore, the north facing of the yard playing a four seasons role, incorporates the elements of passive cooling systems, and these systems are designed in Isfahasn houses to confront the winter cold, giving prevention from radiation as well as providing ventilation and humidification in the summer.

Table 2: Passive cooling systems classification in the Karimi house.

Passive cooling systems	Central yard through air ventilation with proper temperature and humidity in the summer, obtained from water pool, garden, flower vases and shades
	Badgir
	Hozkhaneh
	Use of free plan for better natural ventilation
	Using horizontal and vertical curtains (shields) and white cotton cloth (as orosi room shade provider) to control radiation
	Taking the summer function of Ivan for Talar with orosi windows (orosi room)

Table 3: Passive heating systems classification in the Karimi house.

Passive heating systems	Central yard through the use of sun's ray based on the quality and quantity of radiation required for the winter
	Proper northwest-southeast orientation to get direct solar energy
	Application of spaces according to the season and time (division of internal spaces to hot and cold parts)
	The use of Khesht (unbaked brick) because of high heating capacity, low heating transmission, low radiation absorption and scattered high reflections
	The use of Ivancheh as a heating obstacle
	The use of wooden networks in orosies and Sedaries to reduce the use of glass in windows (wood is also good insulation)
	Application of great thickness of the walls to increase the minimum temperature of the buildings

References

[1] Broun, G.Z, Sun, wind and light: architectural design strategies, John Wiley: New York, pp. 20-90, 1985.
[2] Ghobadian, V, Climatic Analysis of the Traditional Iranian Buildings, university of Tehran: Tehran, pp. 129-146, 2006.
[3] Kasmai, M, Climate and Architecture, khak: Isfahan, pp. 29-217, 2005.
[4] Mahmoudi, M, Wind catcher symbol of Iranian Architecture, Yazda: Tehran, pp. 17-27, 2009.
[5] Pirnia, K, Familization with Islamic Architecture of Iran, Soroush danesh: Tehran, pp. 153-167, 2005.
[6] Ahmadi, F, Town-house central courtyard, Printed in No.41 of "soffeh", Iranian journal of Architecture, pp. 90-113, 2005.
[7] Roaf, S, The Wind catcher of Yazd, Ph.D thesis, Department of Architecture, oxford polytechnic, pp. 70-78, 1988.

Sustainable solutions for spa design, Dubai, United Arabic Emirates: building envelope optimization and impact energy evaluation

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Abstract

In recent years, energy consumption for cooling buildings has become a real concern, particularly regarding the availability of electricity during high load hours. There is a growing sensitivity in architecture for approaches that respect the environment and pursue energy efficiency. Ventilation, like other passive cooling solutions, involves conceptualizing a building as a body able to both recognize and metabolize the resources of its environment. In this context, the role of technology is no longer a "value added" to architecture, but a tool integrated with it. For these reasons, my study and research efforts have been focused mainly on the development of sustainable technologies. The intention is to exploit the natural elements of a site: sun, soil and, particularly, air. Thus, the design of the building is done in steps, starting with the choice of exposure and then moving on to the shape, the study of shielding systems, and the observation of greenery outside. The goal of optimal wellness is to locate buildings in a manner that does not adversely affect the potential use of climatic resources and to position individual buildings so as to maximize the use of winds while maintaining consistent configuration of shape and geometry. Graphics were produced to conclude the study design and to demonstrate CO_2 reduction.
Keywords: sustainable, archetypes, passive design, integrated, green energy, solar control, wellness, ventilation, energy efficiency, passive cooling, soil cooling, evaporative cooling, sustainable technologies, natural elements, climatic resource, insulating, induced ventilation, saving CO_2.

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1 Introduction

This proposal involves the designing of a wellness centre in Dubai using sustainable integrated solutions. The design theme was inspired by an interest in new forms of green energy, and attention was paid to typical Middle Eastern archetypes functions, such as solar control and ventilation. The project consists of the development of a resort designed as a set of housing units with common areas and a wellness spa. The area is located in one of the artificial islands of “The World” in front of Dubai City. Dubai is one of the seven United Arab Emirates (UAE). The homonymous capital is one of the fastest growing cities in the world. Its success is driven by its excellent geographical location, which makes it a connector to the main markets of Europe, Africa and Asia. Today, Dubai is a genuine work site, famous for an innovative spirit that enables architects and engineers to develop and implement projects while testing renewable technologies and new infrastructure solutions. Located about 16 meters above sea level, its territory is almost entirely desert. The appearance of reddish sand is due to a high concentration of iron oxide.

The climate in Dubai is extremely hot and humid, characterized by very low rainfall concentrated in the winter. The largest archipelago, “The World”, is located about 4 kilometres from the coast of Dubai and is comprised of 310 artificial islands. Each island has an area of between 300,000 and 900,000 square feet. Each island constitutes a nation, and together they form the shape of the world map. The islands are independent, each with flexible interpretation regarding uses and urban forms. Nakheel [1] is the company engaged in the real estate development projects, and is responsible for a series of colossal achievements in Dubai. Great importance was placed on the analysis of the needs of various sectors in the territory and to the consequent development of forward-looking projects based on emerged findings.

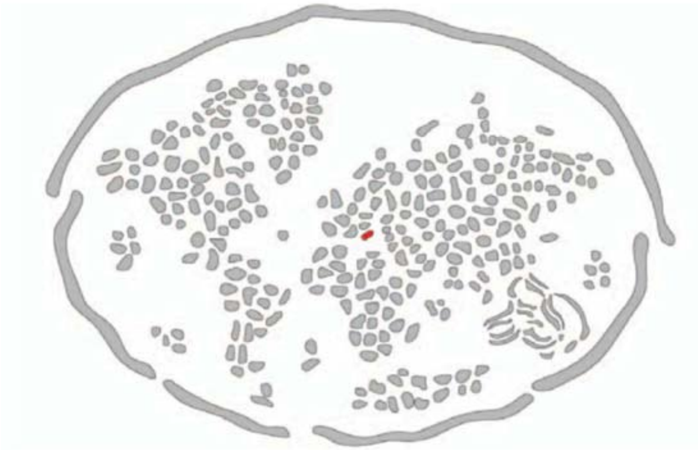

Figure 1: Masterplan “The World”.

2 Middle Eastern archetypes

Research on natural ventilation and passive cooling solutions has been conducted since antiquity in the Middle East. The archetypes described below relate to shares of the building envelope that are typical of Middle Eastern tradition and that perform the function of solar or ventilation control: elements combine and form a relationship between the architecture and the spaces that have to be acclimatized by using natural mechanisms [2]. One can witness construction systems that use *direct* natural ventilation, in which elements of air collection-extraction communicate with the environments that are to be cooled, as well as construction systems that use indirect ventilation, such as passive geothermic cooling with caption elements communicating via an underground pipe.

2.1 Malqaf

The *malqaf* is an example of wind chapter widespread in densely built cities, where the thermal comfort depends mainly on ventilation. In these circumstances, urban density significantly reduces air speed and a common window is inadequate for effective ventilation. The *malqaf* openings face north in order to capture the cooler air. The channel of communication between the *malqaf* and the interior has an outlet in every room. Iranian *malqaf* have a rectangular shape, are built in brickwork, and are high (between 8 to 15 meters). The caption opening is made with a colonnade opening facing prevailing winds. The channel conveys air especially to underground chambers and then makes it rise again.

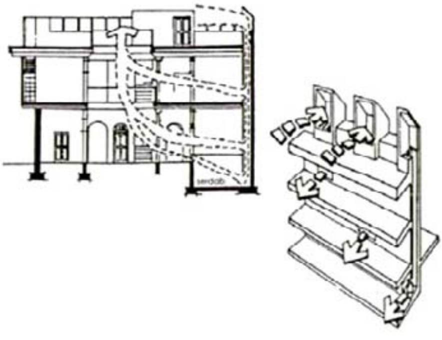

Figure 2: Malqaf.

2.2 Bàdgir

The *bàdgir* ("wind chapter" in Persian) is a system of multi-directional caption and extraction of wind, widespread in Iran and Persian Gulf areas. It consists of a tower with the summit opened on four sides, equipped with an internal vertical partition of bricks. The *bàdgir* functions to either capture the wind or to cool the flow as a result of a thermal mass that acts as a thermal flywheel mass: in the morning it is cooler than the air outside, which, in contact with the wall cools, becomes denser, and then drops down and enters the building. This process is accelerated in presence of wind. During the night the *bàdgir* returns the air absorbed during the day that, having moved into low areas of the building, has retained some of its freshness.

2.3 Qà'a

The *Qà'a* is a spatial element, whose name is of Turkish origin. The *Qà'a* is an environment that is ventilated and cooled by a *malqaf* and a small lantern operating in synergy. Traditionally, it consists of three environments: one *dur-Qà'a*, a central full-height space, with marble flooring and two *iwanat*, annex spaces with a floor level, covered with carpets, slightly raised in comparison to that of the *Qà'a*, and where social life commences. At the cover of one of the two *iwanat*, usually the one facing north, a *malqaf* is placed. The system works by using the pressure difference between the systems involved: the *malqaf*, located in the windward side to the north and, therefore, under an excess of pressure, traps the air of the prevailing winds, that is cooler and faster than the inner one, channels it within the *Iwan* and, subsequently, into the *dur-Qà'a*. In that environment the air, meanwhile heated, tends to rise towards the small lantern placed on the ceiling, passing through the openings. Often, a fountain is placed in the centre of the room, in order to increase the humidity of the environment and lower the air temperature by evaporative cooling.

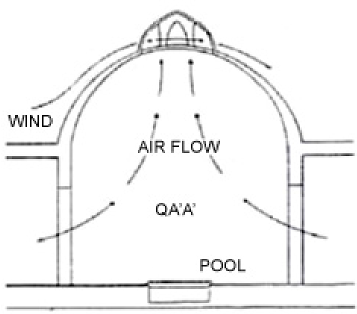

Figure 3: Qà'a.

3 Passive design

Passive buildings represent a more energy efficient type of construction. The design of energy efficient buildings is aimed at achieving perfect thermal insulation of the covering. These benefits are achieved with very careful planning, especially in terms of solar energy and high thermal insulation performance on the perimeter walls and glass surfaces, and through the use of ventilation energy recovery. The design philosophy adopted for these buildings is not easily standardized, because it changes depending on the site, local climate conditions in different seasons, natural resources available, socio-economic circumstances and habits in the area. Environmental, climatic, constructional, morphological, plant engineering, technological and behavioural aspects must all be in harmony, while improving the comfort of living.

3.1 Site analysis

The first step in designing a building that is energy-conscious and equipped with systems capable of capturing, storing and using the energy derived from external thermal solicitations, is a complete and structured analysis of the site and climate. This analysis entails accurately detecting the characteristics of the site area and collecting daily and monthly climate data. The main parameters that must be properly and dynamically analyzed are: air and soil temperature at different depths, windiness (wind intensity and direction), relative humidity, solar radiation, engineering design data, presence of trees or nearby areas intended for greenery, presence of natural or artificial watercourses, as well as other environmental factors. The design of passive buildings requires well-organized implementation and use of appropriate computer software.

3.1.1 Building orientation

When designing buildings, it is essential to provide an optimum orientation in relation to solar radiation. Sun warmth and natural light are free renewable energy sources that can be used to increase housing welfare according to the season. As for the orientation of the building, a good solution is usually represented by a rectangular shape elongated along the east-west, with the living area of the building facing south.

3.1.2 Presence of water

The presence of water such as marine and ocean basins, lakes and large rivers, produces effects on the microclimate and, if large enough, even on the local climate, either in relation to thermal exchange or to air movements. The effects of the presence of water masses in the microclimate are related to different thermal properties of water and soil: water has a higher heat capacity. If radiated, it tends to warm up more slowly than soil, but releases the accumulated heat more slowly. This produces, essentially, two types of phenomena:

a. an attenuation of temperature range, either daily or seasonal, of the air above the water mass compared to that above the ground;

b. a temporal mismatch of the dynamics of thermal transfer between water and atmosphere.

To the thermal mitigation effect produced by masses of water, we must add the cooling effect produced by water evaporation during periods of overheating resulting from the contact with masses of warm air that lap its surface. The presence of water of a certain size produces typical local winds that originate from thermal gradients: coastal breezes, caused by the daily cyclic variation of atmospheric pressure determined by temperature differences and thus by air density. These breezes begin to rise during the day, when the earth warms up and the pressure difference increases. The differential pressure is reversed and decreases at night when ground temperature decreases more rapidly than that of water, causing a decrease in wind speed and a reversal in the flow.

3.1.3 Winds

Air flows through a building are generated by the differential pressure that is established between two or more openings, due to either wind or thermal gradient. This differential depends on the variation of characteristic air parameters: speed, direction and thermal gradient. Thus, before calculating air flows, one should define the parameters that characterize the variation of speed and pressure fields around a building.

3.1.4 Vegetation

The presence of plants can characterize the context of a building and its relative environmental quality, thus having a direct impact on the building itself. High trees and shrubs can play an important control function in the local microclimate, upon which thermal, luminous and acoustic comforts depend. This is because vegetation can play a barrier function to solar radiation, light, noise and prevailing winds. Furthermore, vegetation determines transpiration phenomena that influence air moisture and temperature. The solar control function performed by vegetable barriers is due primarily to their ability to intercept direct solar radiation, by absorbing it before it strikes the surfaces of the building covering, and by reducing the component reflected by the ground through the projection of shadows on it. At low latitudes, the sun remains high for much of the summer day, hence only a very broad and umbellifer coverage (the kind of maritime pine or palm) can have a real function for cooling soil, surfaces and air beneath the foliage. These tree species, by also having a rather high attack of the foliage, allow the flow of ground-level breezes that further contribute to the site cooling.

4 Passive cooling

Passive cooling of buildings includes all natural processes and techniques for the dissipation of heat through climatic resources in order to avoid the overheating

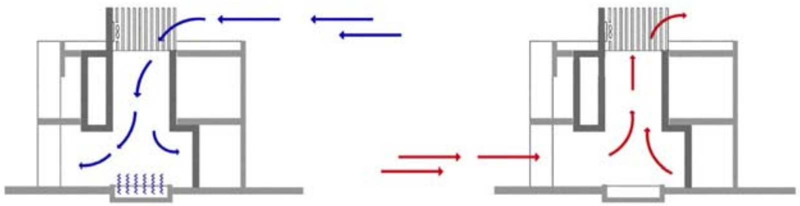

Figure 4: Input and output air.

of a room. It strongly determines the comfort of occupants and may increase in efficiency if assisted and controlled by electronic and mechanical devices [2]. A more advanced cooling strategy leads to the elimination of heat in excess, through natural processes of heat transfer towards the upper atmosphere and the surrounding sky. Cooling takes over whereas high summer temperatures can cause environmental discomfort. It is possible to distinguish among the following main technical solutions:

- *Soil Cooling*: ground temperature is almost constant throughout the year and thus can be used to compensate heat loss through the building walls;
- *Evaporative Cooling*: in a warm-dry environment, adding moisture to air decreases its temperature of dry bulb, thereby improving comfort levels (this can be achieved by spraying water in a stream of air or by placing sheets of water or fountains in a courtyard);
- *Induced Ventilation*: the sun can be used to induce air movement (with a thermal chimney it is possible to activate natural ventilation and increase comfort levels).

5 Control of solar radiation

The need to illuminate interiors with natural lighting is quite clear. Aside from the purely energetic contribution, one should not underestimate the psychological and ecological benefits that are associated with the use of natural lighting. However, natural lighting exhibits two drawbacks that make it difficult to use: directionality and very high intensity [3]. Moreover, in tropical areas, where the environment produces clear sky conditions during the dry season and overcast conditions in the wet season, special consideration must be given to the adequacy of natural lighting. In such climates, the natural lighting of buildings depends on the need of excluding or limiting direct exposure to sun light, which represents a thermal gain.

5.1 Sun-shading system

Shields have an important role in solar control since it is very difficult to reach a sufficient level of solar protection using only high performance covering technologies. Shields, if planned in relation to the seasonal path of the sun, can offer effective summer protection, helping to ensure comfort conditions all year around. There are numerous factors that must be considered when designing a screen. Among the major elements we can list: the latitude of the site, the orientation of the surface to be protected, and the location where the shield itself is planned to be placed. Types of shielding are varied and diverse and can represent significant elements of architectural language. The positioning of a screen is a major factor for thermal control: if placed outside of the transparent surface, its effect is greater than inside, as it intercepts solar radiation before it enters in the building, allowing outside air to disperse absorbed heat. If placed inside of the transparent item, radiation, although it does not directly hit the surfaces of the internal environment, is absorbed by the individual elements of the screen, which by warming, transfers the heat inside, by radiation and convection, thus adversely affecting the energy balance of the summer. The effectiveness of the screen varies, therefore, considerably. In particular, we must consider:

a. the proportion of intercepted solar radiation in comparison to the incident one, which depends on the geometry and management of the screen;
b. the remission of infrared of heat absorbed by the elements that make up the screen, depending on the location, the equipment and its characteristics.

5.1.1 Psychophysical wellness

The presence of shielding has direct effects on the perception of the internal environment by the occupants. In the selection and design of the shielding system, as mentioned above, it is necessary to consider the different needs associated with the presence of individuals within rooms and the characteristics of the activities are conducted within those rooms. In particular, we must consider the requirements associated with the following areas:

- *Thermal Scope*
  - containment of energy consumption for cooling and heating (solar control in summer and winter);
  - control of air temperature within comfort levels;
  - limiting people's direct contact with solar radiation;
- *Lighting Scope*
  - control of the level of natural lighting;
  - test of the distribution of lighting levels;
  - limitation of glare effects;
- *Perceptual Scope*
  - internal-external vision by users.

The designer must choose the type of screen by weighing, from case to case, these needs and trying to minimize conflicts, dictated by the opposite character of some of them. Each technological solution, in fact, will be the right compromise in relation to the intended use of the rooms.

6 Solar energy

Solar radiation can be used in buildings and homes to directly produce electricity, hot water for sanitary use, and/or under floor heating systems. The energy that can be recovered through solar collectors is influenced by a number of factors, such as the overall availability of solar energy and the performance in transforming this energy (influenced by the type and placement of collectors). The efficient use of this form of energy affects the overall design of buildings that must be designed from the onset to adequately capture and store the heat from direct sunlight. The photovoltaic system is the only proven technology for the production of electricity from solar sources. In recent years, the production of such modules has experienced growth rates exceeding 30% per annum.

6.1 Solar collectors

Buildings that have a sunny area (flat roof, sloping roof, garden, etc.) can be equipped with solar systems. The yield of a solar heating system depends on several factors: the local weather conditions, area and type of system installed, heat load, etc. In order to achieve maximum efficiency, these systems are placed in the best possible position in an easily accessible area, non-critical in the anchorages and able to make the most of solar radiation. The collectors should preferably be directed southwards, with a tolerance of deviation to the East or West of 30°. Solar thermal systems can be based on natural circulation or on forced circulation. Natural circulation solar systems consist of collectors and a tank mounted on the same chassis. This is a closed loop system that works on indirect exchange and in which the circuit of the heat transfer fluid is always separated from the water going directly to users. In such systems, mechanical or electrical equipments are not necessary for operation: the sun is the only source of energy for which they are equipped. The thrust of the thermo-conveyer fluid is given by the difference in density between the column of the hotter fluid that tends to rise and the colder column coming out of the tank that tends to fall. The fluid, through a cavity of the shell, releases heat to the water contained therein that flows into the circuit of users. Forced circulation systems are, by contrast, more complex and therefore require more maintenance. For systems with natural circulation, a lower initial investment and minimal maintenance are required and, therefore, are a recommended solution for small users. The installation of forced circulation is rather realistic for every demand, but requires careful monitoring of its performance and is therefore a recommended solution for medium and large facilities with a technical staff for routine maintenance. The main use of solar collectors is inherent in the heating of water for sanitation purposes, but their use can be extended to great advantage in all situations that require heat at low temperature. For example, their use is particularly suitable for heating swimming pools.

6.2 Photovoltaic plants

PV is a renewable source that can help cover the electrical needs by reducing pollutant emissions. The photovoltaic effect can convert sunlight into electricity through the use of photovoltaic cells composed of a semiconductor properly treated (usually the pure silicon). There are two types of modules on the market: crystalline silicon and thin film. Crystalline silicon modules are formed by assembling several cells together. They can be divided into modules with monocrystalline silicon cells or polycrystalline silicon cells. The mounting frame which supports the modules must guarantee a certain resistance to wind and temperature changes, and ensure a lifetime of more than 20 years. The assembly of modules and connections should be as simple as possible and allow the replacement of a module or more modules, without having to disassemble the entire plant.

7 Insulating PCM

Often called PCM, "Phase changing materials," are insulating materials which are intelligent accumulators of heat, exploiting the physical phenomenon of phase transition for absorbing latent heat energy flows and storing a large amount of energy, keeping constant its temperature, and returning the heat outside during a subsequent lowering of temperature. In fact, PCM are solid capsules at room temperature, but when the temperature exceeds a certain threshold, they melt accumulating heat, which is subtracted from the environment. The PCM are a product of NASA research, and only recently have been applied for energy saving in the construction sector. The materials that contain PCM may differ - plasterboard, wood, plaster, plexiglass, and can be applied in various system solutions, such as heating, cooling, solar collectors and heat exchangers. They can also be contained in a layer of plaster, thus allowing the maintenance of pleasant temperatures inside buildings. These wax microcapsules are protected by plastic wrap, so as not to spill out of the plaster during the winding phase.

7.1 Fibreglass insulation – the Nanogel

Nanogel [4] systems are also very innovative and are able to achieve high levels of isolation combined with characteristics of lighting diffusion. They were introduced by the United States in Europe in early 2000, and are used to make public and sports buildings, since they have particular characteristics of lighting diffusion, avoiding shadows and the use of externally applied shielding. Special sandwich panels have an internal aluminium structure or a fibreglass grid with the cavity completely filled with Nanogel. This is an insulator composed of silicon micro-grains and nanoscale-pores that make it similar to a sponge composed of 95% air, with a thermal transmittance of 0.28 W/mqK for a thickness of 70 mm. This value of transmittance is much greater than that of a traditional glazing system, it is in fact similar to an opaque wall, but is much less thick. With this technology it is possible to manufacture large surfaces that are permeable to natural lighting and are capable of ensuring high levels of insulation and energy saving.

8 ECOTECT v5: software for sustainable design

ECOTECT v5 is the most comprehensive and innovative program on the market today for the verification of buildings. ECOTECT [5] allows application of the principles of environmental design starting from the conceptual and ideational phase of the project. The program has an interface for 3D modelling, integrated with functions for control of acoustics, thermal insulation, lighting, solar energy contribution and costs. What really distinguishes the program is that it can serve as a support throughout the entire project phase, from testing early theoretical elaborations to last stage verifications. It is possible to get useful information before the shape of the building has been fully developed. Detailed analysis on the climate can be used to optimize available resources of light, wind, and sun, thanks to the interpretation of models sketched, which are easily analyzed and compared. Verification is done in detail at any stage of design. The most significant feature of ECOTECT is the interactive approach to the analysis of data. It is possible to add a window and immediately see the effects on thermal insulation, compared to the benefits in terms of natural lighting, solar radiation accidents, and the overall cost of the building.

8.1 Hourly solar exposure

The graph shows a single image in the global hourly radiation available on the selected surface, its share in the shadows, the value of the incident and reflected radiation of objects in the model that are set as solar reflectors. The global radiation is calculated according to the geographical location of the project, which refers to the climate data file previously loaded into the model. The direct radiation is the proportion of solar radiation that affects the selected surface, while the scattered radiation is the part of solar radiation emitted by the vault of heaven.

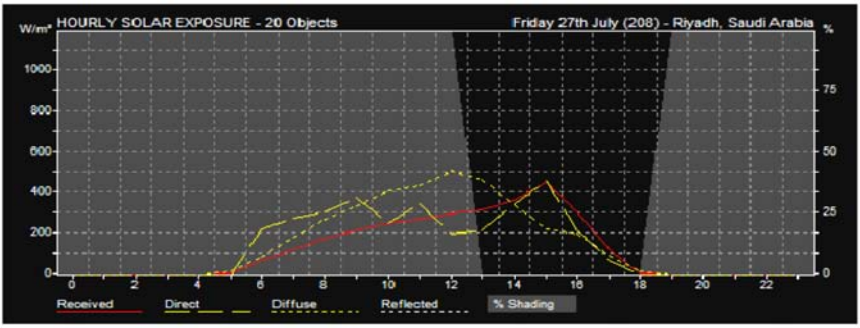

Figure 5: Hourly solar exposure graph.

8.2 Received solar radiation

For each month of the year, the average daily solar radiation that strikes a specific area of the model is determined. The total solar radiation for each month of the year is calculated from climate data file reference and then divided by the respective number of days. The graph shows the resulting hourly average values that might be expected on any day of the month: the warmth of each cell represents the intensity of solar radiation striking the selected surface in a precise time of an average day of a given month of the year.

8.3 Hourly temperatures

This graph shows the time evolution of temperature within each zone on the date selected. Dashed and dotted lines represent the data of the climate of that day, as explained by the legend directly below the graph, while the solid line shows the trend of the temperatures inside the rooms. The temperature of the chosen area is highlighted in double thickness. Gradients red and blue in the graph indicate when the temperatures in the area are below or above the level of comfort, respectively.

9 Conclusion

The combination of the described technologies following the global approach of the sustainable design, allowed one to reduce the global energy consumption of the SPA of about 30-35% with a consistent reduction of CO_2 emissions and of land resource consumption. It is important to underline how an extreme climate, such as the one in Dubai, permits to obtain the maximum performances from almost all the described technological systems. The substantial reductions of the realizing, the management and the environmental costs of the buildings are demonstrated by the first results of the compared LCA analyses actually performed in CITERA laboratories.

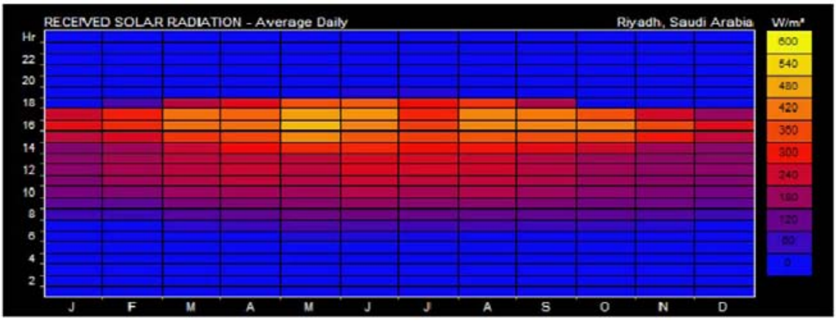

Figure 6: Received solar radiation graph.

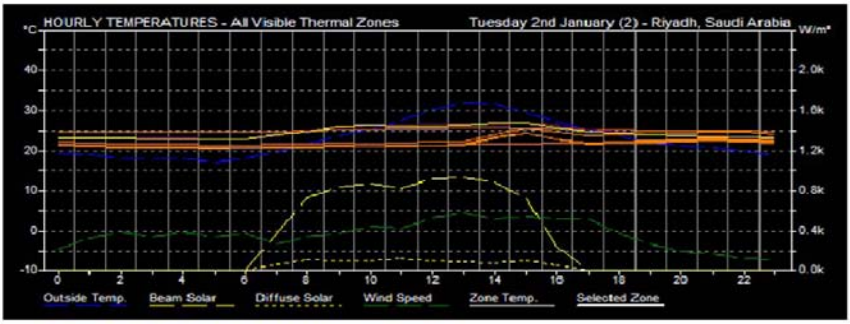

Figure 7: Hourly temperatures graph.

References

[1] Assante E., *Dubai, Las Vegas in the Persian Gulf*, La Repubblica: Roma, 11 Agosto 2008, **intro**.

[2] Pilotti L., *Le torri iraniane: un mirabile esempio dell'arte del costruire,* Urban Review n°44, 10/22/2007, **2**.

[3] Grosso M., *Passive cooling in temperate zone*, Maggioli 2008, **4**.

[3] Hopkinson, *Control of solar radiation*, 1966, **5**.

[4] Spagnolo M., *The future of ultra-efficient materials* www.rinnovabili.it, 18 January 2008, **7(1)**.

[5] Urso M., Integrated simulation solutions bioclimatic- *ECOTECT software sustainable design construction*. ISES Italia, 2007, **8.**

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The harmonisation between architecture and nature in the desert of Iran with a hot and dry climate

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Abstract

In the modern world, achieving the methods of design and construction with the aim of achieving a balance between art and architecture in a special environment is very important. Iran, a four season country with different climates, could be used as a case study about the harmonization between architecture and nature. By reviewing the architecture and urban design in a hot and dry environment, we discover that the traditional architects have had several solutions to overcome the climate challenges. The conclusion of these solutions leads to the creation of practical and executive works. These architectural methods are the main subjects of study in this paper. Some of these methods are as follows: solar orientation of the functional spaces in the buildings; functioning of the complex system of the air circulation between the wind-catcher, fountain, and interior spaces; designing special spaces for different seasons around the inner courtyard in private houses; creating special spaces for different seasons (for example, colonnade, garden, underground gardens, cellar); smart light control systems in openings. In conclusion we can use modern eco-architecture and apply such design solutions to achieve the passive systems for architecture in hot and dry climates without incurring much expense.

Keywords: traditional architecture, desert houses, wind-catcher, passive air conditioning systems, sash windows, court yard, natural lighting.

1 Introduction

A hot and dry climate exists in most areas of Iran's plateau, which is located in the Asia continent.

This area, with its desert nature and different visages of urbanization and architecture, has been favoured for eco-architectural researches. In Iran, on the central plateau, there are areas which have a dry and hot climate, and because of intense and direct radiation of the sun during the day, the weather is very hot and dry most of the time.

Because the sun radiation produces 700 to 800 kilo calorie of energy per hour in each square meter of horizontal surfaces, and because of scattered plant cover, reflection of this radiation causes warm weather. Lack of humidity in these areas causes a meaningful variation in the range of the temperature between the day and night which is around 25^0C, since the temperature in the hot days of summer reaches to $40^0C - 50^0C$ and, it reduces to 15 to 20 ^{0} at nights Kasmai [1].

2 Desert cities, desert houses

In such a climate, the organic plans of the desert cities have been formed based on the solar orientation in a compacted and complex texture.

The passages in these cities are seen with smart orientation against the sunshine and there are also narrow passages with high walls. The passages are covered with roofs in some places which makes shady spaces for pedestrians.

Now we want to review the architectural practical solutions in these houses. As mentioned in the abstract, the first general technique is the orientation of the buildings.

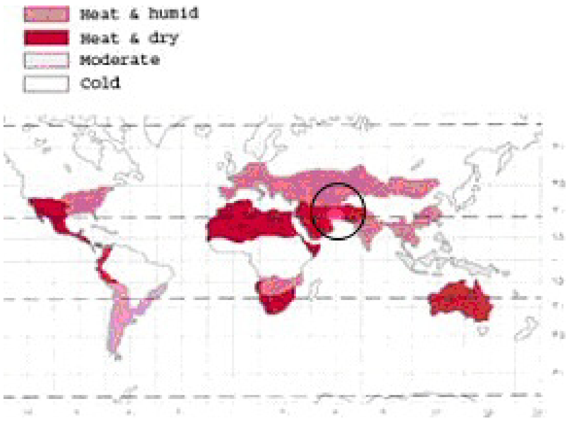

Figure 1: The position of Iran in Asia.

Figure 2: Two views of a passage.

2.1 The building's solar orientation

In these areas the orientation of houses is often toward the east-west axis, so the wider surfaces with long time function stand in the best position to get the desired lighting and temperature from the north and south Ghobadina [2]. The results of such an orientation are:

1. In the hot seasons, the main spaces receive a little light and heat and in the cold seasons, they receive more light and heat.
2. None of the main spaces receive the light and from the west in the sunset.

2.2 The work of the complex system of the air circulation between the wind-catcher, fountain, and interior space

This solution, as a creative way in making natural comfortable conditions, has been built by different methods and forms. The main element of this system is a wind-catcher. Development and evolutional trend of the form and function or optimization of defects of the wind-catcher structures have always been aimed at better exploitation. So the structures of the wind-catcher, except the aesthetic parameters, have been influenced by the following factors:

1. The direction of the desirable wind blow in different periods and seasons of the year.
2. The speed of the wind blow.
3. The height of the desirable wind blow.

The structure of a wind-catcher, as shown in Figure 3, consists of a perpendicular channel. This channel is a rectangular cubic usually made of mud brick for insulation and is often covered by clay and straw. The inner layer of the channel is covered by a plaster layer.

In some channels, the main channel is divided into several perpendicular sub channels Mahmoudi [3]. According to traditional architects this division has been done for two reasons:

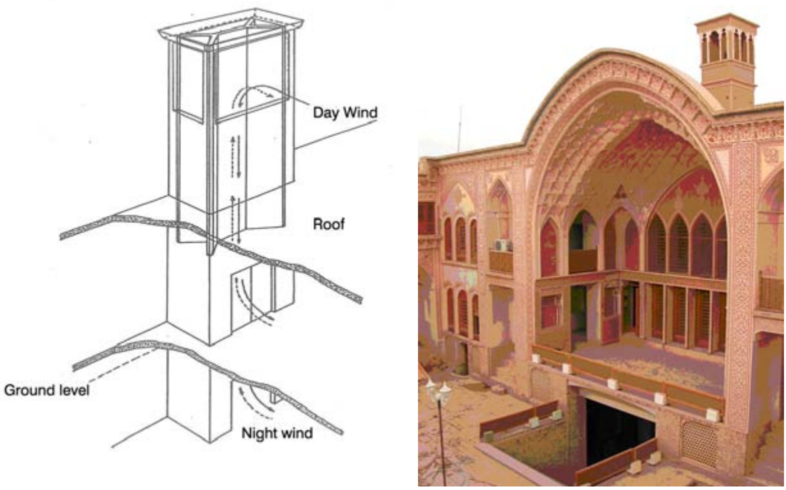

Figure 3: The usual construction of a wind-catcher.

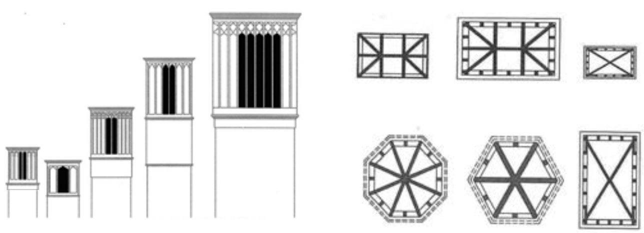

Figure 4: Various shapes of wind-catcher.

1. In some cases the pores of the wind-catcher are oriented in more than one side to get desirable winds in different periods of the year or day. In such a design one channel acts as a receiver of the wind and the others act as the transmitter of the inner air to the outside. The circulation happens because of creating positive pressure in the pore toward the wind direction and negative pressure in other pores which is not toward the wind.
2. Creating smaller channels to speed up the wind as a fluid substance. These sub channels may be seen with different cross sections, for example, it can be seen in the fig 4.

The height of a wind-catcher is normally between 3-8m. In some particular cases, you can see wind-catcher with the height around 1.5m and above or rarely a height around 9m. Two major factors determine the height of wind-catcher:

1. Increasing the height raises the speed of the wind.
2 In the desert area raising the height of wind-catcher increases more temperature gap between the upper and the lower points of the wind-catcher Mahmoudi [4].

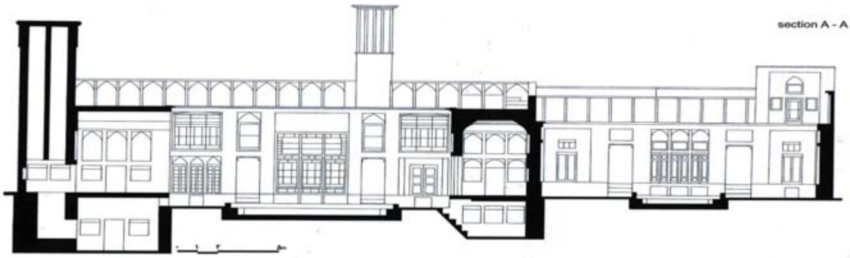

Figure 5: Relation between wind-catcher and spaces (Haji-Ghasemi [5]).

Figure 6: Fountain in the basement "Hozkhaneh".

In the same way it was addressed in the evolution path of the structure of the wind-catcher, the function of the element has also been designed based on three ecological factors:

1. The wind speed.
2. The wind direction.
3. The temperature difference between the air mass at the bottom and top of the wind-catcher.

It's worth mentioning that, the third factor acts when the speed of the wind is lower than 2.5m/s. If the wind flows in a speed higher than 2.5m/s, it overcomes the pressure difference [6]. The second factor is the main factor in the typology of the wind-catcher, determining that the wind-catcher is two, four, six or eight-sided. Another trend in designing passive system of the wind-catcher, to create desirable air in the inner spaces of a building, is to pull in the cold and humid air flow which passes through the water inside the fountain.

In the most cases in residential houses, a wind-catcher is used to cool the air of the main hall which is a summer-sitting space. It's worth noting that, in a desert house, the spaces based on the ratio of the sunshine they receive are known as the summer-sitting and the winter-sitting spaces. Another summer-sitting space that is included in this passive air conditioning system is the basement.

2.3 Designing special spaces in private houses for different seasons of the year, including the inner courtyard, underground gardens and colonnades

The inner courtyard is located at the centre of a house which creates different sides. In these sides the heat of the sun’s rays are different. Such a design creates functional spaces for different seasons. This special lighting was used for a sitting room, so it is called summer sitting spaces or winter sitting spaces.

Below, a residential plan is presented as a sample of different functional spaces. The winter-sitting spaces are shown in blue (down side of the figure) and the summer-sitting spaces are shown in red (up side of the figure) Badkhan [6].

The height of the walls can also affect the lighting and the temperature. The yard's walls are high, which create shadows in the yard and the rooms at most hours of the day.

The other surprising trend in some of the desert houses, which is employed to create shady spaces, is a garden in the underground level inside the main yard.

1. The underground garden is in the shadow at most of the day time, because it is located at the 4-6m below ground.
2. Since it's surrounded by underground cool space, it is colder than the main yard.
3. As the underground garden is located below ground the insulation is naturally completed.

Colonnade (Iwan) is a shady space located between the main hall and the yard. Colonnade is covered by a roof and walls on three sides, which prevents the main hall from exposure to sunshine and heat.

Figure 7: A house with two inner courtyards (Haji-Ghasemi [7]).

Figure 8: A view of an underground garden.

Figure 9: Different depths of colonnade (Iwan).

2.4 Creative use and control of the light

In addition to attention to the control of the light in designing plans, Iranian architects have paid attention to design and construction of details and decoration of the buildings as well as the wise control of the light.

The example of this technique for facing the light are:

1. Pores covered with lattice screens in the ceiling control the entrance of heat and sunshine.
2. The transparent surfaces created with the suitable design, quality, partition and texture. Transparent surfaces control the light as a filter. The screen structure also prevents the transparent body from heat by creating shadows in

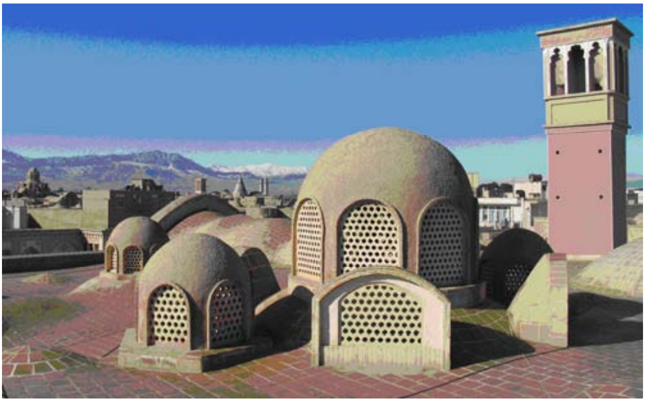

Figure 10: View of complex pores from the roof.

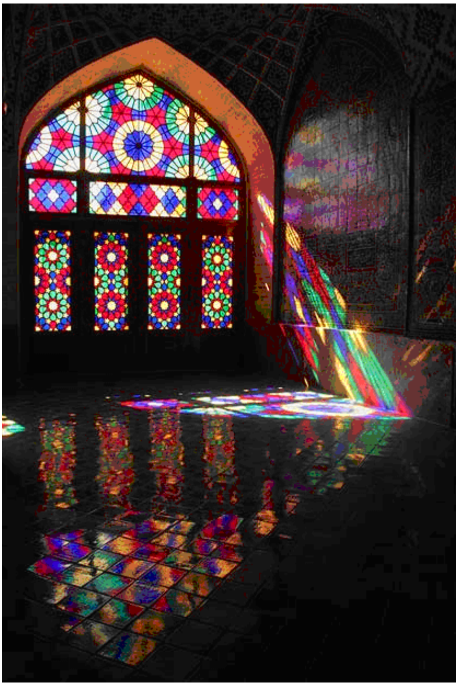

Figure 11: Partition, texture and coloured glasses control the light as a filter.

Figure 12: A transparent surface as a window.

Figure 13: The coloured glasses in a window.

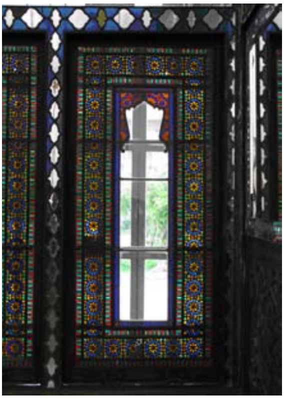

Figure 14: The mirrors in a window.

the same transparent layer. The result is that the warm air circulation will not happen by the windows.
3. Using coloured glasses in the windows controls the ratio of sunshine entering into the building.

2.5 Creative design and the way of using the materials

The first effective factor for choosing materials in desert areas is to be able to act as an insulator against the sun's heat. Henceforth, the majority of the materials from the structure to the cover of the surfaces consists of wood and mud brick.

The walls of 60 to 80cm, or even 1m thick, are made of mud brick and act as high insulators for the interior.

Usage of the materials which attract heat such as stone are limited and they are used in the foundation to prevent the building from the effects of the humidity.

The soil gained from digging the ground was used as the material of building the houses. The humidity of this soil caused to cool the weather of the inner space.

3 Conclusion

Obviously in the modern world paying attention to the design principles based on the climatic condition does not mean omitting the active system, but it means optimizing energy costs.

Design principles in hot and dry climates lead to implement practical techniques in designing details and elements in the modern architecture such as below:

1. Designing condensed buildings: building should be condensed and inner directed so that the minimum surfaces are exposed to the sun radiation.
2. Attention to the north – south direction: It should be noticed that surfaces which need more lighting and less heat should take the light from the north and south directions. The other point is that the western surfaces are critical surfaces as they receive the direct sunshine and maximum heat but the lighting they receive is not desirable.

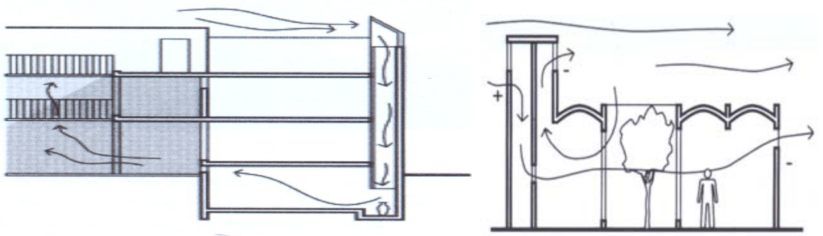

Figure 15: Wind-catcher and courtyard in modern architecture (Holger Koch [8]).

3. Attention to the direction of cool and clear wind in designing wind-catchers: The orientation of the wind-catchers depends on the wind as an important factor. A wind-catcher's direction should be in a way that receives most of the cool and clear winds.
4. Creating natural shady and cool spaces: this can happen by taking benefits of shadow of trees and using fountains as a natural cooling system.
5. Attention and more creativity in designing windows: Taking benefit of this procedure can decrease the waste of energy and help in receiving the most desirable lighting. This solution can be achieved by taking benefit of the following elements:

5-1. Transparent surfaces: management of the amount of the light entered to the spaces is possible by using transparent surfaces such as lattice screens.

5-2. Coloured glasses: management of the wave length and creating the desired light which enters into the spaces is possible by using coloured glasses. Using this type of glasses attract and reflect the desired sun rays better than the ordinary glasses.

5-3. Mirrors: taking advantage of mirrors in windows can reflect the sun light and reduce the heat in inner spaces.

5-4. Sash and double shelled windows: this element can help in insulation by its unique design. The body of sash window is made of a wooden frame which carries woodcuts in the form various plants and geometric shapes. Sash windows are usually in a rectangular form and their upper part has

Figure 16: A sash window and its details.

colour glasses which are in arch or rectangular shapes. Such windows and doors are widely employed in the houses of hot and dry climatic areas to adjust and soften the light. Using wooden double-shelled in this kind of window causes an air layer between two layers of window (double shelled) which acts as a heat insulation system and prevents waste of the energy.
5-5 Knot-works: using various knot-works in the frame of windows causes breaks of the light radiation and prevents the radiation of the direct sun light into the inner space. According to the calculations in opposite knot-works, 40% of the surface is composed of glass and the rest is composed of wood as the main material of the window.

Figure 17: Breaking the light radiation by various knot-works.

References

[1] Kasmai, M, *Climate*, Khak: Esafahn, p.82, 2003.
[2] Ghobadian, V, *Climate Analysis of the Traditional Iranian Buildings*, Tehran University: Tehran, pp: 6-7, 2006.
[3] Mahmoudi, M, *Badgir (The element of Iran architecture)*, Yazda: Tehran, pp.76-79, 2009.
[4] Mahmoudi, M, *Badgir (The element of Iran architecture)*, Yazda: Tehran, pp.80-115, 2009.
[5] Haji-Ghasemi, K, *Ganjnameh cyclopaedia of Iranian Islamic architecture, Yazd houses*, cultural and Heritage organization: Tehran, volume14, p.90, 2005.
[6] Battle McCarthy Consulting Engineers, Natural and wind driven ventilation, (Cahpter2), *Wind Towers*, Academy Press, 1999.
[7] Haji-Ghasemi, K, *Ganjnameh cyclopaedia of Iranian Islamic architecture, Yazd houses*, cultural and Heritage organization: Tehran, volume14, p.75, 2005.
[8] Holger Koch., N, The built environment (Chapter 2), *Stay Cool: A Design Guide for the Built Environment in Hot Climate*, Earthscan Publications: United Kingdom, 2002.

Section 4
Life cycle assessment

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Life cycle design of building elements: selection criteria and case study application

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Abstract

In the last years there has been a multiplication of the International and European political interventions addressed to the diffusion of environmental sustainability in the building sector. In this area the life cycle design of technical elements assumed particular relevance. The materials and construction techniques used, like their durability in the use phase and their disposal strategies, tend to influence the environmental behaviour of a building during its whole life cycle. It is worth recalling the energy consumption connected with the extraction, production and assembly of the materials (initial embodied energy) and with maintenance, replacement, and dismantling activities (lifecycle-embodied energy). At the present time the rules focusing on the environmental certification of technical elements allow one to meet these objectives only in part. The study that will be presented, based on eco-design and Life Cycle Assessment criteria, uses this knowledge to explain research work focused on a comparative evaluation of some technical elements, and analyzes different end of life scenarios, in order to further understanding and improve their environmental impact.
Keywords: eco-design, plaster coverings, life cycle assessment, reuse, recycling, construction waste reduction.

1 Introductory remarks

The present contribution synthesizes a research and experimentation job produced within the Italian Workgroup on the "Identification of minimum environmental criteria for the choice of building materials". The Workgroup works within the Management Commission of the NAP-GPP (National Action

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doi:10.2495/ARC100261

Plan for the Green Public Procurement) aiming at contextualizing, with regard to the national territory, the GPP criteria already developed by the European (CE COM 400/2008).

Within the Workgroup's activities two meaningful requirements emerged:

- the need to harmonize the above-mentioned criteria with the other instruments already adopted by the Public Administration for the planning and awarding of public contracts, such as the technological classification of building works (UNI 8290/1981 Italian system and SfB/1970 international system, in the version revised by the CIB-International Building Council) and price-lists to establish standardized costs, so as to be able to put economical information together with environmental information;
- the need to extend the analysis on the environmental behaviour of materials, products and building elements to the more meaningful phases of their life cycle (ISO/TS 21931-1/2006; CEN/TC 350, under development), so as to be able to integrate environmental criteria with indicators concerning the phases of use, maintenance and demolition, poorly documented by present-day environmental certification instruments, such as the EPD for building products (Environment Product Declaration, ISO 21930/2007) which refers prevalently to the extraction and production phases (from cradle to gate).

1.1 Classification of building elements

As far as the classification of technical elements is concerned, it is interesting to note how a division based on the single categories of usable materials would turn out to be rather fragmentary, in view of the present-day tendency towards the multi-materiality of building elements and the performance specialization of single functional layers. Therefore, it turns out to be easier to adopt the division defined by the Italian UNI 8290 rule and the international SfB system, both based on the identification of some "functional" categories, defined as "technological unit classes" (structures, closures, partitions, plants, etc.) and their subsets or "technological units", and of further "physical" categories of represented by "technical elements classes" and their subsets or "technical elements", which represent the manner to reply to the functions required of the technological units, obtained through the use of specific materials, products and building techniques. In this way, the technical element "wall" or "covering", for example, will be able to be constituted by a plurality of materials and products, joined in such a way as to obtain the expected final performances.

The building solutions adopted will define the correlation methods and joining of the single materials and products, and the workings necessary to guarantee respect for the overall technological performances (construction manner, functioning and maintenance mode, disassembly mode). At this level of in-depth examination, the technical forms associated with the selected materials and products will be able to supply a useful contribution to the knowledge of their specific characteristics and relative construction methods. Furthermore, once they have been developed and integrated, they will also be able to supply information regarding the product's environmental performance (Aninik et al [1]). The single materials (cement and concrete, clay bricks, wood and wood by-products, metals, etc.) and products (panels, fixtures, floors, façade systems, etc.) will thus be able to be identified depending on their belonging to a specific technical element, whose description will also include the workings necessary for their laying, and thus, lastly, the cost relating to the complete realization of the technical element itself.

1.2 Environmental qualification of building elements

In turn, environmental behaviour will be able to be easily identified both at a technical element level, as a summation of the specific environmental performances of the single materials, and at the level of single products, with particular reference to the extraction and production stages (including transports), building, maintenance and demolition. Exceptions are multi-coupled materials or materials mixed on the building site, and more generally multi-material elements, separable with great difficulty at the end of their life. In that case, the environmental behaviour tied in with the demolition, too, will have to be associated with the whole technical element, or portions of it. However, generally speaking, it is possible to hypothesize the traceability of single materials and products inside the building and their specific environmental qualification, associated with corresponding certification of the producer. The most important is the aforementioned EPD, already developed for several product categories, also in the building sector (see: www.environdec.com).

While the task of arranging for the environmental qualification in the production/building phase is easily attributable to the executive firm, and its suppliers, the environmental qualification in the demolition phase is more difficult to manage, both because of the lack of specific certification instruments and for the lack of a consolidated environmental management system of the demolition works based on the separation of the residual products and the withdrawal of the recovered materials by the producers (Berge [2]). The implementation of such a system in contrast with the traditional transfer to landfill would produce meaningful environmental advantages, as is underlined in the ICLEI-Local Governments for Sustainability document "Construction Green Public Procurement Product Sheet" (see: www.iclei-europe.org).

2 The case study: external plaster covering

The case study presented tries to study in depth the aspects relating to the optimization of environmental behaviour in the life cycle of the technical elements of the building, through the analysis of a portion of the building element represented by an external plaster covering. In particular, it studies closely eco-design and environmental assessment aspects tied in with the utilization of different materials and constructive methods. The purpose of this is to be able to identify the most meaningful environmental impact and deduce from that, in an inductive way, a set of minimum environmental criteria.

The materials and building techniques taken as a reference are those most currently used in the execution of public and private works, both for new buildings and for the renewal of existing ones. Reference is made to cement-based plaster and hydrated lime-based plaster, these latter ones having been recently reassessed for their transpiration characteristics. Added to these, it was thought to be appropriate to add a further material used traditionally for the realization of plaster, represented by raw earth with lime, a low-intensity energy material which is being reintroduced for its capacity to combine further ecological qualities tied in with reduced environmental impact during the whole of its life cycle (Basti [3]) with the transpiration quality of hydrated lime. For all three materials, reference was made to the specific techniques of the producers and the descriptions of the executive methods contained in the technical specifications in terms of working phases, number and quantity of the single constituent layers. Furthermore, an industrialized type of productive process was hypothesized.

Table 1: An example of technological classification of the constructive solutions of external plaster covering analyzed.

Technological unit class	Technological unit	Technical element class	Technical element	Constructive solution	Materials and products
Shell	Vertical shell	Vertical perimeter wall	External plaster	By cement	Dry mix
					Water mixing
				By hidrated lime	Dry mix
					Water mixing
				By raw earth with lime	Dry mix
					Water mixing
functional categories		physical categories			

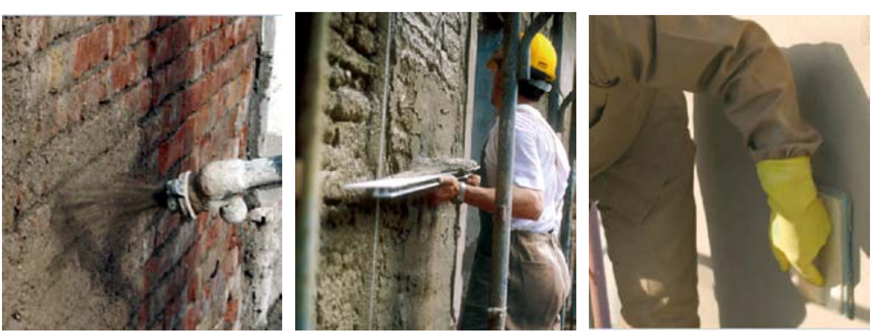

Figure 1: Realization phases of an external plaster (support, covering and finishing).

2.1 Boundaries of the investigated system

For the purpose of the study, it was considered important to adopt an assessment procedure of environmental behaviour divided into two levels of in-depth investigation. The **first level** aims at comparing the environmental impact produced by the same portion of the building element, represented by 1 square meter of external plaster covering (functional unit), carried out through the use of the different materials identified. At this level of in-depth investigation, attention is placed on the comparison of the impact generated in the whole life cycle.

For this purpose were considered the most meaningful life cycle phases, represented by the extraction and production of materials, the transport and mixing on the building site, and the end of life. The laying and maintenance stages have been omitted since literature does not consider them to have much impact. The first one because it is carried out prevalently by hand, the second one because the duration of the technical element has been assumed to coincide with the duration of the building (50 years), provided that maintenance interventions of the paintwork are carried out which, however, are not included in the system boundaries. As for the life end, in this first phase it was considered a traditional method for managing demolition waste, resulting in their transfer to landfill (AA. VV. [4]).

Instead, the **second level** of analysis aims at identifying the possible interventions for improving environmental behaviour with regard to the materials analyzed. For this purpose, it concentrates its attention on the life end phase, hypothesizing a different method for the management of demolition waste. The hypothesis of transfer to landfill is placed in contrast with the possibility of materials selection at a sorting plant, for their reuse as inert fillers.

With further regard to improving the environmental performance of the materials used, it must be remembered that further intervention could be identified also concerning the extraction and production phases. Interventions closely subordinate to the adoption of adequate strategies to increase efficiency in the use of resources and productive processes by producers (Bringezu [5]). Some actions lie outside the control capacity of the Public Authority, if there is not a request for environment qualification of the products at the contract stage. Hence it was decided to omit them from this study, which is primarily geared towards an assessment of a general nature and not tied to a specific product.

2.2 Methodology and instruments

For the purpose of simulation of environmental behaviour, it was considered important to make reference to the LCA methodology (Life Cycle Assessment), as an instrument internationally codified (ISO 14040/2006) and also acknowledged for the purpose of developing other instruments for environmental product qualification, such as ECOLABEL (EC Rule 1980/2000) and EPD (ISO 14025/2006 and ISO 21930/2007). In particular, considering the aim of the study, it was considered important to adopt an approach of a selective type (screening LCA), more suitable for the development of comparative assessment and identification of improvement actions. For this purpose, an LCA software (SIMAPRO, PRE’ Consultant) and inventory data from literature or from data banks associated with the software (ECOINVENT, PRE’ Consultant) were used. Moreover it was considered important to develop the assessments relying on the ECO-INDICATOR 99 method (Geodkop and Spriensma [6]) as it prevalently refers to European territory, the same enquiry field as the European GPP programme. Finally, considered the public finality of the study, it was considered appropriate to make reference to the “egalitarian” profile, corresponding to a person with a strong collective conscience, and therefore more sensitive to environmental issues.

2.3 Analysis and interpretation of the results: LCA of technical elements

With reference to the first hypothesis (a traditional type of demolition waste management, consisting in their transfer to landfill), from a first analysis of environmental behaviour of the three types of materials used, it appears that the building solution (1 sq.m. functional unit) with the greatest impact is the one which uses “cement-based plaster”, which produces overall damage in the life cycle of more than 26% in contrast with “hydrated lime-based plaster” (0.23 pt/0,18 pt) and 53% in contrast with “raw earth with lime-based plaster” (0.23 pt/0.15 pt).

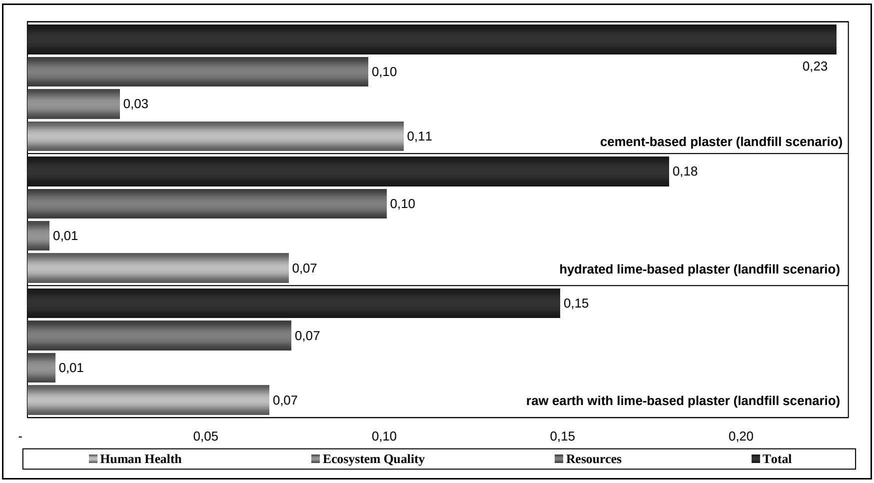

Figure 2: Environmental life cycle assessment of a part of external plaster (1 sq.m. functional unit) made with cement (above), hydrated lime (in the middle) and raw earth with lime (below) materials. End of life scenario with landfill (A. Basti, P. Milano elaboration).

It is interesting to note that environmental damage caused by the solution with cement plaster falls about halfway (46%) into the HUMAN HEALTH category, because of the emissions of nitrogen monoxide, fine dust and carbon dioxide produced during the extraction and production stages (66% of the category total). A further 42% is attributable to the RESOURCES category, this too generated in the extraction and production stages (77% of the category total) because of the use of petroleum (68%), coal and natural gas (26%). The hydrated lime-based solution, despite its having an overall inferior impact, reveals a greater use of resources (+10%), caused by mostly energy-consuming production processes. Less meaningful is the impact concerning the ECOSYSTEM QUALITY category, prevalently generated by the activities of industrial transformation of the extractive sites. In this case, the impact generated by cement-based plaster prevails, which accounts for more than three times as regards raw earth with lime plaster and for more than four times as regards hydrated lime plaster (see figure 2).

The adoption of a different management strategy of demolition waste, consisting in the selection of materials at a sorting plant and their reuse as inert fillers, reveals interesting environmental advantages. In fact, it is possible to find a meaningful reduction of the impact, though the activities concerning the other stages of the life cycle remain unvaried. Cement plaster reduces its impact by 26% (0.17 pt/0.23 pt), hydrated lime-based plaster by 28% and raw earth with lime-based plaster by 40%, also thanks to the lower amount of fine dust produced by this specific material in the demolition phase.

The most meaningful environmental advantages are realized in the RESOURCES category, which, thanks to the recovery and reuse of the inert waste, have a decreased of environmental impacts, variable from the -30% (lime-based plaster) to the -51% (raw earth with lime-based plaster). Further, meaningful environmental advantages are realized in the HUMAN HEALTH category, thanks to the reduction of emissions into the air associated with the elimination of landfill activities and the reduction of future extractive processes (see figure 3). In this case, the values swing from the -19% (cement based plaster) to the -34% (raw earth with lime-based plaster).

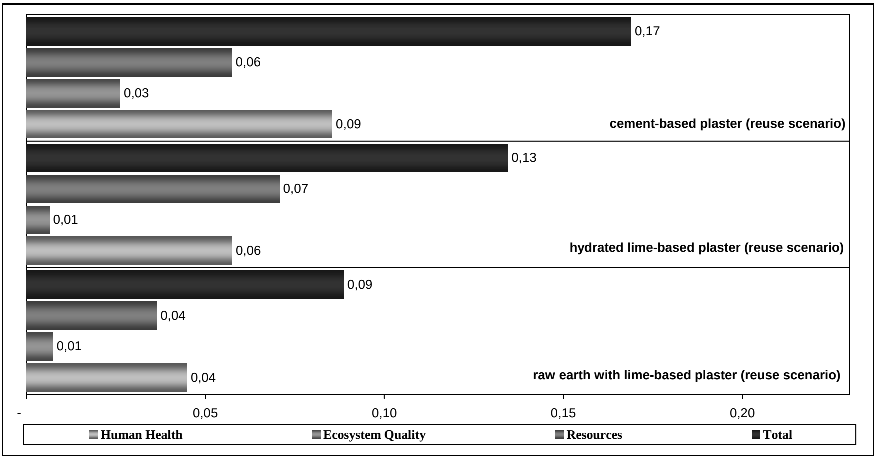

Figure 3: Environmental life cycle assessment of a part of external plaster (1 sq.m. functional unit) made with cement (above), hydrated lime (in the middle) and raw earth with lime (below) materials. End of life scenario with reuse (A. Basti, P. Milano elaboration).

2.4 Analysis and interpretation of the results: LCA of the demolition strategies of materials

As we have already mentioned, the modelling of the disposal phase of materials (1 kg functional unit) was developed on the basis of two distinct hypotheses for the management of demolition waste, among which these alternatives:

- non-selective demolition with subsequent transfer of the residue to landfill.
- selective demolition with transport of the residue to sorting site and stockpiling, for subsequent reuse as inert filler.

In the **first case,** the inventory analysis was developed making reference to a disposal process from a databank (named: disposal, building, mineral plaster, to final disposal). The process includes emissions to air (particulates) produced during the dismantling and handling activities, the transport of residue to dismantling facilities, and their subsequent transfer to inert materials landfill. This latter activity allows for the incidence of the infrastructure used for the building, functioning and environmental requalification of the landfill facilities (calculated with regard to the amount of inert materials dealt with), and burdens relating to its functioning, represented by the land use and energy use. In this case, too, the data are obtained directly from databanks (named: Disposal, inert waste, 5% water, to inert material landfill).

The analysis reveals that the environmental damage caused by demolition activities and transfer of inert waste to landfill, is 39% attributable to emission of

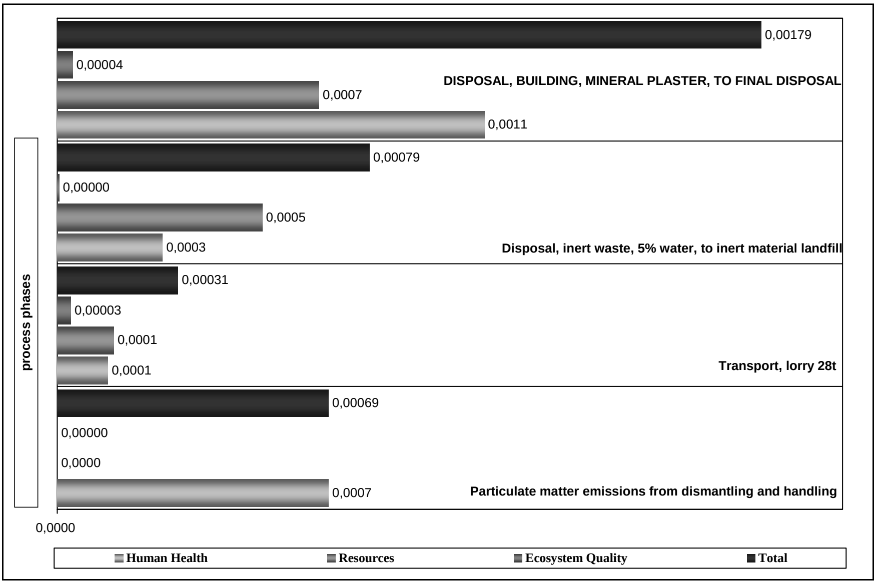

Figure 4: Environmental life cycle assessment of a disposal process of mineral plaster (1 kg functional unit). End of life scenario with landfill.

particulates generated during the demolition works (HUMAN HEALTH category), and 44% to the impact produced by the inert material landfill itself (see figure 4). This activity prevalently weighs upon the preservation of resources and of human health. On the first because of the use of petroleum (88%), natural gas and coal, on the second because of the emissions of nitrogen monoxide, fine dust and carbon dioxide (in the air) and of cadmium and arsenic ions (in the water).

In the **second case**, the inventory analysis was developed through the setting-up of an "ad hoc" disposal process, so to bring out the greater environmental advantages subsequent to the life end strategy adopted. These advantages do not appear in the available databanks. This new disposal process take into account the environmental advantages obtained by two intervention categories:

- the recovery of inert materials, with subsequent elimination of the need to extraction of new virgin resources (product avoided: Gravel, unspecified, at mine);
- the elimination of the transfer of unseparated demolition waste to landfill (process avoided: Disposal, building, mineral plaster, to final disposal, already described in the first hypothesis).

The process (denominated: Disposal, building, plaster, to reuse) includes the energy absorption relating to demolition activities and the correlated particulate emissions, the energy use relating to the transport of demolition waste from the building site to the stockpiling site (considered coincident with the sorting plant),

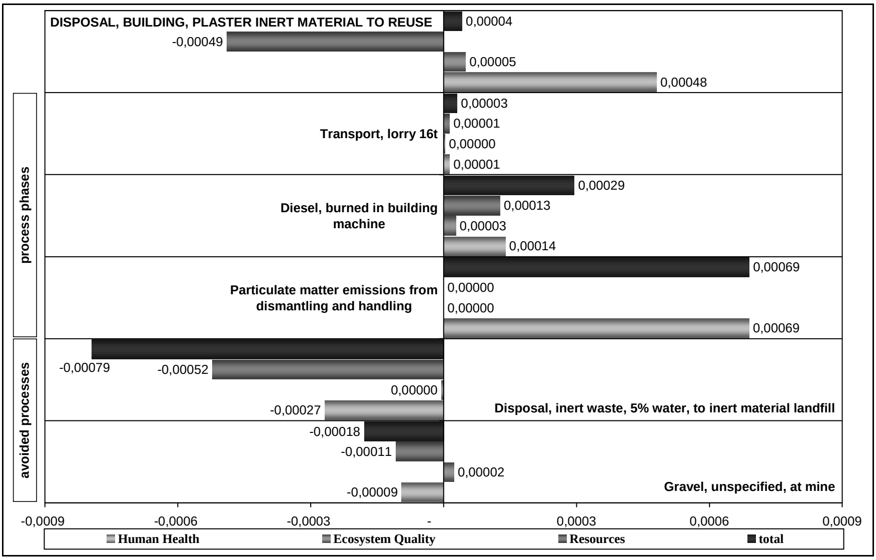

Figure 5: Environmental life cycle assessment of a disposal process of mineral plaster (1 kg functional unit). End of life scenario with reuse. Avoided processes are taken into account (A. Basti, P. Milano elaboration).

the avoided processes relating to the recovery of inert materials and the avoided landfill. This latter process was taken from databanks, and considered corresponding to that used in the first hypothesis.

The analysis reveals an environmental advantage due to the processes avoided, which are able to compensate almost entirely the impact generated by the activities correlated to the demolition and transport of the residuals material, however present in both hypothesis (see figure 4 and 5).

The reuse of inert waste makes it possible to eliminate their contribution to landfill, with consequent advantages in terms of reducing the amount of waste produced, and hence in terms of extension of the landfill duration, and postponement of the need to open new landfills, with resulting consumption of other land. It also allows, as already mentioned, a reduction of the extraction of new mineral resources to use for subsequent productive processes and a consequent reduction of the environmental impact generated by them.

In the final analysis, it is possible to state that second hypothesis allows to obtain, being equal the impact generated in the preceding life cycle stages, a reduction of environmental damage during the life end management of about 97% (see figure 6) in contrast with what would happen by resorting to disposal systems presently in use, frequently based on an undifferentiated transfer of the material residues to landfill.

It is worth emphasizing that, for the analyses, it was considered make reference to the most favourable condition from an environmental point of view, that is, the transfer of the demolition residuals at an inert materials landfill. In fact, the impact generated by the transfer of the same demolition residuals to a Sanitary landfill (a controlled landfill for urban solid waste) would be different, as emerges from the following Figure 7.

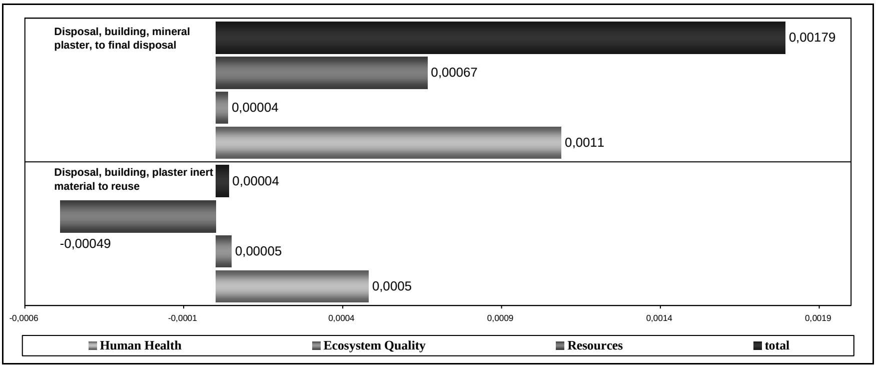

Figure 6: Environmental life cycle assessment of disposal processes of mineral plaster (1 kg functional unit) with landfill (above) or reuse (below) end of life scenario (A. Basti, P. Milano elaboration).

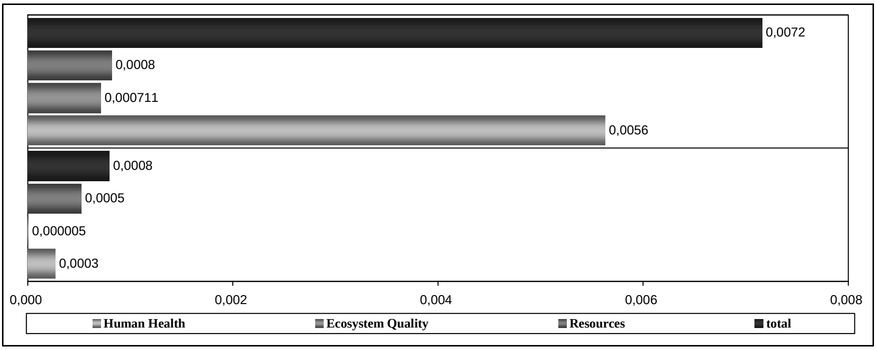

Figure 7: Environmental life cycle assessment of an end of life scenario for inert materials (1 kg functional unit), to a sanitary landfill (above) or to an inert material landfill (below).

3 Conclusions

These considerations tend to confirm what was said about the significant incidence of the management strategies of demolition waste, in relation to the overall impact generated by the individual technical elements of the building. With reference to the case study, it is possible to say that the introduction of some simple rules oriented to reuse of materials, could lead to a reduction of environmental impacts of about a quarter (with reference to cement plaster, see figure 3). A reduction that if combined with the choice of low impact building materials (with reference to raw earth-based plaster, see figure 2) could lead to a total reduction of approximately 60% (see figures 2 and 3). This despite the awareness of the various factors that affecting any LCA's study. The latter consideration suggests the opportunity to introduce between the environmental criteria for GPP, in addition to the possess of the above-mentioned EPD (useful to the choice of materials and products with less impact), more restrictive rules for the realization of building elements aimed at facilitating the separation of materials, their selection and reuse at the end of life. Criterion that needs to be combined with an effective action to support deployment of an enterprises network specialized on selective demolition, separation, shredding and waste treatment for their direct reuse or, at least, their recycling.

Reference

[1] Anink D., Boonstra C., Mak J., Handbook of Sustainable Building. An Environmental Preference Method for Selection on Materials for use in Construction and Refurbishment, James and James Science Publishers, London, (UK), 1996

[2] Berge J., The ecology of building materials, Elsevier Science Ltd, Oxford, (UK), 2000

[3] Basti A., *The environmental behavior of a "raw earth" building*, in S. Briccoli Bati, M. Forlani, M. Germanà, S. Mecca, editors, Terra/Terre-The future of an ancient technology, ISBN 978-88-4672-146-4, ETS Edizioni, Pisa (IT), 2009
[4] AA. VV., Annex 31. Energy-Related Environmental Impact of Buildings, CMHC (Canada Mortgage and Housing Corporation) on behalf of IEA ECBCS (International Energy Agency-Energy Conservation in Buildings and Community), Canada, 2004
[5] Bringezu S. et al., Policy review on Decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries, European Community, 2005
[6] Geodkop M., Spriensma R., The Eco-indicator 99, a damage-oriented method for life cycle assessment. Prè Consultant, (NL), 2000

Life cycle assessment of electricity generated by photovoltaic systems manufactured in Europe and installed in buildings in the city of Rome

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Abstract

The aim of this paper is to evaluate the impact on human health and on the ecosystem caused by electricity produced by photovoltaic systems. The analysis was carried out with the life cycle assessment methodology (LCA) and the eco indicators method.

It includes a study of raw materials and energy consumption and their polluting emissions in air, water and soil during the production phase in Europe and transport, use and disposal in the city of Rome of the crystalline silicon and all other materials and components used to produce 1 kWh of electricity. The kWh is the functional unit of the LCA analysis.

The study considers the relationship between the energy consumption needed to build a PV system and the energy produced by the same system over 25 years. The study also considers the relationship between global and local environmental impact caused by the manufacturing and disposal of the PV system and the avoided environmental impact due to the energy produced by renewable sources. Finally, the analysis compares global and local emissions of CO_2 caused by the PV system's manufacturing and disposal and the avoided emissions of CO_2 using electricity from renewable sources. The study describes the possible solutions to reduce environmental impact through innovation.

Keywords: PV system, LCA, Mayor's Pact, saving CO_2.

1 Introduction

The IV Report on Climate Change, referenced by the European Union in its climate policies points out that within the first half of the century global emissions should be reduced by at least one half compared to 1990. Facts

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indicate that in order to reduce the presence of carbon in energetic systems, an efficient policy should aim at developing technologies and new kinds of combustibles. It is in such a context that the reduction on CO_2 emissions becomes one of the goals targeted by the European Union's new energy politics. With the directives proposed on January 23, 2008, the EU aims at reducing total CO_2 emissions by 20% before 2020. In January 2008 the EU also sponsored the Mayor's Pact, an initiative that involves European cities in a common path towards energetic and environmental sustainability. This recent initiative, based on voluntary participation, urges European cities to develop an Action Plan committed to reducing CO_2 emissions by 20% due to local policies that would make use of renewable sources, increasing energy efficiency and enacting programs to save and rationalize energy use.

Since energy used in buildings is responsible for 30%–40% of CO_2 emissions, in 2002 the EU published the directive n.91 on energy efficiency in an attempt to increase energy performance of buildings, develop and value the use of sustainable sources and energy diversification and contribute to national objectives on global emissions imposed by the Kyoto Protocol.

In this scenario, in order to evaluate the sustainability of a building's energy system, it is legitimate to ask how much energy and raw materials the system took to be built, installed and dismissed and how much energy it produced in its entire life. One would also have to consider emissions released and if and how these emissions have been taken into account by the cities' Action Plans.

This kind of evaluation can be calculated with a life cycle assessment (LCA).

Talking about a photovoltaic system we will consider impacts caused from the production, installation and dismissal of the system and confront them with the lesser environmental impacts resulting from the use of renewable sources.

Values of global CO_2 emissions will be attributed to the city in which the system was built, whereas the city in which the system is installed only the emissions deriving from installation, maintenance and dismissal will be taken into account.

The goal is to provide values that indicate clearly the energy and environmental benefits of using photovoltaic systems in buildings.

2 LCA of PV system: methodology

The environmental impact's evaluation, with the LCA methodology considers data regarding the consumption of raw material and energy and the pollutant emissions of a photovoltaic system produced in Europe and installed in roofs of buildings in Rome and connected to the electricity grid of the city. This PV system can produce 1 kWh peak. The functional unit of this analysis is the kWh peak.

The PV system is equipped with silicon polycrystalline cells with an efficiency of 10–15%. The PV system's life cycle is considered to be 25 years. (The LCA analysis of the inverter and all electrical accessories necessary to work the system are not included in this study.)

The environmental evaluation considers the impacts on human health and the ecosystem coming from the production of the system and during the installation and finally at the end of its lifespan. The evaluation also considers environmental benefits coming from a PV system which produces energy from renewable sources.

The study considers the relationship between energy consumption to produce, install and disassemble the PV system and the energy produced by the same in its 25 year span life; the relationship between local and global environmental damage caused by the manufacture, installation and decommissioning and the damage avoided by using renewable sources.

Finally, the analysis compares global and local emissions of CO_2 produced by the manufacture, installation and disposal of the PV system and the emissions avoided by using renewable sources.

2.1 Inventory data

The data for energy and raw material consumption come from two companies specialized in PV modules assembly, a company that produces silicon and from specific topic literature [1]. (The energy necessary to eliminate the impurities of metallurgical grade silicone in order to obtain electronic grade varies from 430kWh/kg to 600kWh/kg [2]. So to produce a 1 kg of crystalline silicone you need about 600kWh of electricity, which corresponds to 19kWh for every silicone wafer. If 1kg consumes 100kWh just to crystallize, for 7.54 it will use 755kWh and each wafer will consume 23kWh (which will become 46 given a 50% process yield). For the production, installation and maintenance in 20 years of a 1kWp system you need 6MWh of energy [3]).

The data has been normalized by the kWh peak and calculations were carried out assuming the following values:

wafer thickness = 0.35 mm
wafer area = 12.5x12.5 cm = 156.25 cm^2
wafer volume 54.68 E^{-7} m^3
wafer weight = 12.57 E^{-3} kg
silicon density = 2300 kg/m^3
number of wafers necessary to produce 1kWh = 600
efficiency of wafer cutting process = 50%.

2.2 Life cycle phases analyzed

The life cycle phases analyzed are the following: (table 1)

2.2.1 Production phase

The environmental analysis evaluates the impact caused by the following activities:

- Production of metallurgical grade silicon (Si-MG) having a purity of 95%;
- Production of Trichlorosilane ($SiHC1_3 + H_2$) having a purity of 98.9%;
- $SiHC1_3$ purification (distillation) with a purity grade of 2 parts per billion (triple stadium distillation);

- Deposition of the pure silicon micro crystal (reaction with H_2 at 1000°C, Siemens process) $SiHC1_3 + H_2 = Si + 3HC1$ with a purity of 2 parts per billion;
- Crystallization in order to obtain the bars (if mono crystalline with Czochralsky where a seed of pure silicon is grown slowly, if polycrystalline with deposit in a quartz crucible and radio frequency mixer even using leftovers from silicon grains or the head and bottoms of pure bars produced by the Czochralsky method);
- Cutting and work of bars needed to produce the wafers;
- Work needed on wafers to obtain the cells (washing, spinning, texturizing, pickling, serigraphy, efficiency tests);
- Module assembly.

Table 1: Energy consumption data relating to each of the materials and components needed to produce 1kWhp of electricity with a photovoltaic system in polycrystalline silicone.

Process	**Energy consumption: European mix UCPTE kWh/ kWhp**
Production of metallurgical grade silicon (Si-MG)	450
Production of Trichlorosilane ($SiCl_3 + H_2$)	75
Purification $SiHCl_3$ (distillation) (triple stadium distillation)	225
Deposition of Si pure micro crystal (reaction with H_2 at 1000°C, Siemens process)	6750
Crystallization	1500
Cutting and work of the bars to produce wafers Work on the wafers to obtain cells	733
	Energy consumption: Italy mix kWh/ kWhp
Module assembly	301
	Total 10034

During the production phase, the following assumptions were made:

Energy:

- The electricity needed during manufacture was produced using the continental Europe energy mix: UCPTE region medium voltage level, [4] since two European countries are the main producers: Germany and Spain. (Average data of medium voltage (1–24kV) electricity energy production in Europe. It includes initial investments, exploration of energy sources and transport. Power distribution system is included up to delivery of medium voltage electricity. Grid loss of 1.8%. Data on waste disposal is not included. The emissions caused by burning and recycling are however included. All of the “radio nuclides” are combined in one category as radioactive substances.) The European energy mix was used in the production of metallurgical grade silicon, in the purification to obtain electronic grade micro crystalline silicon (Czochralsky process) and poly crystalline silicon (radio frequency mixer oven process), for wafer and cell production.

- For the module assembly and module disassembly phases, the Italian energy mix was used [5].
- The energy produced by the PV system and thus the energy saved is assumed to be the same as the Italian energy mix.

Raw materials:

- The data regarding the argon, ammonia, hydrochloric acid, nitrogen, hydrofluoric acid and mineral oil production processes was taken from the ETH-ESU Zurich data base;
- The EVA production process was assimilated to that of high-density polyethylene.

2.2.2 Installation phase and transport

- This phase should include all the processes from the finished product to its use: the assembly, the transport, the construction site activities and the installation modes. The methodology proposed, quantifies the environmental impacts derived from transporting the PV cells from Germany (1200 km by railroad). The incidence of transport related air pollution, due to the reduced weight, is irrelevant compared with the impacts caused during the production phase. If we consider air transport for 1200 km and an average weight of 12 gr. per cell for 585–600 cells the impact is equal to 0.6Pt.
- The impacts derived from transporting the various components from the production plant to the building site for a distance of up to 50 km with a 40-ton diesel truck are also considered and similarly inconsequential.

2.2.3 Use phase

- The use phase quantifies the environmental benefits deriving from the production of 1kWhp of electricity from a renewable source during the 25 year life cycle of a PV system installed in building’s roof in the city of Rome.
- The average sun radiation is equal to 1737.4lWh/m^2.
- The average amount of direct current electricity produced in one year is equal to 1737.4kWhel/kWp (=8m^2 of PV panels).
- We assume that panels’ inclination angle is 30° and that they are pointing south. A conservative value of 12.5% has been considered for efficiency (modules can be up to 16–17% efficient) and 85% for BOS (this includes inverter efficiency and cable loss) [6].

- The average amount of alternating current electricity produced in a year is equal to 1477 kWhel/kWp.

2.2.4 End of life phase and waste treatment scenarios

- The end of life phase provides an hypothesis, based on the referenced legislation, about environmental damage evaluation of different waste disposal operations deriving from the panel assembly and disassembly activities.
- At present there is not enough data to conduct a study on PV panel recycling. The only data available refers to recycling glass and aluminum recovered from a panel disassembly at the end of its life cycle [7].
- Disposed cells will be treated according to the 2002/96/CE Directive, effective since August 2005, regarding electrical and electronic equipment (RAEE). In Italy the Directive was transformed into law by the DL 151/2005 and the DM 18/2007. All these new obligations started on January 1st, 2008 and force producers to deal with product's end of life.
- The hypothesis on waste treatment considered in this study assumes: 100% recycle of aluminum and glass, and waste treatment according to Directive 2002/96/CE, keeping in mind that "Printed circuits contain heavy metals like ammonium, silver, chrome zinc, lead, copper and tin" (according to some estimates there is no other product for which the sum total of the environmental impact on unrefined materials, extraction, processing, finishing, production, use and sales is so noteworthy as it is for printed circuits [8]).

3 Results

The LCA includes all the phases previously described:
LCA = Production phase + Transport and installation phase, Use phase; maintenance/management, End of life phase and waste treatment scenarios.

The results regard energy consumption, environmental damage and CO_2 emissions associated with the PV system's manufacture in Europe and during 25 years of use in the city of Rome.

Table 2: Environmental damage caused by the production of a PV system in Europe.

Damage category	Unit (Pt)	Total	Si-MG production 1kg	Purification in Si-EG 1kg	Crystallization Si-EG 1kg+ water	Work on wafer and cells	Panel assembly
Human health		115	4.79	75.1	16	11.6	7.53
Ecosystem Quality		27.2	1.17	18.3	3.89	2.42	1.44
Resources		325	13.3	209	44.4	35	23.2
Total		467	19.3	302	64.2	49	32.2

Table 3: Environmental damage caused during the life span estimated in 25 years of the PV system installed in the city of Rome.

Damage category	Unit (Pt)	Total	Production phase	Use phase	Disposal phase
Human health		-618	115	-732	-1.25
Ecosystem Quality		-125	27.2	-152	-0.341
Resources		-1.88E3	325	-2.2E3	-0.484
Total		-2.62E3	467	-3.09E3	-2.08

Table 4: Results of energy consumption, environmental damage and CO_2 emissions in Europe and in the city of Rome.

	Energy consumption (kWh/kWp)	Damage points (Pt)	CO_2 emissions in Europe (ton)	CO_2 emissions in Rome (ton)
Manufacture	9733	435	4.93	-
Assembly and installation	301	32.2	-	-
during 25 years	- 36925	- 2620	-	-32
during 1 year	- 1477	- 124	-	-1.26
Payback time (years)	8	5	5	0

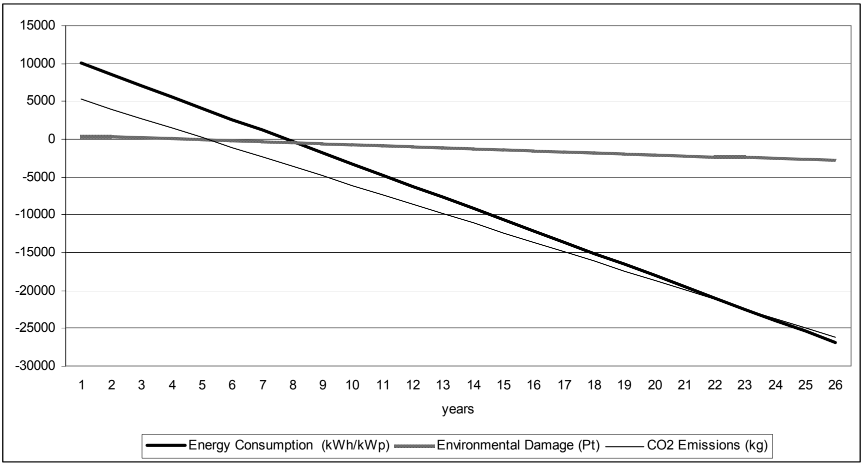

Figure 1: Trend of energy consumption, environmental damage and CO_2 emissions during the entire life cycle of the PV system.

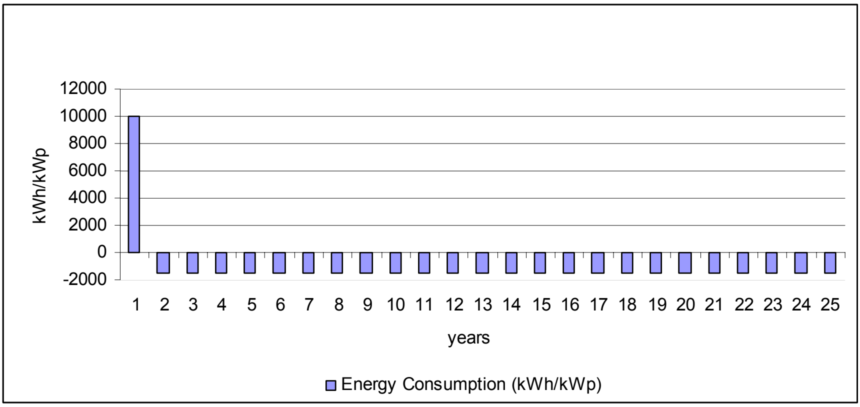

Figure 2: Energy consumption during the period (1 year) of system manufacture and energy saving during the PV system time operation.

4 Exploring improvements

- Reduction of wafer's thickness.
- More efficient wafer cutting.
- Other sources of silicone procurement: currently the two sources of silicone for the photovoltaic industry are waste products from the electronics industry and direct extraction and refinement. Both are related however to the production process of electronic grade silicone. The proposed solution, which already exists but is not yet economically competitive, is the development of technology for "true" solar grade silicone.
- In this study we have not included materials resulting from recycling. However innovations in this sector, regarding both the silicone and the recycling of the wastewater from the cutting of the wafer, exist and should be noted and perhaps included in subsequent studies.
- Silicone resulting from wafer recycling, developed by IBM. With this patent IBM ensures the reuse of wafers that would otherwise be thrown away. The Semiconductor Industry Association estimates that 250,000 silicon wafers are produced daily and 3.3% of these are defective, so rejected and thrown out. IBM using a delicate abrasion technique with water counts on being able to recycle, for cell production, about 3,000,000 wafers yearly (equal to 13MW).
- The Japanese company, Sharp, produces about 710MW of solar modules per year. Recycling however is energy intensive even though it reduces the current 21 phases of processing to 5–12 phases.
- The process of recycling the water used during the cutting of wafers with a diamond saw would result in a 15% reduction in environmental impact.

5 Conclusions

Photovoltaic systems that use renewable sources to produce energy cause an environmental impact close to zero during the usage phase even though one should evaluate the impacts caused by maintenance that have not been considered in this study. For this reason photovoltaic systems seem, at first sight, to be environmentally friendly solution.

If we evaluate the PV system using LCA we must include the environmental impacts caused by the production of modules. During this phase the consumption of raw materials and energy necessary to transform these raw materials in a finished product are relevant. The activities necessary to produce modules are the reduction, purification and crystallization of the silicon, the production of cells and wafers, the assembly of the modules and finally the installation of the panels. The LCA of a PV system produced in Europe and installed in Rome points out how, even for latitudes that guarantee a high level of sun radiation, the energy payback time is about 8 years, mainly due to the processes necessary to obtain electronic grade silicon. The payback damage time in terms of environmental impacts and CO_2 emissions are less than the energy pay back due to various reasons: the environmental damage is evaluated considering not only the energy consumption but also the associated emissions. At equal consumption, the European energy mix is more efficient than the Italian one. Therefore it is more convenient to manufacture the PV system in Europe rather than in Italy. Moreover, the energy produced by a renewable source in 25 years in Rome avoids having to use the Italian energy mix. Considering the sun radiation in the city of Rome, the convenience in terms of environmental damage amounts to 4 or 5 years of payback damage time compared to the 8 years needed for the consumption energy. The same can be applied to CO_2 emissions.

The energy consumption to manufacture the PV system is 10034kWh/kWp and the energy produced in 25 years from a renewable source is 36925kWh/kWp.

The environmental damage associated with the manufacture of a PV system is 467 eco points and the avoided damage in 25 years is – 2620 eco points.

The CO_2 emissions during the manufacture of a PV system in Europe are 5 tons and the avoided emissions in Rome during 25 years are – 32 tons.

In order to evaluate the CO_2 emissions and use the data in the elaboration of a city Environmental Action Plan to improve measures for its reduction, a PV system built in Europe and installed in Rome guarantees for the city a level of zero emissions in 25 years (except for the emissions caused by maintenance and decommissioning), compared to the 17 years of zero emissions of the same PV installed in one of the countries that produce silicon. Also, the change in latitude will influence the results.

Energy consumption during manufacture can further be reduced by using new technologies to produce crystalline silicon and by using thin films and other silicon alternative materials, such as cadmium, natural substances or plastic. In the future, the LCA analysis will have to include the environmental impacts associated with the decommissioning of panels about which we still do not know anything.

The quantification of energy consumption associated with each of these activities point out how, aside from the economic considerations, there is an energy pay back time of from 8 to 14 years. Moreover, since energy use is associated with polluting emissions, the environmental compatibility of the system must also take into account the damage caused by these emissions. Only after having carried out an LCA will we have the true “measure” of environmental compatibility.

References

[1] Crawford R.H., Treloar G.J., Fuller R.J., Bazilian M. (2006), ‘‘Life-cycle energy analysis of building integrated photovoltaic systems (BiPVs) with heat recovery unit’’, Renewable and Sustainable Energy Reviews, Vol. 10, pp. 559–575
[2] Fickett B., Mihalik G. (2001), ‘‘Multiple batch recharging for industrial CZsilicon growth,’’ Journal of Crystal Growth, Vol. 225, pp. 580–585.
[3] www.energoclub.org
[4] ETH, Swiss Federal Institute of Technology Zurich, 1994.
[5] ENEL, Ente nazionale Italiano per l’ENergia ELettrica, 2006.
[6] Dati Italia Ministero dell’ambiente e della tutela del territorio e del mare (2009).
[7] See http://www.pvcycle.org
[8] CARE Conference, Vienna 1994.

Section 5
Quantifying sustainability in architecture
(Special session by R. Smith)

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Quantifying eco-architecture

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Abstract

Qualitative methods of evaluation predominate in designing for green building. Although accessible for architects, this paper makes a case for data driven quantification to aid in fostering change in finding a balance between the triple bottom line of sustainability: environment, society and economics. The paper proposes three functionalities that should be considered by the design team, including architects and engineers, in order to develop a unique quantification method and select appropriate tools, including subject, scale and scope. Challenges are discussed and suggestions are proposed for the future of method and tool development for sustainable design processes.
Keywords: quantification, green building, life-cycle assessment, simulation.

1 Introduction

A key factor in quantifying sustainability in design and building includes not only environmental issues, but economic, social and cultural considerations as well [1, 2]. The U.S., and other free market capitalistic societies, as the EPA and Bruntland (1987) suggest, must assess sustainability from the perspective of both natural and human capital [3]. The need for quantifiable data related to sustainable design of buildings is therefore necessary in order to make effective decisions regarding the future of resource use. Data is also necessary to convince decision makers of the need for regulatory changes. Quantification is a key component in order to foster real change in public attitudes and actions with regard to sustainability. In addition, as sustainable practices, including green building, continue to progress in different sectors of the world economy, it will be necessary that an effective balance is found between social, economic and environmental concerns.

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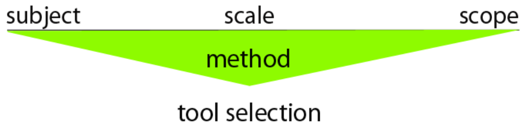

Figure 1: Three functions in developing a method for quantification of sustainability include subject, scale and scope. These together constitute the methodological framework for a project. A tool is then developed or selected based on the methodological approach.

Designers interested in performing a sustainability assessment are often at a loss as to how to begin. Design teams are confronted with a myriad of methods and tools, each carrying potential opportunities and challenges. Each quantification study is unique and requires a strategic critical development of an analysis method. This paper will outline items to consider in developing a method for sustainability quantification during design, the subsequent selection of appropriate quantification tools, and relate the challenges associated therein. The paper will then conclude with suggestions on how design professionals may conceptualize the next generation of quantification tools.

2 Method development

Sustainability quantification includes three general functionalities: Subject, Scale, and Scope (Fig. 1). Identifying these parameters ensures an appropriate development of method and selection of tools to perform a quantification evaluation during design.

2.1 Subject

In looking at the methods for evaluation of sustainability, one must consider the subject under investigation. Designers should target the subject specifically so that no wasted time is spent gathering innocuous data not pertinent to the project at hand. In order to do this, a mission statement and goals need to be outlined so that all who are participating understand from the beginning the intentions of the study. For example, a study to influence legislation for green building regulations may or may not be similar in method as a study to evaluate the environmental performance of a new construction for the owner of the facility. Once the purpose has been defined, all who are involved set the goals and objectives of the project. Often this results in a number of varied subjects that need to be investigated for a given project.

These subjects can be evaluated separately or independently, depending on the parity of the data and whether the data will be assessed comparatively or aggregated. For example, a company considering moving their business because of a lack of space and the desire to invest in a new building are deciding between demolition and build new or remodel an existing building on the site and add on. In order to evaluate the natural and human capital the design team needs to consider not only a comparison of material but also resource data. At first glance new construction consumes much more resources than reusing an existing building. However, upon quantifying the comparison, designers need to take into consideration operational energy and water use, air quality, etc. These additional subjects might point in favour of new construction as the preferred option, depending on the situation.

Green design quantification includes the following subjects of consideration:

- Site: brownfield/greenfield development, erosion control, permeability, soils, proximity to transportation and life sustaining resources, vegetation, habitat disruption, etc.
- Water: underground waterways, water recycling, landscape watering, wastewater treatment, water catchments, water runoff, water use
- Energy: construction energy, operational energy, passive and active systems, renewables
- Materials: embodied energy, local materials, sustainable harvesting and extraction, recycle, reuse
- Air Quality: exterior and interior air quality, toxins, low VOC materials, passive and active ventilation systems

These subjects can be isolated or evaluated holistically. Designers also need to determine what kind of social and economic subjects will be evaluated against these environmental considerations. The green building criteria listed above are all subjects that give purpose to the study. Once the subjects under assessment are established the design team needs to consider the scale of the inquiry.

2.2 Scale

Sustainability covers a range of scales from the macro city, region or world scale to the micro individual building scale. After selecting the subjects under consideration, design teams must break the study into a smaller subject scale. Although not presented herein as such, scale can be performed before the subject selection as well. For example, a building may need evaluation of operational energy, however many factors contribute to the operational energy quantification including: passive and active systems, enclosure definition, fenestration makeup, etc. One might choose to isolate the study and evaluate different enclosure definitions and their impact on the energy quantification study.

These smaller scale studies often are included into a larger aggregate at either the entire energy quantification, entire building, or even folded into a larger planning model. There exist many methods for quantification at the planning scale including cities, regions and even nations, as well as many methods for individual building or component assessment. However, there is a noticeable lack of method available for the in-between (Fig. 2). Macro level studies require less specific data, usually taken from census or publicly available information. Building level assessment data is taken from data sets with known values for materials. An assessment of neighbourhoods for example requires teams to often develop data themselves purposed for the study in question. This points to larger problems of communication between the macro level study and micro level study that will be discussed later.

MACRO	IN-BETWEEN	MICRO
World Continent Country Grouping Nation Region Metro Area City	Neighborhood Voting district Street Development Urban Design Corporation (dispersed) Campus / Cluster	Building Building Component Infrastructure Isolated system

Figure 2: Macro and micro level studies are well supported with data available parsed for their respective scales. So-called "in-between" studies such as a neighbourhood scale required medium level data not readily available requiring evaluators to develop data or use a combination of both macro and micro level data.

2.3 Scope

In addition to subject and scale, design teams need to critically select a scope mechanism. Scope in this context refers to the type of operation that will be performed on the subject and scale of project. The following are a list of scoping operations and their respective descriptions:

2.3.1 Life cycle assessment

Referred to as whole building assessment, LCA is an International Organization for Standardization 14000 environmental standard. An advantage of using the LCA procedures is that LCA can potentially cover a wide variety of impacts not accounted for in other types of studies such as more detailed data concerning the life cycle energy of specific materials, called embodied energy. To calculate embodied energy of material a comprehensive Materials Flow Analysis (MFA) procedure is performed [4]. This evaluates the cradle-to-cradle life cycle of a specific material or system [5]. MFA is encompassed within LCA. Other benefits of utilizing LCA not commonly used in Green Building Assessments should be noted such as human toxicity and acidification.

ISO sections 14040 and 14044 identify 4 phases in order to perform an LCA: 1- goal and scope; 2- life cycle inventory; 3- life cycle impact assessment; and 4- interpretation. The goal and scope of assessing buildings is quantifying the total energy consumption over the life cycle of a facility [6]. The inventory in order to accomplish this goal includes both construction energy, including the embodied energy of materials, the energy of construction, maintenance energy and demolition/recycle energy; and operational energy including HVAC, power and gas to operate the facility. In addition to quantifying the total energy or total environmental impact during a life cycle, LCA also includes an economic and cultural cost benefit evaluation. Although not many tools have been developed, one called Life Cycle Cost Analysis (LCCA) [7] uses the same method but adapts it toward economic analysis.

2.3.2 Performance assessment
This approach uses simulation to evaluate how a city or building will perform with regard to a specific subject if designed in a particular way. For example, a building in design is modelled as a parameterized simulation and tested for thermal gain so that orientation adjustments are made, alternative energies suggested, and different materials determined in the envelope system. The data produced in simulation is can be used within an LCA. Simulations are becoming more and more accurate as verification assessments are performed. Performance assessments can include cost/benefit analysis regarding green building initiatives and operational cost to illustrate return on investment for sustainable building systems. To date, most developed software tools fall under the category of performance assessment in order to quantify sustainable building practices.

2.3.3 Verification assessment
Verification relies upon post occupancy data being gathered concerning the subject in question. If one is evaluating water efficiency, monitors may be installed or data can be gathered from the local water company to evaluate peak and low water usage throughout an annual cycle. Post occupancy studies are the data that feed performance assessment models. An example of how this is occurring can be seen in the related field of seismic vulnerability assessment methods in the U.S. In order to develop accurate designs in buildings for structural performance, engineers continue to gather data from devastations as a result of seismic events across the globe. Scenario events are documented and compared with damage sustained by different types of building construction, structure, and configuration. This data feeds the algorithms in performance models. As with green building, isolated full-scale mock ups may be tested, however no earthquake or performance simulation digital or actual can account for the many variables present in actual practice.

2.3.4 Qualitative assessment
Instead of using data that quantifies energy, carbon, or some other unit of measure that puts environmental impact in terms of hard numbers, qualitative methods use a unique relative point system to measure the potential green quality of a city or building. These systems appear user friendly: environmental scientists, engineers, and specialists within design teams do not have to be the calculators, but the system can be manoeuvred by laypersons. This is deceiving however as it relies upon the interpretation of the user to make sustainable judgments and translate them into representative points. In addition, many green building characteristics are given the same amount of value, but may or may not be equal in environmental impact. There is inherent bias in each system, but the qualitative methods are not flexible in their ability to accept much adaptation in the evaluation.

The scoping operation will vary according to the subject and scale. The scope also varies depending on the condition of existing remodel, adaptive reuse or new construction. For example, if operational energy as a subject and building enclosure as the scale have been selected, one might select a performance assessment that evaluates how the facility will perform once it is constructed. As discussed in the qualitative assessment, metrics vary depending on the method. However, this is true for all the other scoping methods. Environmental impact metrics can be manifest in as many ways as there are methods of evaluation. For example, the industry preference to calculate life cycle energy consumption including construction, operational, and demolition/recycle is MJ/Kg, BTU/Kg or carbon emitted into the atmosphere as a result of energy production measured in CO2. These basic units are also often converted to a number of other metrics.

3 Tool selection

Tools refer to software, spreadsheets, algorithms, and mechanisms for capturing data and evaluating it. Each tool is based on a method or a purpose. Using the right tool is critical to getting an accurate and mathematically complete answer. Tools have multiple functionalities and can serve diverse studies. There are many tools, and rather than being decided by subject, most often they are determined by scale and scope, with many subjects being covered by one tool. To provide a comprehensive list of tools and their functionalities would be difficult. Instead, below are a listing of resources, agencies and organization that continually provide sustainability quantification tools, where design professionals may find resources available.

The U.S. Department of Energy oversees many organizations and teams with funding centres at universities and private companies to develop software tools for purchase or free download for the public [8]. Organizations that fall under the DOE include the Federal Energy Management Program (FEMP), and the National Renewable Energies Laboratory (NREL). Teaming groups include the Pacific Northwest National Laboratory, Carnegie Mellon, Lawrence Berkeley Laboratory and other universities. Software developed by the DOE are varied in their purpose and can be applied to unique situations due to their multifaceted applications. In addition to developing new tools, The Energy Efficiency and Renewable Energy section of the DOE website has catalogued over 341 building software applications for evaluating sustainability in buildings, with many developed outside of DOE oversight [9]. The website includes a directory database with descriptions so design teams may use tools as needed or access links to additional software. The website is updated continually. The website database is catalogued to allow users to query based on subject or scope. Links are offered to the U.S. Green Building Council, which has produced the LEED products (Leadership in Energy and Environmental Design), and the National Institute of Standards of Technology, which developed the BEES program (Building for Environment and Economic Sustainability). The software tools primarily focus on performance measures assessment.

Precedent green building studies are important to both the legacy of information and to design and building practice. Rather than reinvent the process, using relevant or similar existing studies and their findings to develop a custom and more specific method for a given situation is desirable. Design teams on the precedent projects will have more information concerning the day-to-day challenges that are not found in the formal reports or papers. A phone call or email can go a long way to determine how to approach a related assessment study. A report produced by Todd and Fowler provides an up to date listing of studies that establish precedent methods [10]. Many of the precedents discussed by Todd and Fowler have provided background and a purpose to instigate new tool development.

William Rees and co-author Mathis Wackernagel wrote *Our Ecological Footprint: Reducing Human Impact on the Earth* [11]. Since this seminal book Ecological Footprint (EF) analysis has gained in popularity as an environmental impact assessment tool because of the accessibility of its technique and simplicity of interpretation. EF is an accounting method that illustrates the environmental impacts of human consumption and the earth's bio-capacity to accommodate. EF studies are generally at the macro scale including evaluations of nations, regions, states, cities, but can also be used for individual lifestyle evaluations [12]. The EF is calculated in global hectares (gha), an area that is converted to actual area on earth. Ideally, EF accounts for all aspects of consumption of resources for lifestyles per capita. The EF is therefore, a feedback tool to tell us how sustainable we are living within our resources on the planet [13].

Other methods for macro level sustainability quantification exist including the Living Planet Index, Environmental Sustainability Index, and a number of key indicator studies, most of which are based off of the tools described above. They illustrate what elements of everyday living contribute to a more or less environmentally impact. These all rely on a similar goal of the EF studies to render to users how lifestyle impacts environment. Few studies focus on economic or social impacts however, as this has been less important in these models. Tools related to sustainable balance between environment, society and economics have had much more headway at the individual building scale.

Todd and Fowler state,

> "One of the most persistent questions about sustainability design is its cost – does it cost more to build and operate a green building and if so, how much more? How long does it take to recoup these costs in operating savings? Which investments in green design pay back more quickly?" [14]

Todd and Fowler provide a listing of recent studies that provide a precedent for design teams searching for cost models regarding sustainability [14]. These models rely on the cost/benefit of green building in order to justify initial increase in cost compared with traditional construction. In addition to precedents, LEED has developed a cost study that works in tandem with LEED evaluation tools. This measures the first cost (construction capital) impacts of LEED requirements on the design and construction process. The Federal Energy Management Program, under the U.S. DOE, has developed a sustainable cost and performance metric. Carnegie Mellon has produced in collaboration with the U.S. DOE an e-building Investment Decision Support, or e-BIDS for short, which compares cost to energy saving efforts such as day lighting, temperature control, etc. The National Institute of Standards of technology has produced a life cycle cost analysis to ride on top of general LCA analyses. The method developed by Sieglinde Fuller provides more discriminating evidence of the need for verification of cost with traditional LCA analyses for initial and operational investment [15]. These studies focus on the building proper, but do not make a connection to evaluation at the planning scale. Ironically, it is macro level studies that have a much greater impact on changing attitudes with respect to environmental stewardship. Ideally, these costing studies would fold into a larger methodological study that then can feed a planning or policy model.

Although many new precedents, methods and now tools are becoming available, resources focused on social and cultural aspects are not readily available. Social and community tool evaluation is not only the least available, but also the most difficult to develop a method around and quantify. By nature these are qualitative functions. Future environmental studies will need to develop connections to social, behavioural and health sciences in order to devise effective ways of translating these studies to have a much greater social impact. Studies completed to date that have been successful in linking environment to social issues have relied on verification methods. Utilizing post occupancy evaluation through interviews, surveys and other data collection devices common to the social sciences will provide the necessary background to illustrate how green building decisions are impacting human capital: health, culture, and well being.

4 Challenges

The challenges of developing sustainability quantification methods are far reaching. The problems point to the relative immaturity of the field. One of the major difficulties with measuring sustainability is the investigator themselves. Already discussed before, beginning a study without a clear understanding of one’s purpose, what one would like to measure, how and at what scale is a recipe for disaster. This is exacerbated because of the lack of training among design professionals in research. For example, in architecture, design is often an intuitive process. Expecting an architect to be able to perform a quantification study in many ways is against the grain of training and practice.

Another challenge to developing and performing a green building assessment is the issue of interoperability of methods and tools. Currently there exist no common systems for sustainability rating. With varying levels of scale, specificity of data and metrics, each method and tool uses its own logic to determine sustainability of a facility proposed or existing. There first needs to be a common agreed upon metric for methodological comparison that thereby software might also be developed to talk to one another. For example, in a recent study performed by the author, the planning level data produced outputs in an EF model that were in hectacres (a metric developed specifically for EF), while the building specific data that fed the EF was in MJ/kg of energy. A conversion process was necessary. The data is also not as detailed in the macro study as in the micro. As opposed to large-scale studies, whose purpose is to provide convincing evidence to state and regional elected officials that might result in smart-growth initiatives or metropolitan environmental policies, micro studies are usually targeted at local decision makers of the built environment including the professional design community of planners, urban designers, and architects to influence neighbourhood design and form. Finding common ground so that diverse scaled studies may be able to support one another and different subjects and scopes can be mutually supportive is necessary for impact.

Although quantification is valuable, it also points to the problem of computation in general - the reliance upon data - whether correct or incorrect. In the event of bad data, the problems are obvious. However, often data driven design also does not give space for the designer to look at a problem qualitatively and intuitively in order to manipulate spatial environments and natural materials to emerge as climatically, socially and culturally responsive solutions. In addition, data in tools are only as good as the algorithms that drive them. These methods are built upon smaller scale studies and verification needs for simulation. Therefore, current buildings are being designed using quantification performance software that is based upon best practices known. As additional data is discovered through verification, the algorithms may change. Aforementioned, in seismic design building assessment models, the algorithms continue to be updated after each scenario event as additional knowledge is gained concerning more effective design.

This is especially true in qualitative measuring methods such as LEED. Armpriest and Haglund report that although the Seattle City Hall was designed to a LEED standard in 2004 it is a poor energy performer [16]. The Seattle Post-Intelligencer wrote, “Seattle’s new City hall is an energy hog” on July 5, 2005 [17]. Based on data from the local utility, operating costs due to energy for the new City hall ranged from 15% - 50% higher than for the building it replaced. Granted, the new building has a higher person to space ratio, however the new building is smaller than its predecessor and other design such as extensive glazing and double height spaces have made anticipating the performance difficult. Once commissioning continues through its beginning years, much of the inefficiencies in the environmental controls will hopefully be mitigated. However, in 2005, the utility company report showed that in the summer months, the building performs very well, but suffers in the cold winter and spring. This building is a victim of the sustainability hype that surrounds many cases of new “green” architecture, towns and products in general. Without quantification, relying on qualitative measures for sustainability assessment during and after design may lead to more conscientious owners and designers but not necessarily lead to better buildings. Perhaps the best outcome of this building is the lessons to be learned that can drive revision and development of future LEED and other qualitative methods.

Qualitative systems also have difficulties with inherently heavy-laden bureaucracies. In order to gain credits or evaluate for green building quality, rating systems rely upon a top down imposed system of order. This inherently places bias regarding the special interests of the organization administering the evaluation system. For example, in LEED a point system is used, giving equal weight to parameters that may or may not have as much environment impact with regard to the building at hand. A vernacular building that uses passive methods to heat and cool are not given credit in the point system. The previous example of the Seattle City Hall illustrates that a building may gain a LEED rating but not be truly sustainable from either an environmental, social or economic perspective. In this case, because it is difficult to measure the success of the building socially, it is failing from the perspective of both environment and economics. Larry Scarpa of Pugh + Scarpa, an architecture firm in Los Angeles, stated in a recent lecture on green building, “an energy hog - community loved building is more sustainable than a green - community loathed building” [18].

5 Conclusions

The American Institute of Architects recently published a white paper titled; “Quantifying Sustainability” where three major green building tools used for evaluation was reviewed [19]. Each of these methods is a building rating system, using a qualitative mechanism for scoping. Ironically, the study was commissioned because of a lack of outcome and performance based building evaluations that were occurring leaving sustainability and building still a mystery. The AIA’s goal is to promote these recommendations as the way to reduce carbon emissions as a result of the design and construction industry.

The AIA’s focus on qualitative methods is telling concerning the state of the design profession regarding sustainability assessment. The reality is that although we do need more precise and hard data methods of evaluation for green design in general, these methods also need to be accessible so that users and continual critique and updating of the methods can be done on a regular basis. For a whole building assessment, LCA is the most thorough and in depth, using many other scope mechanisms described above as part of its methods. However, data does not always exist or is available to do such an evaluation. Rather than focusing on data, a focus on people and process seem to hold the most promise to achieving the goals of a balance of environment, society and economics in order that the green building quantification process will be well established as data becomes better in the future.

The National Renewable Energy Laboratory (NREL) performed an in-depth case study of six high performing buildings [20]. The study has spawned numerous additional studies and metrics that have taken cues from this precedent. The research focused on understanding the culture of practice of architecture and planning that aided the process of sustainable design, construction and more specifically, high performing energy buildings. It found that the greatest contributors to realizing high performing architecture were communication among partners with owner driven goals and an integrated approach to project delivery. Integration in the process of design and construction delivery is the key to reaching green building objectives and goals whether they are high performing architecture or some other aspect of green building.

Although changes will continue to refine the tools and methods for environmental analysis, real success is not uncovered in technique, but will be found when a balance is struck in environment, society and economics for a sustainable system. This can only be realized as we work toward quantification. However, as this article suggests, the development of such methods requires an integrated collaborative. Integration, as in so many industries before construction, leads to innovation [21]. This paper has referred to the entity performing green building quantification analysis as "designers". This is to suggest that integrated teams involved in design in which sustainable decisions are made can use a process of subject, scale, and scope to determine a method and finally, the tools for evaluation for a given project. These players may be as traditional as architects and engineers, but in an integrated process also include owners, subcontractors, and commission agents/facility managers. Capitalizing on the skills of all involved in a building architectural project, sustainability quantification during the design phase will have much more depth, critical thought, and the end building design will be much more innovative.

References

[1] http://epa.gov/sustainability/, accessed November 2009.
[2] Our Common Future, Report of the World Commission on Environment and Development, World Commission on Environment and Development, 1987. Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment August 2, 1987.
[3] Hawken, Paul. *Natural Capitalism*. Little, Brown and Company 1999. Pg. 6
[4] Barrett, J., Vallack, H. Jones, A., Haq, G. *A Material Flow Analysis and Ecological Footprint of York*. Stockholm Environment Institute. Norwich Union.
[5] McDonough, William and Braungart, Michael. *Cradle to Cradle: Remaking the Way We Make Things*. North Point Press. 2002
[6] International Organizing Standards. ISO 14000 Environmental Impact Industry Standards.
[7] Fuller, Seiglinde. *Life-Cycle cost Analysis (LCCA)*. National Institute of Standards and Technology (NIST). 2005.
[8] http://www.doe.gov, accessed November 2009
[9] http://www.eere.energy.gov/buildings/tools_directory, accessed November 2009.
[10] Todd, Joel Ann and Fowler, Kim M. *Measuring Performance of Sustainable Buildings.* Pacific Northwest National Laboratory Report. May 2008.
[11] Rhees, William and Wackernagel, Mathias. *Our Ecological Footprint: Reducing Human Impact on the Earth.* New Society Publishers. 1995.
[12] Smith, Ryan and Senbel, Maged. *Assessing Housing: ecological footprint study of neighborhood form.* Eco-Architecture 2008. WIT Press. Southampton, UK 2008.
[13] *Ecological Footprint Standards 2006.* Global Footprint Network. June 16, 2006.

[14] Todd and Fowler.
[15] Fuller, Sieglinde.
[16] Armpriest, Diane and Haglund, Bruce. *A tale of two city halls: icons for sustainability in London and Seattle.* Eco Architecture: Harmonisation between Architecture and Nature. Broadbent and Brebbia (Eds.) WIT Press. Southampton, UK. 2006. pg. 133-142
[17] Mulday, Kathy. *Seattle's new City Hall is an energy hog.* Seattle Post Intelligencer, July 5, 2005.
[18] Larry Scarpa. University of Utah, College of Architecture + Planning Spring 2008 Lecture Series.
[19] *Quantifying Sustainability: A Study of Three Sustainable Building Rating Systems and the AIA Position Statement.* American Institute of Architects. AIA Sustainability Discussion Group. May 2008.
[20] *In-Depth Case Studies of Energy Performance of Six High Performance Buildings.* U.S. Department of Energy, National Renewable Energy Laboratory.
[21] Tonrnatzky, Louis and Fleischer, Mitchell. *The Process of Technological Innovation.* Lexington Books 1990. Pg. 153.

Renewable and durable building materials

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Abstract

Present ecological circumstances call for severe and immediate action. The debates that raged in Copenhagen at the United Nation's Climate Change Conference in 2009 spoke to the enormity of the problem as well as the complexity of the solutions. While many initiatives have begun to create public awareness and, in a few cases, have had a minor effect on decreasing our continuing consumption of natural resources, it is not nearly enough. The construction, occupation, and disposal of buildings should be a critical focus of any discussion on sustainability. This paper explores the efficacy of renewable building materials used in construction in Canada and the United States. The discussion centres on two examples, engineered wood products and earthen blocks. This paper assumes that the durability or long-life of the material in service is a key component to sustainability and that the construction of housing has a substantial role to play. The emphasis is on materials used in the building envelope or structure.
Keywords: sustainability, renewable resources, durability, LEED®, engineered wood, adobe, pressed earth blocks.

1 Introduction

University of British Columbia professor William Reese wrote about our "mass-delusion in consumer culture," arguing, "that most mainstream approaches to sustainability today – hybrid cars, green buildings, smart growth, the new urbanism, green consumerism – do not, in fact, address the fundamental problem. Instead, they attempt to reproduce the status quo by other means. Consistent with our prevailing cultural illusion, today's global society essentially equates sustainability with maintaining growth through technological innovation and greater material and economic efficiency." [1]

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Ed Mazria, founder of Architecture 2030, points out that, “Architecture consumes approximately 48 percent of all the U.S. energy produced and is responsible for 46 percent of all U.S. CO2 emissions annually, almost double any other sector. It’s also the fastest growing energy-consuming and emissions sector.” [2]. Buildings are around a long time, often 50 to 100 years or more, making changes to their construction critical. A point missed by Mazria in his seminal article, titled “It’s the Architecture Stupid!” is that the majority of the construction dollar goes into housing and architects do not design most housing. It is estimated that in the developed world “perhaps 80 percent [of buildings] by value, are not designed by architects…and most of that 80 percent are houses.” [3]. Consequently a change made in the housing market resonates more quickly and has a greater effect than those made in the non-residential market even though this is often where experimentation is occurring.

2 Sustainability and durability

Durability is of upmost importance in the design and construction of sustainable buildings and the building envelope is where most failures occur. LEED®, the third party energy rating system developed by the U.S. Green Building Council (USGBC) in 2000, does not presently give points for durability or reduced life cycle costs. In the catalogue of possible points for Innovation in Design the one that comes closest to producing a more durable building is for a “preventative maintenance program.” USGBC has an on-going working committee looking at introducing Life Cycle Analysis (LCA) into LEED®, but it is a difficult task, the ideal being on-going, whole building modelling for energy consumption. But equally important is durability of the component parts and assemblies. A cladding system that lasts 30 years will have half the embodied energy and contribute half of the demolition waste as a cladding that lasts only 15 years. Failing claddings can also affect the thermal properties of the wall and hasten the failure of all wall components. Durability is difficult to compute and often has less to do with the material than with the protection of the assembly particularly from moisture and differential movement.

When LEED® Canada was initiated in 2003 a single point was introduced for durability. The intent was to: “Minimize materials use and construction waste over a building’s life resulting from premature failure of the building and its constituent components and assemblies.” The durability point references the Canadian Standards Association’s document titled *Guidelines on Durability in Buildings* (S478-95, reaffirmed 2001), an important guideline. As in the U.S. one or two more points are possible with innovative design. While the steps taken by Canada are admirable, the onerous paperwork involved means that these points are often ignored. It is simpler to add a bike rack or use bamboo flooring for a point. If the durability point were a requirement for all LEED® accredited buildings in the United States and Canada our buildings would last longer. Both Canada and the U.S. have introduced LEED® for Homes with similar expectations but no requirements for comprehensive durability.

Although the efficacy of LEED® is continually being observed, debated, and revised, the system has a long ways to go if real substantive results are expected. The USGBC conducted a study last year and found that 53% of LEED® certified buildings did not qualify for the Energy Star label, another rating system in the U.S., and that 15% scored below 30 in the Energy Star program, meaning that they used more energy than at least 70% of comparable extant buildings. The best performing buildings were smaller and had less glass, which should surprise no one [4]. The reliance on rating systems such as LEED® exemplifies what Reese has labelled the ”mass-delusion in consumer culture.”

We are inundated with “sustainable” building products to the point that designers and owners have a difficult time separating fact from fiction. Brick is touted as a durable material that comes from the earth. Glass towers receive LEED® accreditation. Does a truly sustainable building material exist when we define sustainable as conserving an ecological balance by avoiding the depletion of natural resources?

3 Natural materials

The few renewable and/or easily biodegradable or reusable resources used as building materials are found in a group of natural materials either mineral (non-renewable) or organic (renewable) in composition and comprised of stone, earth, grasses, and trees. These materials have been used for constructing buildings throughout history leaving a rich vernacular legacy of earthen homes, thatch covered roofs, stone structures, and log houses to name but a few. Most of the uses were born of necessity for shelter and were dependant on availability of the material. Following is a brief discussion of how these materials are presently used in exterior wall construction.

3.1 Stone: veneers

We no longer use stone as a load-bearing construction material. It is a finish, a cladding producing a pleasing aesthetic and the image of durability. Stone is commonly quarried on one continent, shipped to another for fabrication, and then finally put in service in North America. Stone cladding systems are not easily reused and durability not always what it seems. As stone is sliced thinner and thinner its inherent structural capacities are reduced. Note the failure of the Carrara Bianco marble that clad Alvar Aalto’s Finlandia Hall (1972) in Helsinki. Although concerns were raised about this marble being a suitable cladding material for a building in Finland’s climate, they were ignored. New technology had allowed for the fabrication of thinner pieces of marble than previously. The marble began to permanently warp severely within a few years of the building’s completion and eventually had to be replaced. The citizens’ of Helsinki voted to replace the failed marble with the same Carrara Bianco with a better attachment system. This new cladding started to warp within six months of its installation due to hysteresis. Thin (25-38 mm) crystalline marble slabs will permanently and cumulatively deform, with a corresponding loss of strength, due to thermal expansion and moisture ingress, a phenomenon known for many decades. It is not unreasonable to suggest that the marble cladding of Finlandia Hall will need to be replaced again in another 25 years or so. The embodied energy of this cladding is multiplied by a factor of four when one considers that the expected lifespan of stone has been reduced by a similar factor [5]. Stone can now be sliced as thin as 10 mm. This thin slice is bonded to a stabilising panel of aluminium honeycomb, reducing weight and cost. But the durability of such systems should be seriously considered.

3.2 Grasses: straw boards, straw bales, bamboo

Of recent interest is the use of straw and bamboo in buildings. While bamboo is a quickly renewable grass, straw is a waste product from a variety of grains including, but not limited to, wheat, oats, barley, rye, and also rice. There are few uses for straw other than animal bedding and landscape covering. In many areas it is burned in the fields severely affecting local air quality. Straw can be pressed into structural boards that replace standard western platform framing or "2x4" construction. The product is extruded under heat usually around 200dc (400df) and pressure. The process uses minimal energy to produce the highly dense, fire-resistant board. The compression releases natural resins that bind the straw together. Straw boards from Agriboard Industries, in the United States, were used as exterior walls in the Bank of America building in Frisco, Texas, helping to create a building with a negative carbon footprint. Four weeks of construction time was saved, which lowered construction costs, and the steel-framed building was enclosed in six days [6].

Straw is also used as a wall system of stacked bales usually with a wood post-and-beam structural system. This system requires carefully baled straw, typically 450-600 mm (18-24 inches) in depth. Perhaps the biggest problem is that the straw must remain dry during storage, transportation, and installation. It is also advantageous to wait until the straw has compressed before weatherproofing the exterior. All of this adds to construction difficulties and extends the construction time. Straw bales have been used historically along with sod blocks for construction, but it is a material that may not make the translation to a sustainable way of building for the future, except in limited geographical areas.

Bamboo is emerging as a possibility for a quickly grown raw material with inherent structural properties. Much experimentation is occurring with laminating this fibre into claddings, sheathings, and floor coverings. Because of its fast growth, bamboo may fill construction requirements more easily than trees. It is not commonly used as a structural building material except in small houses and as scaffolding or similarly framed constructions. This may well be a material with future potential as the structural and moisture-resistance properties are more fully realized.

3.3 Earth: sun-dried brick, compressed earth blocks, fired-clay brick

The first "building product" was the sun-dried brick produced 10,000 years ago. Historically houses have been constructed of earth in various forms from sun-dried brick to rammed earth walls. Today approximately one-third of the world lives in houses constructed of earth. In developing countries it is over one-half [7]. Sun-dried brick or adobe is still used for construction in the southwestern United States. Fired-clay brick is the outgrowth of sun-dried brick. Concrete and other cementitous materials are often deemed to be materials of the earth; however the energy expended to produce cement removes these products from a list of truly sustainable building materials.

Brick is a material that exudes durability, an implied sustainability of the product. But fired-clay bricks may not be the sustainable product manufacturers would have us to believe. The majority of "brick" buildings have only a single veneer wythe, frequently with a back-up wall of light-gauge steel studs. The brick serves merely as a cladding, albeit a heavy one. Rarely is the load-bearing capacity of fired-clay brick utilized in Canada or the United States. When the propensity for failure of this single-wythe veneer is considered, the argument for brick being a sustainable material is further maligned. The Brick Industry Association's (BIA) Technical Note 48, titled Sustainability and Brick, states, "Brickwork is durable, having a life expectancy of *hundreds* [author's emphasis] of years. Brick buildings can be and are reused…" [8]. These are not "brick buildings" but rather buildings *clad* with brick. The problems with brick claddings are widespread in the United States and Canada. The author's masonry forensics firm spent over a decade studying anchored brick veneer failures and designing solutions on primarily institutional buildings. A University performing arts centre illustrates the problems with this cladding in the U.S. and Canada. The building has a cast-in-place concrete load-bearing wall that was clad with anchored brick veneer. First occupied in the mid-1970s, problems were noticeable within a few years. When the author first observed the building had been in service less than 15 years. After a lengthy investigative period it was determined that the brick veneer would need to be replaced. Insufficient horizontal and vertical expansion joints and inadequate anchorage of the veneer and its supporting shelf angles were the primary problems [9]. A design architect was hired to work with the exterior aesthetics of this prominent building. The very carefully researched and designed new veneer was then analyzed through a value engineering process required by the State. The University had expressed a desire for a 100-year cladding. Designing and constructing a 100-year brick veneer cladding is possible but unlikely given the cost and design restrictions. With compromises made through working with the design architect and the value-engineering process the author determined that the estimated life was 75 years. The cost of replacing anchored brick veneer on this relatively new building with anchored brick veneer was over $7.5 million in today's U.S. dollars.

Reusing brick is also questionable. As the BIA states in Technical Note 15: "… it may be next to impossible to salvage brick from modern structures which use brick set in Portland cement mortars… It is virtually impossible to completely clean these [cementitious] particles from the surfaces of the brick units. This may greatly affect the bond between brick and mortar when reused." [10].

The most sustainable use of the earth in contemporary practice may be in creating earthen blocks whether they are sun-dried brick (adobe) or pressed earth blocks. These materials can at minimum be returned to the earth. They can also be reused and the fossil flue used in production is minimal.

3.4 Trees: plantation trees and engineered wood

In Canada and the United States wood is used extensively in the popular and economical, western platform framing, or “two-by-four” or “stick-built” construction as it is sometimes called. This system, using dimensional lumber and wood sheathing, produces a quality structure for minimum cost. It can be used in housing developments up to six stories in height in Vancouver, Canada and five stories on a one or two-story, non-combustible base, in Seattle, U.S.A. The flexibility and economy of scale make it a highly competitive structural system. It is unlikely that the basic method of construction will radically change in the housing industry in the very near future. The author has investigated the use of this system in Japan, Chile, and Switzerland, as an economical method of meeting current housing needs. Other systems consist of solid wood walls formed by laminating smaller pieces of wood into structural panels. These are more prevalent in Europe.

Trees regenerate, but wood is a limited renewable resource at the rate deforestation is occurring in many countries. Although there are numerous products that use wood fibre and waste from milling, the desirable woods from hardwoods, structurally sound softwoods such as fir, and decay resistant woods such as cedar and redwood can hardly be called renewable resources. Wood acts as a carbon sink, an advantage that underscores the need for durable wall systems. And wood is durable when protected. The Norwegian stave churches, some of which are close to 1000 years in age are good examples. The wood cladding has been replaced, but the original structures are intact.

Timber that is grown quickly on plantations may be the best renewable wood resource to date. However even this wood can carry a high-environmental cost in waste, product production, transportation, disposal, and loss of natural eco-systems. As these are weaker trees and smaller in diameter, smaller pieces of wood are often laminated using glues and resins creating engineered wood.

4 Sustainability and houses

Most efforts in making housing more sustainable emphasize alternative ways of producing energy or methods of increasing performance of the building envelope. The discussion focuses less frequently on reducing the embodied energy of the structural components or increasing the life span of the building. Is it possible to use materials that are truly renewable and durable? Are they still sustainable when the procurement of raw materials, manufacturing processes, and transportation, followed by the ecological cost of maintaining, and finally recycling or reusing the materials, are considered. Equally important is the continuing purposefulness with cultural and economic changes. The following discussion focuses on engineered wood and earthen blocks.

4.1 Engineered wood

A Japanese housing manufacturer, KST-Hokkaido, offers an interesting look at a sustainable house using engineered wood in a broader context. Although the company no longer manufacturers houses, the model is worth reviewing. Hokkaido, the northern most the archipelago that makes up Japan has almost a quarter of Japan's land mass but only 5% of the population, making detached homes more viable. The KST-Hokkaido House was a hybrid of structural post and beam pre-cuts, prefabricated panellized walls, and on-site construction that was uniquely designed for this specific region and culture. The design of this simple house was the culmination of over fifty years of experimentation by the KST-Hokkaido founder and owner, Mr. Akira Yamaguchi. Although the KST-Hokkaido House attracted the interest of researchers from around the globe, the house was never exported even to the northern regions of Honshu, which has a similar climate. It was designed specifically to meet the environmental and social needs of Hokkaido residents.

Because Yamaguchi felt strongly that the multigenerational family was important to the sustainability of Hokkaido's society, he developed a housing form to support this family relationship. As a result of the harsh winters, construction often stopped for up to six months of the year in Hokkaido. Yamaguchi believed that the year-round construction of houses was important for the community. He also noted that the highly specialized temple carpenter – who stressed quality and respect for materials – could never meet the post war production needs for housing. During this period he observed and experimented with the "two-by-four" construction used by American companies in the area. He noticed the benefits of using modular pieces that could easily be assembled by unskilled workers. He also recognized that poor-quality housing was a major problem in Hokkaido as in the rest of Japan. To keep costs down and still maintain quality, he started prefabricating as much of the KST-Hokkaido House as possible in a factory with each worker performing only a few tasks using precision equipment in an assembly-line fashion, providing year round employment. Emphasis was on durability, creating a 200-year house where the typical Japanese house lasted only 26 years [11]. In an interview between the author and a grandmother who had recently purchased a KST-Hokkaido House for herself and her son's family, she stated she chose the house because of its "durability."

Perhaps Yamaguchi's greatest concern was a respect for the natural environment. He remarked that his "mind was always on wood and winter in Hokkaido." In following this philosophy, Yamaguchi tried to use only local wood, much of it engineered from smaller pieces. This combination of modern industrial house-building techniques and traditional values made the KST-Hokkaido House distinct [12].

The author followed the KST-Hokkaido House for over a decade. Unfortunately the company was unable to weather the departure of Mr.

Yamaguchi from the company in combination with the aftermath of Japan's economic bubble. This model for sustainable living and working required the strength, focus, and vision of a person such as Mr. Yamaguchi.

Making use of excess local woods is worth the effort, but it usually is only a stopgap strategy that will eventually peter out. Recently a scourge of pine beetles, most likely due to the effect of global warming, has killed a large swath of tress in Canada and the United States. This wood is usable if properly processed. While this is not sustainable, looking at methods of using that which is waste should be a high priority.

Wood, from plantations, is one of our few renewable resources. If the environmental concerns can be addressed and non-toxic binders developed then engineered wood products from plantation trees may make a difference. Utilising the engineered wood to its maximum, decreasing the size of housing units, and emphasizing durability might mitigate the sustainability concerns about wood. Added to the list of engineered products might be straw boards and laminated bamboo. Reusing or recycling these products may be difficult but there is no reason why a structure of wood cannot last 200 years if properly designed and maintained. And a house of wood is also the cultural expectation in Canada and the United States.

4.2 Earthen blocks

As previously noted, using fired-clay brick as a cladding makes little sense environmentally. But what about using earthen blocks as structure? Adobe or sun-dried bricks and compressed earth blocks both have potential in modern construction. (This discussion does not include rammed earth or cobb construction, similar construction types with many of the same attributes as adobe brick.) Blocks of earth have low embodied energy and when used in a properly designed wall are very durable. With frequent maintenance adobe can last for centuries. The six-story, Taos Pueblo in northern New Mexico U.S. has been continuously occupied for over 500 years. This construction method is being resurrected in the Southwest of the United States. The earth blocks have aesthetic, acoustical, and thermal advantages over many other construction types, particularly for housing. While many small operations exist, there are also larger commercial producers of adobe brick. Typically the "loam" used in adobe construction is a mixture of clay, silt, sand, and sometimes larger aggregate. Clay acts as a binder similarly to cement in concrete. Fibre such as cut straw is added as reinforcing to reduce shrinkage cracks in the blocks. Additives can be added to increase the performance of adobe. These include artificial stabilizers such as synthetic resins, mineral and animal products, cement, lime, and bitumens [13]. Numerous field and laboratory tests can establish the right mixture for the given application. The diurnal thermal change in the houses with adobe walls is much less than in houses of wood frame construction. Modern applications to walls can create durable and pleasing interior and exterior surfaces. And demolition of the material is easy, the earth returns to the earth. In New Mexico, factories produce traditional adobe bricks of blended soils with straw for reinforcement. They also produce semi-stabilized blocks that have 4-

5% asphalt emulsion, and fully stabilized blocks with 8-10% asphalt emulsion, which according to the New Mexico Code can be left exposed. Although not part of model codes to date, New Mexico has a “New Mexico Earthen Building Materials” Code that covers various methods of building with earth. The author visited one structure that was being restored in New Mexico. There had been a fire in the 70-year-old building that destroyed the wood roof and floor joists. Approximately two-thirds of the walls were standing. Some had fallen because of lack of protection from the weather for the last 20 years but some of 70 year-old adobe blocks were salvaged for use in the repair. The remaining brick were being produced on-site with locally sourced materials including some of the disintegrating adobe brick.

Is this a viable method of construction? One can certainly argue that it is sustainable. Perhaps an even better use of loam or soil is using it in compressed earth blocks. The Cinva Ram became popular worldwide in the 1950’s as a method of producing a structural block using local materials and requiring only human power. Although cement made the blocks stronger, binders such as eggs and cow manure were also used with straw serving as reinforcing. The latest generation of these simple rams have compressors fuelled usually by propane or gas that compacts the earth, adding considerable strength when compared to those produced with the manual press. Some companies have been experimenting with adding waste materials such as gypsum wallboard to the mix. The GreenMachine manufactured by TerraBuilt can produce 4-5 brick per minute. In 20 to 24 hours enough brick is produced for a 100 square meter house. They can be made of 100% loam or up to 8% cement can be added to increase the compressive strength and resistance to moisture. In a certified independent testing lab it was found that the Terra Bricks exceed the New Mexico adobe compressive strength standard of 300 psi, measuring from 900 to 2,240 psi depending on cement content. They also out performed the adobe wall standards for modulus of rupture, lateral loading, and shear strength. The Oakridge National Laboratory Building Technology Center ran thermal dynamic tests that showed a properly engineered TerraBuilt wall significantly out performs an equivalent wood frame wall system [14].

Additional benefits of earthen blocks are their low moisture content that allows for contact with wood, their ability to absorb pollutants, and their capacity to store moisture and heat.

5 Conclusions

If we ever adopt an aggressive attitude towards stopping the overuse of natural resources and try to start reversing the cumulative damage, engineered wood and earthen blocks may play a role. This requires a paradigm shift in the way we understand our homes. Housing may take more labour to construct and require more frequent maintenance. There should be an expectation that houses will last 100 to 200 years, which means neighbourhoods need to be preserved. Our attitude of everything, including our buildings, being disposable needs to stop. The amount of space required for living should be challenged. None of this implies a lower standard of living, just a different standard. The status quo may not be maintained but the quality of our lives need not decrease.

References

[1] Reese, William E. The ecological crisis and self-delusion: implications for the building sector, *Building Research & Information*, 37: 3, pp. 300 — 311, 2009.

[2] Mazria, Edward, It's the architecture, stupid! *Solar Today Magazine*, pp. 48-51, May/June 2003.

[3] Davies, Colin. *The Prefabricated Home*, Reaktion Books Ltd: London, p.8, 2005.

[4] Navarro, Mireya. Some buildings not living up to green label, *New York Times*, August 31, 2009.

[5] Brock, Linda. *Designing the Exterior Wall: An Architectural Guide to the Building Envelope*, John Wiley & Sons Inc: Hoboken, New Jersey, pp.264-270, 2005.

[6] Agribond, http://www.agriboard.com/

[7] Minke, Gernot. *Earth Construction Handbook: The Building Material Earth in Modern Architecture*, WIT Press: Southampton, p.9, 2000.

[8] Brick Industry Association. Technical Note on Brick Construction, *Sustainability and Brick*, #48, June 2009.

[9] Brock, Linda. *Designing the Exterior Wall: An Architectural Guide to the Building Envelope*, John Wiley & Sons Inc: Hoboken, New Jersey, pp.274, 2005.

[10] Brick Industry Association. Technical Note on Brick Construction, *Salvaged Brick*, #15, May 1988.

[11] Cole, Raymond, Lorch, Richard, eds. Buildings, culture and Environment: Informing Local and Global Practices Blackwell Publishing: Oxford. p.318, 2003.

[12] Brock, Linda. *Designing the Exterior Wall: An Architectural Guide to the Building Envelope*, John Wiley & Sons Inc: Hoboken, New Jersey, pp.323-332, 2005.

[13] Minke, Gernot. *Earth Construction Handbook: The Building Material Earth in Modern Architecture*, WIT Press: Southampton, p.9, 2000.

[14] TerraBuilt, http://www.terrabuilt.com/index.asp

Predicting green building performance over time: data mining untapped information in LEED

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Abstract

This paper will present a method for data mining building performance information available in the LEED™ rating system project applications to show predicted environmental impact and improved performance over time. A study initiated by the City of Seattle analyzed data from over 50 LEED projects within the city limits to quantify the climate change impact of LEED buildings, developing aggregate performance predictions for water, energy and solid waste measures and savings. This paper demonstrates the efficacy of mining LEED derived performance data to make predictions about environmental impact, including carbon reduction, of green building programs using the City of Seattle Performance Evaluation Program as an example. This paper probes key findings regarding the most common green building measures, aggregated savings, the market penetration of specific strategies, and opportunities lost. The LEED Documentation Data Mining Methodology® magnifies its value if used to compare varying building cohorts to identify regional, programmatic, and owner-related performance patterns and to inform continuous improvement of sustainable building approaches. The paper explores how this data mining methodology could be adapted and developed for any rating system and any cohort of buildings, and thus utilized to predict sustainable design and related climate impacts of building programs.

Keywords: data-mining, sustainability, LEED.

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1 Introduction

Buildings are major users of energy and materials that produce by-product greenhouse gas emissions; close to 40% of annual CO_2 emissions are a result of building construction and operations. Therefore, there is a need to understand the potential of building rating systems and programs to slow the growth rate of greenhouse gases and meet climate change targets.

The most accurate method for evaluating building performance is through monitoring utility consumption, cost and occupant satisfaction for a large portfolio of buildings over time. However, there are limitations and challenges to this process. First, the process is time consuming and costly, representing a significant annual investment throughout the life of the building. Second, there is no clear agreement on standardized baselines or methods to estimate savings.

However, there are a variety of green building rating systems that establish standardized procedures to predict performance of green building designs. Rating systems, such the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED), collect data based on standardized calculations of energy, water, and materials savings, with prescribed baseline definitions and calculation methods. This data is available now and can be "mined" to provide a valuable window into expected building performance over time. The large number of buildings that have participated in this rating system provides a significant database of information that can inform responsible use of energy and resources, show the need for policy changes, and demonstrate whether the investment in broad green building programs delivers the climate change goals that are desired.

Section 2 provides background information on the project history and the LEED program, and describes the methodology and analysis tool used for the study. Section 3 depicts representative graphs and data summaries that are generated by the tool.

2 City of Seattle performance evaluation program

A study initiated by the City of Seattle analyzed data from over 50 LEED projects within the city limits to quantify the climate change impact of LEED buildings, and to develop aggregate performance profiles on water, energy, and material savings. This analysis provided insight into the most common green building measures and market penetration of specific strategies, as well as opportunities lost.

2.1 Background information

The City of Seattle initiated this study in 2005. Paladino and Company performed the study, which consisted of data mining predicted building performance from the LEED applications of 15 buildings within the City of Seattle limits. The study summarized and aggregated the LEED application data to evaluate the potential long-term impacts of green buildings on the City's infrastructure and resources.

Recognizing that the value of the study would increase over time, as more LEED buildings are added to the database analysis, the City became interested in an annual study of LEED projects. The City worked with Paladino to develop a tool so that the analysis could be easily performed on an annual basis. Another element of the tool development was to integrate a filtering feature to allow segmentation of building cohorts for analysis and comparison. For example, the data could be filtered by date to determine measures implemented before and after a code change; or the data could be filtered to compare office buildings with school buildings. Filtering the data allows the City to understand the most commonly implemented sustainable design strategies, as well as identify potential conservation measures and opportunities not currently implemented by Seattle buildings.

2.2 LEED rating system

The LEED rating system, developed by the U.S. Green Building Council, is the predominantly-used program for rating the design, construction and operation of green buildings in the United States. LEED is a third-party certification program and is a benchmark tool for the evaluation of sustainability, not a design guideline.

LEED utilizes a point-based approach with different rating system "products" specifically tailored to various building construction types, such as new construction, commercial interiors, and existing buildings. The LEED rating system is organized into five major categories: 1) Sustainable Sites, 2) Water Efficiency, 3) Energy & Atmosphere, 4) Materials & Resources, and 5) Indoor Air Quality. Credits and associated points are available in each category for achieving specific performance or prescriptive criteria.

Because the City of Seattle was interested in the potential impact that new green buildings have on City infrastructure services like water and electricity, they decided to track buildings certified under three LEED rating systems: New Construction (NC), Core & Shell (CS), and Commercial Interiors (CI). Although many credits are similar across these rating systems, some credits are unique to a specific system. For example, credits related to stormwater are found only in the NC and CS rating systems.

Within each system, projects receive a rating of Certified, Silver, Gold, or Platinum, depending on the number of points achieved. In order for a project to achieve a rating, the design must meet a set of prerequisite credits, supplemented by a group of credits commensurate with that rating level. Point achievement is validated through the development of the LEED application, which consists of required documentation for each credit that the design pursued and achieved. A LEED Submittal Template for each credit summarizes a majority of the required information, but the project team is also required to provide supplemental documentation.

2.3 Methodology

Paladino developed a LEED Documentation Data Mining Methodology to extract and aggregate the wealth of data found in a single LEED application. The methodology is executed through a data mining tool, which takes standardized inputs from individual LEED applications, aggregates the data from multiple projects, and outputs a single report based on the chosen cohort of buildings.

To obtain the LEED applications, Paladino referenced the U.S. Green Building Council website, which publishes a list of certified projects. Projects may confidentially register with the USGBC, and their contact information and project data is not available. Confidential projects are not included in this study. Teams from all available projects located within the City of Seattle, up to October 2009, were contacted to request participation in the study. Most project teams agreed to participate, and to provide their final LEED application data and scorecard for input into the study.

After the project LEED documentation is received, credits achieved, points earned and additional documentation data are entered into a standardized input sheet in the tool. The tool for analyzing the data and outputting reports is designed in Excel using embedded macros and pivot tables. The pivot table creates a mechanism that enables data filtering across several parameters, including LEED rating system used, rating achieved, building owner, zip code, and certification date. Based on the selected filters, the tool produces standardized outputs reporting calculated savings for water, energy, carbon emissions, and materials.

The tool tracks the number of projects achieving any specific credit compared to the total number of projects in that cohort. However, for targeted credits, the tool also provides detailed information on how the credit intent was satisfied, supplying a wealth of data for predicting total savings and identifying commonly-implemented technologies.

Currently, the data from 54 LEED projects has been analyzed using the spreadsheet tool. These projects use LEED for New Construction (NC), Core and Shell (CS), or Commercial Interiors (CI) rating systems as shown in Table 1. The New Construction system addresses new building construction and substantial additions or renovations; Core and Shell addresses construction that impacts only a portion of the building, such as structure, building envelope, and HVAC systems; and Commercial Interiors addresses the tenant improvement

Table 1: City of Seattle LEED portfolio summary.

Number of NC Projects	33
Number of CS Projects	7
Number of CI Projects	14
Total Number of Projects	**54**
Total Square Footage	4,238,540

market and encompasses interior spaces. The New Construction and Core and Shell projects are reported together as their credits are identical for the targeted credits analyzed. Because the LEED-CI credits differ somewhat from NC and CS, CI project data is analyzed separately and then added to the NC/CS data as appropriate. Information gathering on the LEED for Commercial Interiors projects occurred retroactively, so not all publicly available CI projects are included prior to 2008. A majority of projects currently in this study use the New Construction rating system.

3 Performance profiles

The City uses this evaluation tool and its resulting reports to develop aggregate performance profiles of water, energy and solid waste measures and savings. Each report profile consists of specific credits within the LEED rating systems. Although the data from a single project is interesting in itself, the real value in this type of reporting comes from analyses of the data over time or between different cohorts of buildings. These comparisons can indicate trends in design and construction choices over time or over different building types or geographic locations.

Figure 1 shows the LEED-NC project certifications in the City of Seattle for each year from 2003 through 2008.

3.1 Water savings and strategies

Water management and conservation are a critical component of green buildings. Buildings have many water use functions, from irrigation to wastewater and indoor plumbing fixtures. Process water is another component of water use that can be quite high in certain building types, such as industrial buildings or fire stations.

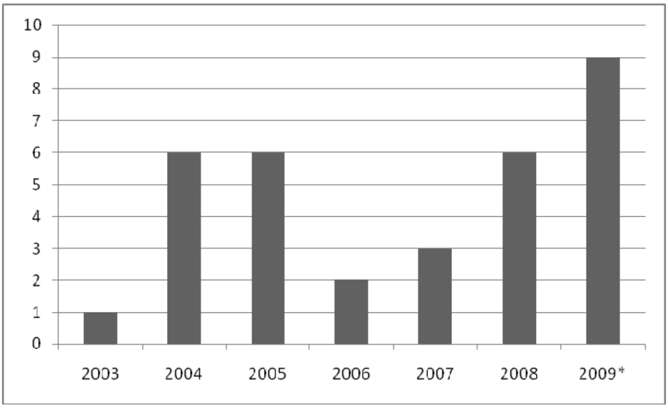

Figure 1: Number of LEED-NC projects certified over time. *2009 information does not include projects certified after October 2009.

Green buildings demonstrate water conservation strategies in many different and creative ways. LEED offers points based on an overall percentage of water use reduction for both irrigation and indoor plumbing when compared to a building with EPACT water consuming fixtures and systems.

3.1.1 Irrigation

The irrigation credit is only available to projects certified under LEED for New Construction and Core & Shell projects, because projects using the Commercial Interiors rating system do not include exterior landscaped areas. Of the 40 total NC & CS projects, 14 projects reduced potable water consumption used for irrigation by at least 50%, and 21 projects did not use potable water for irrigation or had no permanent irrigation system.

Seattle is a city with plentiful rainfall; however, it is still common to see irrigation systems installed to water non-native plant species. LEED buildings in Seattle utilized a range of water saving strategies, summarized in Figure 2. Note that projects often implemented multiple strategies, thus the total number of strategies used is higher than the 40 projects that achieved the credit.

3.1.2 Indoor water use

All three rating systems (NC, CS, & CI) utilize an identical method to estimate water use reduction from use of low-flow indoor plumbing fixtures. The estimated water use reduction is a percent calculation using the gallons per use for installed fixtures compared to a standard baseline, and estimates of usage are based on the total occupancy and occupancy type.

Figure 3 shows indoor plumbing water savings across the entire portfolio and highlights which strategies provide a significant percentage of water savings. For instance, 14% of water savings comes from rainwater harvesting, which is

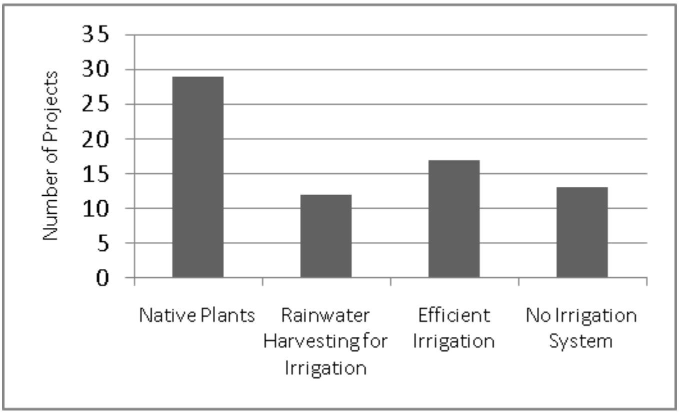

Figure 2: Key irrigation water saving strategies implemented for City of Seattle LEED buildings 2003-2009.

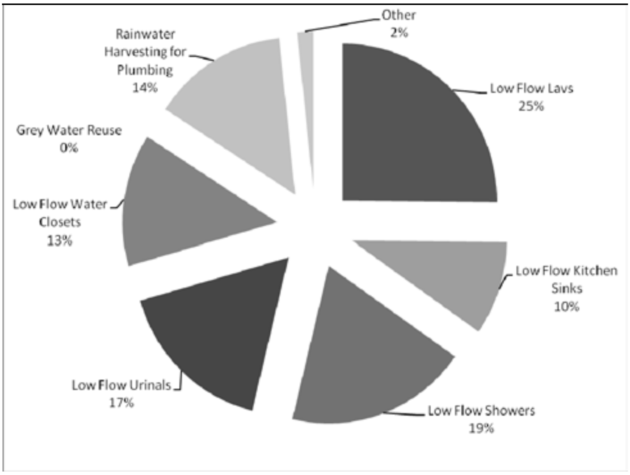

Figure 3: Percent savings by strategy implemented for City of Seattle LEED buildings 2003-2009.

slightly higher than the 13% savings from low-flow water closets. However, these percentages do not give any indication of how many projects are implementing a given strategy. A comparison between water savings and number of projects implementing each strategy, as in Figure 4, shows that although the savings are almost equivalent, almost four times as many projects install low-flow water closets, as compared to the number that implement rainwater harvesting. This fact indicates an example of an underutilized strategy, with a potentially large impact on overall water savings for a building portfolio.

3.2 Energy

3.2.1 Overall energy savings

The LEED for New Construction and Core & Shell rating systems offer a credit specific to the optimization of energy performance, which is achieved by demonstrating predicted energy savings. Achievement of this credit reduces environmental impacts associated with excessive energy use. Projects must demonstrate increasing levels of performance above an ASHRAE (American Society of Heating, Refrigerating and Air-Conditional Engineers) Standard 90.1 baseline through a whole-building energy simulation.

The LEED for Commercial Interiors rating system, on the other hand, does not require an overall energy analysis. Instead, project teams show energy savings through reduction in selected end uses, such as lighting power density, lighting controls, and equipment installed. These savings are predicted with standardized calculations and do not require computer simulation.

Figure 5 shows the number of projects using the NC or CS rating system each year in the study (total bar height) and the ratio of those projects that did or did not achieve energy savings when compared to ASHRAE 90.1. The overall

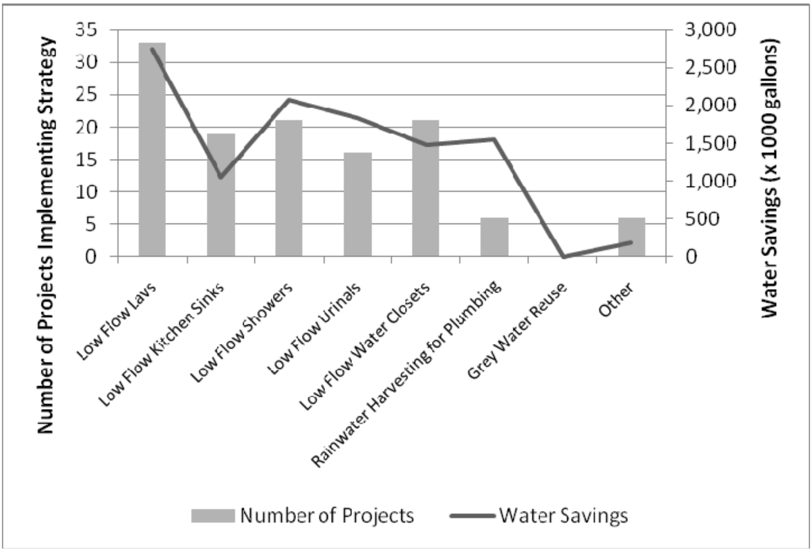

Figure 4: Key strategies implemented and water savings for City of Seattle LEED buildings 2003-2009.

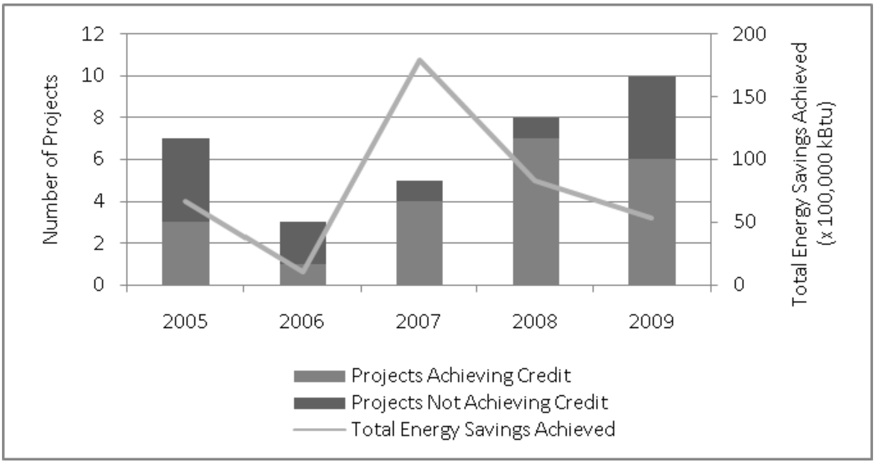

Figure 5: Energy savings over time for City of Seattle LEED-NC and CS buildings 2005-2009.

energy savings per project fluctuates and does not seem strongly correlated with the number of projects achieving the credit. However, in 2007, one Seattle LEED building demonstrated considerably high energy savings than the other projects. Such outliers can potentially obscure data trends. Omitting this project reveals a closer relationship between energy savings and the total number of projects, as seen in Figure 6.

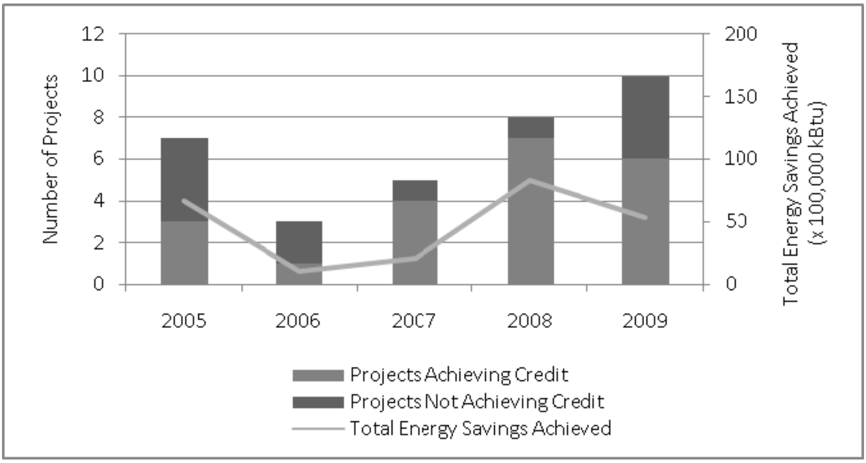

Figure 6: Energy savings over time for City of Seattle LEED-NC and CS buildings 2005-2009 with outlier 2007 project removed.

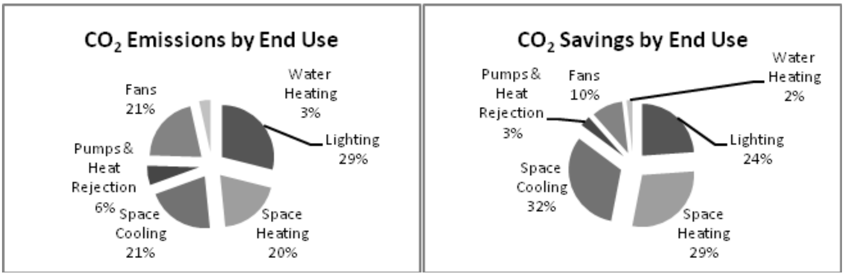

Figure 7: CO_2 profile for City of Seattle LEED buildings 2003-2009.

3.2.2 Carbon reporting

Estimates on carbon emissions are derived directly from the LEED projections of energy use, as LEED does not currently require documentation of carbon emissions reduction. Using conversion factors provided by the City of Seattle, a profile on carbon emissions and savings from LEED buildings is developed. This information can validate progress against the City's carbon reduction goals.

Figure 7 shows pie charts of CO_2 emissions by end use compared to CO_2 savings by end use. Most areas with large contributions to emissions, such as lighting, heating, and cooling, also have comparable or higher savings percentages. However, this trend is not followed for fans that make up 21% of CO_2 emissions yet only contribute to 10% of the CO_2 savings by end use.

3.2.3 Renewable energy

LEED also awards points to projects that install renewable energy systems that offset a percentage of the overall energy use, such as solar panels or wind turbines. This is a credit with very low achievement; within the cohort of City of

Seattle LEED Portfolio analyzed, only 12.5% of projects installed a renewable system that provided a minimum of 2.5% of the total building energy use.

3.3 Materials

There are several credits in all rating systems associated with materials, and two of these credits were tracked in detail for this study.

3.3.1 Construction waste management

The City of Seattle has set ambitious goals to increase the degree of recycling and waste reduction from construction-related activities. All buildings, regardless of whether they are pursuing LEED certification, contribute to meeting the City's Zero Waste Strategy, which has a 70% of total construction waste recycling target by 2025. According to the City's Department of Planning and Development, because there are so few landfills with free capacity, roughly 80% of City waste is exported.

The City's ambitious goals are reflected in construction waste diversion from LEED projects. In the complete City of Seattle LEED Portfolio, 96% of projects diverted a minimum of 50% of construction waste from landfills.

Figure 8 shows a bar chart with the total bar height equaling annual percentage of construction waste diverted from LEED-NC and CS projects. The chart shows a consistent diversion level above 70%. The bar is subdivided to show what percentage (by weight) of construction waste was recycled through commingling, as source-separated concrete, or is another material recycled by source separation. The reduction in the waste diverted by commingling appears to be decreasing with time.

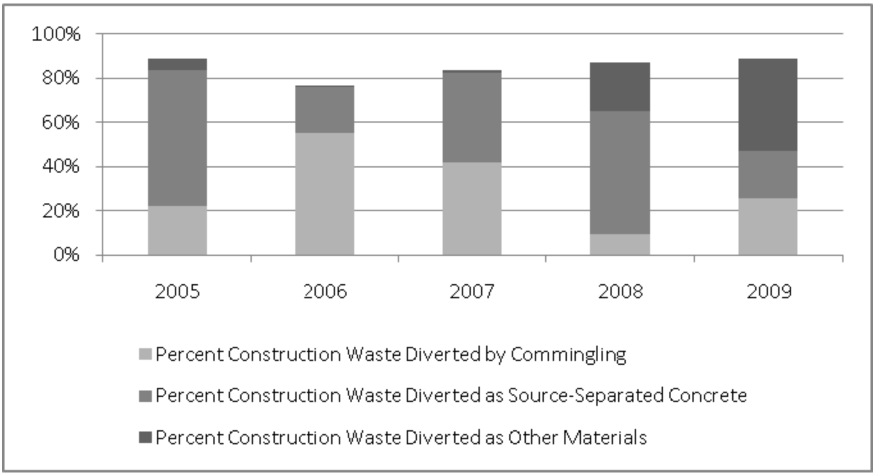

Figure 8: Construction waste diversion profile for City of Seattle LEED-NC and CS buildings 2005-2009.

3.3.2 Materials with recycled content

Using materials with recycled content helps to minimize impacts resulting from extraction and processing of virgin materials. To evaluate the LEED project impact on recycled product purchasing, the tool tracks the value of recycled materials incorporated into projects. The analysis indicates that the complete City of Seattle LEED Portfolio used materials with a recycled content value totaling over $39 million dollars.

4 Conclusion

Although LEED documentation is originally generated to demonstrate compliance with sustainable building design objectives for individual project ratings, in aggregate the data reported in the documentation represents a gold mine of information that can be mined to extract trends in implemented measures and predicted and actual savings. The rigorous, standardized calculation methods and documentation requirements of the LEED system ensure that savings calculations and reporting protocols are consistent across all rated buildings. Further, the evolution of LEED to an online documentation process allows this data to be made accessible for research purposes.

Building owners and design/construction teams across the United States and throughout the world are choosing LEED as a method to validate their green building successes. Whether the decision to pursue LEED is mandated or voluntary, a growing number of projects, project teams will document the projected building performance based on design decisions and will provide actual data on construction waste and construction materials. This information is available now in a growing database of thousands of buildings. Aggregating and analyzing these individual LEED applications can reveal green building performance trends for different cohorts of buildings and provide information about the market penetration of specific green building strategies and their associated savings.

Comparisons between different cohorts can provide information about how these trends vary across geographical locations, building types, year of construction, and even building owner. The possibilities and applications are vast. Tapping into this available information is an important first step to understanding the potential buildings have to reduce environmental impacts on our planet.

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Section 6
Resources and rehabilitation

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An emergy evaluation of a medieval water management system: the case of the underground "*Bottini*" in Siena (Italy)

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Abstract

In the middle ages, Siena had a high population density and had to face the problem of water supply within the city walls for housing, crafts, industrial activities and fire risks. With this aim, a series of underground drifts, namely "*Bottini*", was built at the beginning of the 13th century and achieved a total length of 25 km in the 14th century. *Bottini* have been capturing rain water and conducting it from the countryside to the fountains in the city centre for centuries. Brick pavements and other structures, such as brick vaults (where necessary), guaranteed water clearness and allowed a special team of workers, "*bottinieri*", to move throughout the tunnels for management and maintenance. *Bottini* still bring 9.5 l/s of clear water. Currently water is only used to fill the fountains and is then wasted. Based on statistics on water use, we argued that the activity of maintaining *Bottini* is not only a good practice for the conservation of a precious cultural heritage, but could also be potentially an opportunity for improving urban ecology. In this paper, we propose to investigate the environmental impact of water use comparing *Bottini* with a contemporary water management system. In particular, an "emergy evaluation" was developed for providing information about the sustainability of water use, both nowadays and in the past. Preliminary results showed that *Bottini* have a much lower environmental impact and can be potentially reused by withdrawing water and using it for some activities – such as irrigation of gardens and playgrounds, street washing and sanitary use – within the historical centre of Siena.
Keywords: cultural heritage, energy systems diagrams, water management.

1 Introduction

The city of Siena was built upon three hills (about 350 m sea-level) and was an extremely dynamic centre during the middle ages, in particular, in the 13th and early 14th centuries [1]. In 1328, the population achieved around 80,000 people [2], and Siena prospered with an economy mostly based on agriculture, services, such as banking and lodging, and industrial activities, mainly textiles, butchers, wool and leather [3]. The high population density and the emergence of new activities within the city walls caused an increasing demand of water for housing and industrial uses. An innovative water management system was thus built in order to bring water from the external countryside into the city and supply all the districts of the medieval city (1226-1460 a.C.) [2]. The geological composition under the surface of Siena, basically made of various layers of sedimentary materials (from fine sandstone to clay), allowed one to build an efficient underground aqueduct, namely the "*Bottino*" (due to the brick vaults built in some sections of the excavated tunnels) [4]. Made of a network of underground drifts with an average slope of 1-2%, it achieved a total length of about 25 km in the late 14th century [2]. *Bottini* (plural of *Bottino*) have been capturing rain water, filtered through the ground, for centuries and conducting it to the fountains, namely "*fonti*" (plural of *fonte*), in the city centre. Fountains in Siena were built to be highly accessible and efficient, 24h/day, held in check by guardians and well managed and cleaned [2]. The main fountains had three collection pools, located at different levels: a) the highest, which received the water directly from the *Bottino*, used for drinking and cooking; b) the medium used by animals; c) the lowest used for washing clothes. Finally, the overflow was often used for crafts or industrial activities. The average section of the *Bottino* has a height of 1.8 m and a width of 0.8 m In the *Bottino*, brick pavements (with a sort of gutter, namely *gorello*, made of bricks and clay) and other structures, such as brick vaults (built where necessary), guaranteed water clearness and allowed a special team of workers, "*bottinieri*", to move throughout the tunnels for management and maintenance. In the present time, *Bottini* still provide an average of 9.5 l/s of clear water to the fountains, although it is not drinkable [6]. The main problems to their efficiency are due, firstly, to the calcification of galleries and floors that obstruct water outflow and, secondly, to the construction of buildings in the northern periphery of Siena, out of the ancient walls, that caused in recent years a decrease of rain water inflow to the underground.

Since *Bottini* are an amazing evidence of an ingenious work of architecture and engineering in the past, they are nowadays considered as cultural heritage. Moreover, they are an efficient system that still provides water to fountains within the historical centre of Siena. Nevertheless, once conveyed in the fountains, water is not used and is wasted. Based on statistics on water use [7], we therefore argue that the activity of maintaining *Bottini* might be not only a good practice for their conservation, but could also be potentially an opportunity for promoting a reuse of water and improving urban ecology.

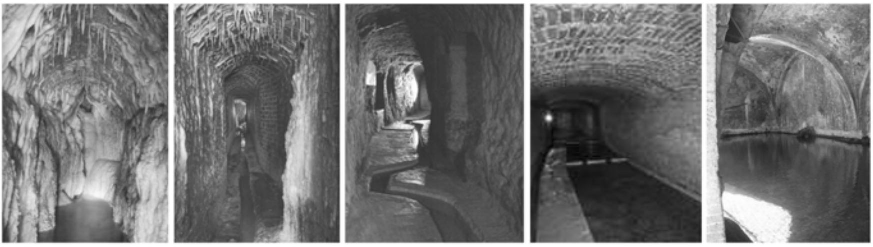

Figure 1: Images of the underground *Bottini* in Siena (Italy).

In this paper, we investigated the environmental efficiency of water use comparing the system of ancient *Bottini* with a contemporary water management system. In particular, an emergy evaluation (EE) (emergy spelled with an "m") was developed for providing information about sustainability of water use, both nowadays and in the past.

The following analysis focussed on the *Bottino* of *Fonte Branda* (built in 1195 a.C.), 6326 m, excavated at an average depth of 17.5 m. This brings to the fountain (*Fonte Branda*) an average quantity of water of 3.5 l/s [3].

2 Method

Emergy (spelled with an "m") is a measure of available energy that was used previously, directly and indirectly, to generate the inputs for an energy transformation [9]. Emergy means energy memory. The emergy evaluation uses the thermodynamic basis of all forms of energy and materials to convert them into equivalents of one form of energy, the solar energy [9]. Emergy is thus given in units of solar energy, namely solar emergy Joule or solar emjoule (seJ). In general emergy is a measure of natural resources that have been used throughout a sequence of processes towards a final product. Previously calculated coefficients (emergy per unit energy or mass) can be used to transform a specific product or service into emergy. These unit emergy values are used for multiplying mass quantities (kg) or energy quantities (joule) and accounting for their emergy content.

Emergy values per unit are usually given in literature and represent the environmental resource use per unit mass or energy in a given process, such as human work, or product, such as bricks or mortar. Values usually refer to current procedures and systems. Since these values should be coherent to a specific production process or a reference system, a special accounting was performed here. In particular, unit emergy values of human work and materials were accounted taking into account procedures and environmental resource use in the age of the Siena Republic (XII-XVI century).

In the first case we inventoried the main inputs to the regional system including renewable resources, such as solar irradiation, rain, geothermal heat and soil erosion (the latter being renewable considering sustainable eco-agricultural systems), local non renewables (extracted materials) in a area of 8325 km^2 with an average population of 70000 people. We obtained an emergy per person equal to 1.46×10^{16} seJ/yr and thus a unit emergy value of 3.18×10^{6} sej/J with a portion of renewability almost equal to 100%. In the present year, the emergy per person was estimated at 1.24×10^{7} sej/J (5% rate of renewability) [9].

In the second case, considering the production process of bricks, inputs inventoried were: materials (clay and sand), energy (fired wood) and human work. The specific emergy of brick in the XII-XIV centuries was thus 2.39×10^{9} sej/g, with a portion of renewables of 14%. In the present time, specific emergy of bricks is 3.68×10^{9} sej/g, 100% non renewable [9].

3 Results and discussion

The emergy analysis was performed considering the main energy and material inflows to the system *Bottino Fonte Branda*. This included:
1) the main renewable inflow that corresponds to an amount of rain water that falls within a hypothetical region along the course of the underground *Bottino*;
2) inputs to the construction process for building the *Bottino* performed 720 years ago. This includes materials such as brick and mortar for the floor and the vaults, and human work (estimated 2152 working hours/yr × 8 workers × 5 years);
3) inputs to the construction process for building *la fonte*, namely *Fonte Branda*, 720 years ago. This also includes materials and human work (estimated 2152 working hours/yr × 12 workers × 1 year);
4) human work needed for the management and maintenance of the *Bottino* from its construction to the end of the historical Republic of Siena (maintenance: 2152 working hours/yr × 2 workers × 362 years; management: 2152 working hours/yr × 1 worker × 362 years); (note that human work for the management was not added);
5) human work (2152 working hours/yr × 2 workers in the last 10 years) and energy (electricity use for lighting and machines) needed for the maintenance of the *Bottino* in the last 10 years until now.

The analysis is shown in table 1. Columns in the table report the estimated quantity and units of inputs, operational time values (i.e. the amount of working hours in a give process), specific emergy values (transformation coefficients), total emergy (the correspondent emergy quantity of each input given in seJ), lifetime values (lifetime of a given structure), emergy per year values (estimated emergy flow, given in sej/yr, up to the present state).

About lifetime of structures such as pavements or vaults, this corresponds to a maximum of 720 years if a structure has persisted since its construction, or to a lower value if parts were progressively degraded and substituted within an estimated time.

Results show that, considering the total emergy memorized in the *Bottino* as it is at its present state, the emergy flow, namely empower, is equal to 1.52×10^{18} seJ/yr. Almost 99% of this emergy flow comes from renewable inputs. The Environmental Loading Ratio, given by the ratio between non renewable resources (both local N and imported F) and renewable is 0.1, therefore extremely low.

Table 1: Emergy evaluation of the *Bottino Fonte Branda* in Siena. The emergy value per unit water is given in the last row.

Items	type of input	quantity	unit	operational time	specific emergy	total emergy	life time	emergy per year
				hours	sej/unit	sej	years	sej/yr
Local resources								
rain	R	9.83E+10	g/yr		1.45E+05			1.42E+16
Construction "bottino"								
brick (floar)	14%R - 86%N	3.04E+08	g/yr		2.39E+09	7.27E+17	100	7.27E+15
brick (structure)	14%R - 86%N	2.47E+09	g/yr		2.39E+09	5.91E+18	720	8.21E+15
mortar (20%brick)	14%R - 86%N	4.94E+08	g/yr		2.39E+09	1.18E+18	720	1.64E+15
human work	R	5.23E+05	J/h	86080	3.18E+06	1.43E+17		1.43E+17
Construction "fonte"								
brick (structure)	14%R - 86%N	5.00E+08	g/yr		2.39E+09	1.20E+18	720	1.66E+15
brick (floar)	14%R - 86%N	1.73E+07	g/yr		2.39E+09	4.14E+16	100	4.14E+14
mortar (20%brick)	14%R - 86%N	1.00E+08	g/yr		2.39E+09	2.39E+17	720	3.32E+14
gravel	N	8.00E+07	g/yr		2.39E+09	1.91E+17	720	2.66E+14
human work	R	5.23E+05	J/h	25824	3.18E+06	4.30E+16		4.30E+16
Past management and maintenance								
human work (management)	R	5.23E+05	J/h	1558048	3.18E+06	2.60E+18		2.60E+18
human work (maintenance)	R	5.23E+05	J/h	779024	3.18E+06	1.30E+18		1.30E+18
Maintenance								
human work (bottinieri)	5%R - 95%F	5.23E+05	J/h	43040	1.24E+07	2.79E+17		6.49E+12
electricity	F	2.93E+07	J/h	5061	2.07E+05	6.05E+12		2.07E+05
								1.52E+18
Physical data								
lenght of *bottino*		6326	m					
water		3.50	l/s					
annual water provided		1.10E+08	l/yr		**1.38E+10**	**sej/l or sej/kg**		
						EMERGY PER UNIT WATER		

Moreover, the emergy per unit water brought into F*onte Branda* by the *Bottino* is $1.38\text{x}10^{10}$ seJ/kg and corresponds to an amount of resources used almost totally renewable.

This value can be compared with the corresponding value obtained for a litre of water provided nowadays by the modern water management system [9]. This corresponds to $3\text{x}10^{9}$ seJ/kg with a renewable portion of 25%. The ELR was 3. The results clearly highlighted that the environmental impact of water in *Fonte Branda*, referring to the demand for environmental resources, is much lower than the impact of the modern system because completely renewable and sustainable.

4 Conclusion

Dealing with housing, in Italy about 1% of water use is for drinking and 16% is used in the kitchen, 39% is for bathroom and 20% for other sanitary uses, 12% is for laundry and 6% for car washing, 6% is for other uses. Based on statistical data we can argue that drinkable water is just a portion of around 20% of total water use. The ancient water management system in Siena, the underground *Bottini*, still provides an average of 9.5 l/s of non drinkable but clear water. This is currently used to fill the fountains and then wasted.

In the present time, the maintenance of the *Bottini* in Siena is due as a practice for managing cultural heritage but this could also improve urban ecology. Water from the *Bottini* could be easily used for street washing, gardening, playgrounds watering and other uses. Through an emergy evaluation we demonstrated that this is desirable because the environmental impact of water in the *Bottini* is much lower than the water provided by the modern management system. The emergy per unit water are $1.38x10^{10}$ seJ/kg and $3x10^{9}$ seJ/kg, respectively, but the emergy used in the ancient system, that is still efficient, is totally obtained by renewable inputs. Promoting a reuse of the ancient *Bottini* in Siena is probably a good opportunity not only for managing precious cultural heritage but also for improving urban ecology.

References

[1] Kucher M P. The Use of Water and its Regulation in Medieval Siena. *Journal of Urban History*, 31, 504-536, 2005.
[2] Bargagli Petrucci F. *Le fonti di Siena e i loro acquedotti. Note storiche dalle origini fino al MDLV*. Vol. I. Firenze, Olschki, 1905.
[3] Balestracci D, Vigni L & Costantini A. *La memoria dell'acqua. I Bottini di Siena*. Protagon editori. Siena, Italia, 2006.
[4] Barone L, Calzolari V, Costantini A, LA DIANA, Santini R, Serrino G, *Siena città dell'acqua - Bottini*. Progetto C.E. Raphael, Siena, Italia, 2000.
[5] Baldi A M. Gli antichi Bottini Senesi. *Tecnica di Idraulica Antica - Supplemento* 4, SIGEA, 2006.
[6] Becatti A, Ceccanti M, Vigni V. L'acqua dei Bottini: una risorsa da rivalutare. *ARPAT News*, 117, 2007.
[7] Amministrazione Provinciale di Siena. *Relazione sullo Stato dell'Ambiente della Provincia di Siena 2008*. MicroCosmos Onlus, Siena, 2009.
[8] Odum H T. *Systems ecology*. Wiley, New York, US, 1983.
[9] Odum H T. *Environmental accounting: Emergy and Environmental Decision Making*. Wiley & Sons, New York, USA, 1996.
[10] Pulselli R M, Pulselli F M, Rustici M. The emergy accounting of the Province of Siena: towards a thermodynamic geography for regional studies. *Journal of Environmental Management* 86 342-353 2008.
[11] Pulselli R M, Simoncini E, Pulselli F M, Bastianoni S. Emergy analysis of building manufacturing, maintenance and use: em-building indices to evaluate housing sustainability. *Energy and Buildings* 39(5) 620-628 2007.
[12] Pulselli F M, Pulselli R M, Patrizi N, Marchettini N. Emergy evaluation of water management in the Florence area. (Ed.) Brown M T, *Emergy Synthesis 5: Theory and Applications of the Emergy Methodology*. University of Florida. Gainesville, FL 355-366 2009.

Editing Eisenhower: rethinking the urban segments of the U.S. interstate highway system

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Abstract

Almost since the passage of the Federal-Aid Highway Act of 1956 (commonly known as the National Interstate and Defense Highways Act) the urban segments of the Eisenhower Interstate Highway System have been controversial. Flashpoints for protests and tools for radical reshaping of the urban fabric, over the last half century the urban sections of the system have had a profound social, environmental, and structural impact on numerous American cities.

Today the greening of the American city is a linchpin of a sustainable global future. As we look for ways to retrofit U.S. cities with green infrastructures, the elimination of urban interstate segments could create intriguing sites for these developments within the otherwise crowded and difficult urban landscape. *Editing Eisenhower* explores this possibility.

Through an analysis of urban interstate typologies, candidate cities are identified. One city is then investigated in detail with attention given to each of the various conditions of interstate/urban interface encountered along the spine of the right-of-way. For each condition, strategies are suggested for the placement and integration of new green infrastructure. Through a series of diagrammatic studies possibilities for reshaping each condition are presented. In this way, the urban segments of the Eisenhower System are seen as having played an unexpected role in the development of the American city – that of placeholder within the urban fabric for infrastructures unimaginable at the time of their construction.
Keywords: urban, infrastructure, highways, sustainability, retrofitting.

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1 Introduction

The Dwight D. Eisenhower National System of Interstate and Defense Highways, most often referred to simply as the Interstate Highway System, is the largest piece of infrastructure ever created. During a half century of existence it has done what infrastructure often does – underpinned a way of life so thoroughly that the very contours of society would be drastically altered were it removed. There is little doubt that the Interstate Highway System has been a significant benefit to the country in many ways, particularly with regard to the movement of goods and the sense of personal access to the vast continent that has, in many different guises, long been part of the American identity. Yet, these blessings have been accompanied by various curses: air and noise pollution; the environmental, fiscal, and social strains of suburban sprawl; and the destruction of vital urban neighborhoods to name a few.

Figure 1: President Eisenhower receives the report from the advisory committee on a National Highway Program.

This paper proposes an editing of the Eisenhower System; selectively removing portions of the network where it interacts with mid-sized American cities. This reconsideration of the system promises to change its very meaning and function and profoundly alter the relationship between the city and the countryside in America. Embedded in this proposal is the notion that in these cities the Interstate Highway System has been serving a purpose never imagined for it – acting as a placeholder within the urban fabric for a host of new infrastructures that will shape the 21st century as profoundly the interstate shaped the 20th.

2 The interstate and the mid-sized city

The loci of this project are the numerous places where the Interstate Highway System intersects mid sized American cities, which are here defined as cities

Figure 2: Relationship between U.S. mid sized cities and the Eisenhower system. Circled cities are examined in greater detail.

with populations between 100,000 and 300,000. Figure 2. This project focuses on mid sized cities for several reasons. In 2006 U.S. Census data classified 198 cities as mid sized. These cities contained a total population of 31.5 million citizens or about 11% of the total population of the country at the time. By way of comparison the 59 cities that were larger than 300,000 in 2006 contained 49.3 million people with half of those located in the ten largest cities in the country. [1]. Therefore, by using mid sized cities as the places where we edit the interstate system two goals are achieved that are vital for any infrastructure project that endeavors to be an environmental, cultural, and economic springboard for the 21st century. First, the benefits of the project must impact the lives of a large number of people. Second, the benefits of the project must be widely dispersed geographically. The mid sized city provides a mechanism through which both of these goals are automatically achieved.

The intersection of the Interstate Highway System and the mid sized city was chosen for important structural reasons as well. In many ways this project is about undoing the damage inflicted when a particular infrastructure, the interstate highway, collided with an incompatible construct, the city [2]. It is in mid sized cities that the wounds of this collision are most apparent – in many cases the healing scars have not yet formed despite the intervention of many decades of time. It is here also that the resulting difficulties can be identified and dealt with most easily. Often in larger cities, the interstate has been subsumed by the accretion of urban growth such that the surgery necessary to allow for the healthy functioning of each has become very difficult (though still necessary in the long run.) *Editing Eisenhower* then is concerned with a very specific set of infrastructural conditions - mid sized cities already having bypasses as part of the Eisenhower System – that provide for the efficient restructuring of the relationship between these two entities. Figure 3.

In these locations the work of the project is very straightforward, though profound. Long-distance traffic will use the bypass to move around the city. Within the bounds of the bypass the interstate right-of-way will be recaptured as

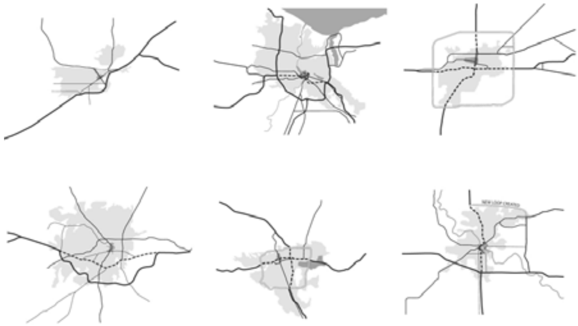

Figure 3: Interstate typologies – (clockwise from upper left) billings, MT; Rochester, NY; Amarillo, TX; Cedar Rapids, IA; Reno, NV; Greensboro, NC. Dashed lines are segments that could be removed without impacting connectivity.

an integral part of the city rather than as a portion of a sprawling continental infrastructure. This new found urban land will then be used to introduce infrastructures vital to the greening of the American city: the reconnection of historic street grids, efficient and diverse transit options, waterway and habitat protection zones, sustainable urban drainage systems, decentralized green power generation, a system of small schools, a network of public parks, urban agriculture, and significant opportunities for transit oriented infill development.

Editing Eisenhower then is an intervention that is simultaneously surgical and massive, focused and far reaching. It is, in a way, an audacious proposal, but no more audacious than the proposal for the Eisenhower System itself. That proposal has not only come to pass but has become so rooted in the fabric of our lives that taking the nearby on ramp and traveling across multiple states is so commonplace as to be completely unremarkable. It is the hope of this project that a sustainable lifestyle underpinned by the new infrastructures of *Editing Eisenhower* will one day be equally unremarkable for millions of Americans in mid sized cities across the country.

3 Selective case study – Knoxville, Tennessee

Looking at the mid sized city, Knoxville, Tennessee, as a more detailed example, the possibilities of the *Editing Eisenhower* project become clearer. The location of the bypass in relation to the urbanized area and central core creates a hierarchy of conditions with respect to the portions of the Eisenhower system that are to remain and those that are to be reclaimed. Primary among the goals of the proposal is the redirection of future development away from the suburban edge and toward the center city and reclaimed corridor. Figure 4. Specifically addressing each of the conditions along the corridor encourages this redirection.

Within the bypass one of the primary opportunities is the reconnecting of street grids. Figure 5. When the Eisenhower System was routed through urban

Figure 4: Knoxville, Tennessee – existing urbanized area, light gray with projected growth, dark gray (left) and refocused growth corridor (right).

Figure 5: I-40's impact on the urban core and neighborhoods.

areas it often plowed through residential areas, disrupting the continuity of these neighborhoods and placing on them significant noise and air pollution burdens [2]. Many of these inner ring urban neighborhoods are ideal for resettlement and redesign as contemporary green neighborhoods [3].

Urban neighborhoods represent a sizeable collection of cultural artifacts and their scale, proximity to the central core, and relationship to commercial districts and transit lines make them desirable assets for the city's future. The removal of the interstate in these areas will not only allow for the introduction of selective infill and amenities, but more simply and more importantly will provide for the reconnection of the street grid, which is the lifeblood of these neighborhoods.

Away from the urban center there are two other important conditions that need to be considered in each city where interstate editing takes place. The first of these occurs at the junction of the bypass freeway and the reclaimed right-of-way (Figure 6). These locations, previously spaghetti junctions, now become important nodes of arrival into the city. It is here that one changes speeds and perhaps modes of transport. The generous size of the right-of-way at these interchanges will allow for the construction of an intermodal transportation station that will allow travelers either to transfer from private vehicles or high speed rail to trams or busses, or if remaining in their vehicle at least change to the pace of the urban boulevard from that of the interstate.

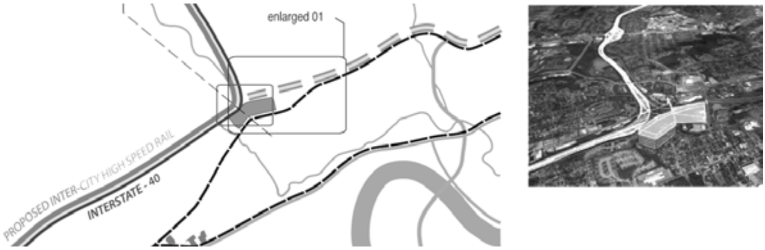

Figure 6: Junction of bypass freeway and reclaimed right-of-way.

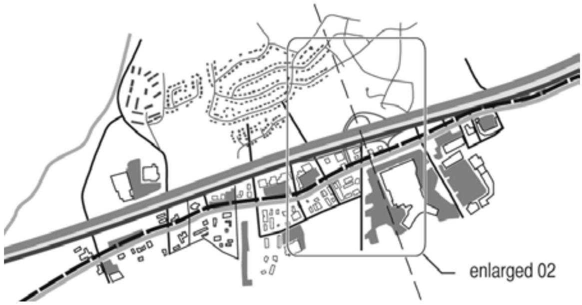

Figure 7: Interstate and suburban development.

The second condition occurs as one moves away from the bypass loop and into the city’s suburban development (Figure 7). Here we typically find development patterns that are antithetical to the goals of *Editing Eisenhower*, which seeks to promote more compact, urban, energy efficient lifestyles. However, by extending some of the principles and technologies of the project to these areas some of their benefits can be realized even here and the fundamental relationship between the suburbs and the center city might be changed from one of sprawl to a network of related nodes.

3.1 Reclaimed land

One of the greatest benefits arising from *Editing Eisenhower* is the liberation of a great deal of valuable urban land. Because this land is already aligned along important corridors within the city, it is ideal for the introduction of new transit intensive avenues that provide for pedestrians, trams, and dedicated bicycle lanes in addition to automobiles (Figure 8).

Yet, this new infrastructure, along with generous planting strips only accounts for a small portion of the previous interstate right-of-way leaving a significant area available for the other new infrastructures proposed by *Editing Eisenhower* as well as enough infill properties to absorb the city’s projected growth for many years if developed to ideal transit-oriented densities. This allows the city to greatly increase its tax base while minimizing costs associated with expanding services to the periphery.

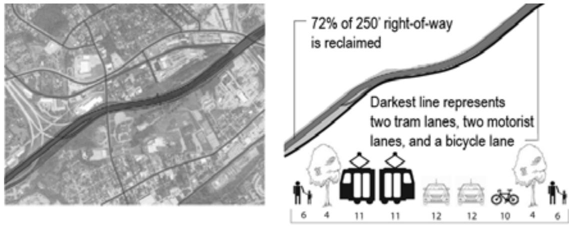

Figure 8: The I-40 right-of-way ranges from 250’- 450’. After generous space space for transit options, 72% can be converted to taxable land.

Figure 9: Public land and large scale uses adjacent to I-40 corridor.

Interstates tend to attract large scale industrial and public uses and encourage the nearby development of large parking lots (Figure 9). When these adjacent properties are taken into account, the potential impact of *Editing Eisenhower* is tremendous in terms of reshaping the urban landscape. Changing the nature of the relationship between the interstate and the city can serve as a catalyst for change even in suburban areas. By strategically locating stations for new intracity transit adjacent to existing interstate exits, new intermodal links are created. Encouraging cross sectional density in these areas strengthens communities and has many positive environmental effects.

3.2 Distributed power generation

The immense amount of contiguous land that can be freed up by *Editing Eisenhower* allows for the possibility of thinking in new ways about the provision of municipal utilities. Centralized utility infrastructures that exist in much of the United States, such as those for waste water treatment and power generation, will likely begin to give way to local, decentralized systems that can produce the same results through much less resource intensive means. For example, remote generation of electricity (largely used for domestic consumption) is highly inefficient with significant energy loses related to

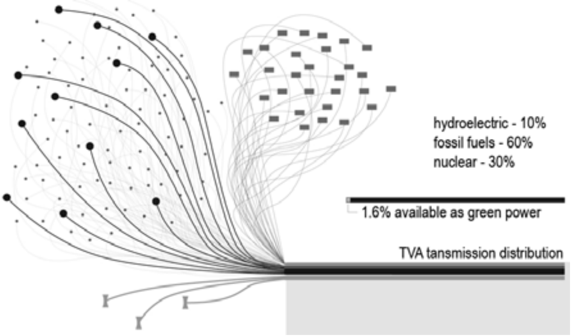

Figure 10: TVA power generation: hydroelectric 10%, fossil fuels 60%, nuclear 30%.

generation and distribution of power. In addition, the required scale of centralized generation plants discourages the use of renewable sources of energy for electric power production. Most today rely on fossil fuels, predominantly coal [4] (Figure 10).

Whereas, small neighborhood scaled solar and wind arrays might be placed at advantageous locations along backbone of the reclaimed urban corridor to serve the adjacent neighborhoods. The large parking lots adjacent to the existing interstate are superb candidates for both wind and solar generation as they inherently have very little obstruction. *Editing Eisenhower* might also provide the locations for neighborhood combined heat and power (CHP) stations that, while probably running on natural gas, are extremely efficient when compared with central generation. This improved efficiency arises from a much more effective distribution tree and the capturing of “waste” heat for use in meeting local space heating needs during the winter.

3.3 Small schools

Public schools are considered a vital infrastructure within the *Editing Eisenhower* project. Not only are they an essential part of the American social contract, but access to quality schools remains a prime motivator in choice of home location. Thus, schools can be a very powerful tool in directing urban growth toward desired locations (Figure 11).

The school infrastructure proposed by the *Editing Eisenhower* project leans heavily on proposals made by the small schools movement. The fundamental concept of these schools is that children learn more effectively in a small environment where they know everyone and everyone else knows them. Such settings are better for discipline and are much more conducive to the faculty’s ability to track children through the curriculum, addressing problems and building on strengths. In this proposal, schools districts within the interstate bypass would be broken down into smaller districts and linked with public transit, which would be free for public school children. For instance in the case

Figure 11: Small school strategy capitalizing on existing park facilities and proposed public transit.

of Knoxville, Fulton High School, which currently has about 1,000 students would initially be broken into five 200-student academies each with a distinct specialty such performing arts or international studies. The academies would be linked for the purpose of after school programs such as clubs, band, and athletics and students would travel to these activities on free public transit.

3.4 Sustainable urban drainage, parks, and urban agriculture

Editing Eisenhower is an urban greening project. A key component of this is a literal greening. This project proposes to strategically intensify plant life within the urbanized area in a variety of ways. Wetlands and streams within the reclaimed district will be protected with buffers that prohibit development, allowing these fragile ecosystems the space necessary to function properly. An expansion of the city's park system will be coordinated to coincide with these protected areas wherever possible, creating larger contiguous areas for habitat and recreation. The park network is a tiered system ranging from small pocket

Figure 12: Proposed park and water retention in reclaimed right-of-way.

parks occurring frequently to large athletic fields or hiking areas being rather infrequent and serving the largest populations. Where possible, these largest types will supplement the facilities at the new public schools. Using the proposed bike lanes and land within or adjacent to the reclaimed right-of-way, all new parks will be linked by a pedestrian/bicycle greenway

Like distributed power generation systems, sustainable urban drainage systems (SUDS) are another type of distributed low-resource infrastructure. These systems, which use natural or modified topography and water tolerant plantings to impound urban runoff and allow it to seep into the ground at a more natural rate, recharging the local aquifer rather than being conveyed to a central wastewater plant and unnecessarily treated along with black water. In urban conditions these systems take a variety of forms and sizes, from sidewalk planting strips to rain gardens the size of city blocks. *Editing Eisenhower* proposes to begin by analyzing the floodplain for advantageous locations for large scale SUDS that will then be supplemented by a network of smaller iterations reaching out to cover the entire reclaimed site.

While it would be unrealistic to feed an entire city on the land that will be reclaimed by *Editing Eisenhower*, urban agriculture, both growing and composting, within the newly developed area offers a significant opportunity to close nutrient loops within the city, drastically reduce transportation energy connected with the city’s food supply, and provide a source of fresh organic produce for citizens. Areas within the reclaimed area will be evaluated for solar access and adjacency to SUDS systems that might offer supplementary irrigation. The enhanced transit system will allow for these distributed growing locations to connect to a series of fresh produce markets serving neighborhoods along the corridor.

4 Conclusion

Viewing history from the vantage point of the present, it is tempting to think that the narratives were preordained – that the outcomes borne of actions taken long ago were as clear to some visionary planners as they are to us today. It is comforting to think that Roosevelt and his advisors were confident that the infrastructure projects of the New Deal would begin to stabilize the economy, set the stage for the defeat of fascism, and be useful long into the future. We want to believe that when Eisenhower gazed at a map of the proposed interstate highway system that he unquestioningly saw the expansion of American commerce and steady growth of the middle class for decades to come that would eventually win the cold war that was just beginning. We want to imbue historic men and women with the gift of foresight; with a confidence that their actions would bring about the results they desired, or at least results that would be widely positive. The story just reads better that way.

Doing so isn't fair to them or to us. It minimizes the real gravity of such decisions; makes light of the guts it takes to stand by one's vision when the stakes are so incredibly high. This tendency for writing retroactive manifestos also makes the visions themselves seem more powerful than they actually are by coating them in a patina of inevitability. Viewing history in this way underplays the validity of and sometimes completely obscures the opposing views of the day. Fortunately the struggle over the place of the interstate highway in the American city gained a vociferous and vocal advocate in the person of Jane Jacobs. She insisted that the other side of the story be heard and in doing so scored the first significant victory in a conflict that rumbles on today on battlegrounds like Seattle's Alaskan Way Viaduct, Boston's Big Dig, and Octavia Street in San Francisco.

We must remember then that the results of our actions are not foregone conclusions. We know only this. Americans are the world's great consumers, accounting for about 2/3 of worldwide resource use. 80% of us live in urban areas. If we are to live up to even the most minimal of our global responsibilities in the next century we must learn to live effective, happy, low-energy, resource smart lives in cities. If we are to lead in the world during the coming century, we must do so boldly and quickly. As it is comforting for us to assign prescience to leaders of the past, it would likewise be comforting to possess it ourselves; to confidently sketch out the answer on the back of an envelope and be assured of its effectiveness. Alas, as always, such problems require of us a vision and an iron stomach. *Editing Eisenhower* proposes to suggest some small part of a vision by removing from cities an anti-urban infrastructure and inserting a host of urban infrastructures in its place. The hope, of course, is that infrastructure will, as mentioned in the introduction, underpin a way of life so solidly that it becomes inevitable.

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References

[1] U.S. Census Bureau at http://factfinder.census.gov
[2] See for example: Fullilove, M., *Root Shock: How Tearing Up City Neighborhoods Hurts America*, Random House, New York, 2004.

[3] Shelton, T., “Visualizing Sustainability in Urban Conditions” in *Eco Architecture II: Harmonisation between Architecture and Nature*, ed. G. Broadbent and C.A. Brebbia, Southampton: WIT Press, 2008.
[4] http://www.tva.gov/power/

Global benchmarking? Taking a critical look at eco-architectures resource usage

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Abstract

"Eco-architecture, eco-society…this is the gentle hell of the Roman Empire in its decline" Jean Baudrillard, America, Verso, 1988. Human life has always depended on variables such as population, resources, and environment. Today, however, we are perhaps the first generation to face the simultaneous worldwide impact of expanding populations, depletion of resources, massive military built-ups for resource wars and homeland security, environmental degradation, and climate change. The causes and consequences are global and collective action is critical in driving an effective and equitable response on the scale required. All of this is common knowledge, endlessly discussed, widely published, and yet industrial and urban expansion carries on regardless. Eco-Architecture in its infrastructural context of a city's resource use only survives because of human, material, and communication networks with their hinterlands or bioregions, by placing them into a broader geographic context. The author examines how Eco-Architecture should be measured with resource foot printing on a common metric scale, which can only be realistically applied and globally benchmarked when interrelated life cycles of systems (GEMIS, Life-Cycle-Software: Global Emission Model for Integrated Systems Version 4.5, Oeko Institute Freiburg, Germany, http://www.oeko.de/service/gemis/en/), materials, and land-use planning in this wider geophysical perspective are considered. The author investigates the differences in measuring and certifying Sustainable Architecture (or Eco-Architecture) between the U.S. and Europe against international benchmarking.
Keywords: eco-architecture, sustainability, eco-systems, life-cycle-systems, benchmarking, energy performance measuring, climate change.

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1 Global resource use and eco-architecture benchmarking

Urban planners, architects, and engineers contribute through their designs, planning, and realizations approximately 50% of all man-made greenhouse gases. The long term solution for this environmental felony lies in the way our planned eco-architectures and cities actually measure, perform, consume resources, and generate pollution on a global scale. For decades, resource assessments for international performative benchmarking of countries, cities, and buildings have been monitored under the umbrella of the United Nations Framework Convention on Climate Change (UNFCCC). The UN Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to scientifically assess socio-economic information concerning climate change, its potential effects, options for adaptation, mitigation, and the development of public policies. UNEP facilitates the transition to low-carbon societies, biodiversity protection, and climate-proofing efforts. It improves understanding of climate change science, raises public awareness about this global challenge, and develops guidelines for calculating GHG Emissions for benchmarking countries, cities, businesses, and non-commercial institutions [2]. These organizations are also international clearing houses for data collaboration and coordinators for international building energy efficiency, carbon metric measuring, and resource use indicators, including sustainability rating systems such as The International Standards Organization (ISO 15392:2008), The Sustainability in Building Construction and General Principles of ISO (14040/44:2006) on Life Cycle Assessment, UK BREEAM, DNGB in Germany, CSTB in France, CASBEE in Japan, Green Star in Australia, Green Building Council South Africa, EEWH in Taiwan, UEA in Dubai, and Energy Star or LEED in the US, some of which are also united under the umbrella of the World-GBC [3].

The common metrics are usually the Energy Intensity = kWh/m2/year (kilo Watt hours per square meter per year), or Carbon Intensity = kgCO2e/m2/year or kgCO2e/o/year (kilograms of carbon dioxide equivalent per square meter or per occupant per year). In several countries, such as Germany and Switzerland, the metric is even more detailed in primary, secondary, and tertiary Energy Intensity. In general, the Energy Performance and Carbon Metric tools are applied to the specific inventory of the buildings under post-occupancy study. Such an inventory can be developed from a top-down or bottom-up approach, depending on the scope and goal of the investigation. Monitoring carbon mitigation measures on a regional or national scale would require a top-down approach, while assessing individual building projects would require a bottom-up approach.

1.1 Bottom-up approach

Each country obtains MRV data on GHG emissions for statistically representative samples of building types. These data may be readily accessible through utility and/or fuel providers. A building inventory requires that buildings be cataloged by location (country, region, and municipality) and identified by street address. The inventory can be correlated with a climate region by the number of heating and cooling degree days of its location. Building stock is to be quantified by type: 1) Residential (a) single-family and (b) multi-family dwellings, and 2) non-residential which includes mixed use and excludes industrial buildings. The stock shall additionally be characterized by age (year built), gross floor area, and occupancy (if available). Average or generic data can be used if it is representative of the subject building type, technologies, and construction techniques and of systems common to the reporting region. The latter is recommended only when measurable statistical sampling is not possible or feasible. Representative sample data can be scaled up or aggregated to the portfolio at the local, regional, or even national level using relevant statistics of the building stock to verify accuracy of the top-down approach.

1.2 Top-down approach

Where GHG emissions reports are required at a regional or national level, estimated performance data for subsets or total building stock should be used and coupled with estimates of building stock characterized by age, building type, gross floor area, and occupancy. Where relevant, such aggregated performance data shall be compared with a statistically representative sample set of building performance data (bottom-up) from the same area to verify the accuracy of both data sets. Green Building Councils have an important role in adopting the metrics and offering 3rd party verification of the top-down approach. It is also critical that other established or newly forming national and international data collection efforts adopt the metrics so that data can be compared easily across the world." [4].

2 The building industry has the greatest potential for delivering Greenhouse Gas (GHG) emission cuts

According to UNEP-SBCI (United Nations Environment Programme, and Sustainable Building and Climate Initiative), buildings are responsible for approximately 40% of global energy use and up to 30% of global GHG emission. UNEP-SBCI pledges that countries must support the building industry to meet their existing commitments to Kyoto Protocol from 1997 and to the Bali Roadmap in 2009. The building industry has the greatest potential for delivering greenhouse gas (GHG) emissions cuts using available and mature technologies. This enables market based measures that can support investments in building projects that are energy efficient at a low cost and that reduces GHG emissions, while encouraging governments to conduct inventory and set performance goals for GHG emissions from national building stocks. By 2020, UNEP-SBCI states that measuring baseline GHG emissions to develop and enforce meaningful energy & sustainability codes and standards can achieve 40% improvement in energy efficiency for existing buildings and 40% reduction in GHG emissions for new buildings and the necessary skills and performance standards for those skills. It is required to support the development of GHG emission standards for building types, location and use, and to renovate buildings we occupy so as to reduce direct and indirect GHG emissions. We can then improve climate adaptability, and dedicate research and development to climate neutral, net-zero-fossil-energy buildings, continue to work with governments on policy development and educate our supply chain [5].

The Fourth Climate Change 2007 Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) was part of a series of reports intended to assess scientific, technical, and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation. The report is the largest and most detailed summary of the climate change situation ever undertaken, involving thousands of authors from dozens of countries [6]. The main findings urge country leaders, stakeholders, the building industries and others to move from "climate change is real" to "here is the information you need to make good decisions for your stakeholders." This urgency includes risk management framing, multiple stress framing, and full immediate partnership for adaptation of all the necessary steps to assess and improve the building industry. The IEA (International Energy Agency) in its World Energy Outlook of 2009 estimates that energy efficiency will account for more than 60% of global CO2 emissions reductions to 2030. A significant part of this will need to come from existing and new buildings. [7]

2.1 How will this knowledge be transferred into practice and governance?

Eco-Architecture or Sustainable building means to build intelligently. The focus is on a comprehensive quality concept that serves the building and real estate sectors as well as society and culture in general. Sustainable properties are beneficial to the environment because they conserve resources, and make living more comfortable and healthy for their users while fitting optimally into their socio-cultural surroundings. In the same way, they stand for economic efficiency and long term value retention. Sustainable properties are cost effective due to their lower operation and maintenance costs. The manageable additional planning, commissioning, and construction costs will usually amortize in a few years [8], depending on the political-economic context of the location, size, and scale of the property.

Sustainable building design practice and marketing in the US has changed dramatically in recent years. What started out as a charismatic environmental crusade has matured into an established sector of the US architectural and construction industry. The passion has not diminished, instead it has become more firmly grounded in the realities of the marketplace, and more incentives are given by the new White House Agenda on Energy and the Environment [9]. However, when it comes to the benchmarking of buildings and cities of one of the biggest resource consumers in the world, energy data collection in the US is very parochial. It is hard to get comparable global benchmarks for US cities and buildings. Too often, they are based on theoretical models and not on actual city and building energy performance auditing. According to the U.S. Energy Department, only about 1% of all US buildings have been commissioned to date.

US legislative efforts must be based on actual, yearly, measured building energy performance rather than on modeled assumptions or samples from somewhat exceptional national "demo" buildings. If this approach were to be used, it should be compared against systematic global best practices, rather than only US peer groups of buildings. Doing so would allow pressing questions to emerge about why buildings in Germany or Switzerland use 50 to 70% less energy in similar climate zones than the average US equivalent. There is an urgent need in the US for new, globally comparable, benchmarked building energy performance policies and indicators based on comparable life cycle costs. Disclosure laws for improved energy performance for new and existing buildings to meet short, medium, and long term goals of the 2030 carbon neutral challenge of the AIA are also warranted. These targets may be accomplished by implementing innovative sustainable design strategies, generating on-site renewable power, purchasing renewable energy and/or certified renewable energy credits [10].

2.2 The U.S. Green Building Council (USGBC) actual building energy use measuring in relation to modeling

In March 2008, a report by Cathy Turner and Mark Frankel of the U.S. based New Buildings Institute (NBI) analyzed measured energy performance compared to initial design and baseline modeling for the voluntary LEED (Leadership in Energy and Environmental Design) New Construction (NC) certified buildings (11). Of 552 LEED-NC version 2 buildings certified through 2006, only 22% or 121 buildings were able to provide the requested information. Measured energy savings for these buildings averaged 28% compared to code baselines, close to the average 25% savings predicted by energy modeling in the LEED submittals. Some buildings performed much better, but as the report notes, "There is wide scatter among the individual results that make up the average savings, and nearly an equal number are doing worse—sometimes much worse." Indeed, roughly a dozen of the LEED-NC certified buildings used more energy than predicted by code baseline modeling. The variability between predicted and measured performance has significant problems for the accuracy of prospective life-cycle cost evaluations for any given building. Much more feedback from actual building performance results is needed.

Nevertheless, a good start in the right direction is ASHRAE's recent release of a new Building Energy Quotient labeling program as a pilot phase at the end of 2009, similar to what was launched in the European Union in 2002. [12]

According to the Institute for Market Transformation (IMT), more good news for the US Green Building Industry is that Building owners in Washington, D.C., will start measuring the energy use of commercial properties on January 1, 2010. This new law aims at reducing energy use and costs for building owners and tenants [13]. Under this new law, the Clean and Affordable Energy Act, passed in 2008, will prompt building owners to publicly disclose energy ratings starting in 2012, which will give prospective tenants and buyers an easy-to-understand way to compare the energy consumption and operating costs of buildings. The benchmarking will be done through a U.S. EPA online tool called the Portfolio Manager. It asks for information about the building and its energy use, rolling them into a rating on a 100-point scale. A building performing better than 60% of the stock would receive a 60. It remains unclear if the metrics can be further compared on a global level or if they only relate to the US EPA's peer buildings rating.

2.3 Energy performance of buildings directive (EPBD)

One of the key driving forces of European energy-efficient design is the European Union's 2002 Energy Performance of Buildings Directive (EPBD), inspired by the Kyoto Protocol of 1997, which commits the EU to reduce CO2 by 8% in 2010. This means a reduction of 5.2% below 1990 levels, using radical energy reduction, resource conservation strategies, and renewable resources wherever possible. Each of the twenty-seven member states of the European Union is responsible for individual implementation of the EPBD through national laws. The focus of European sustainable building design at this time is on reducing energy use directly and carbon emissions indirectly. The yearly certification inspections are publicly displayed when buildings are constructed, sold, or rented out, and the actual energy use certificate must be made available to the prospective buyer or tenant. The display certificate is valid for only one year, which means that the continuing title of sustainable building (or Eco-Architecture) has to be earned, based on city or district wide performance standards and ordinances such as Low-Energy (30-60 kWh/m2), Passive Energy (15-20 kWh/m2), Zero-Net-Fossil or Plus-Energy-Buildings (which can produce more renewable energy than they need, and sell the surplus to the public grid). The display must include the rating from a prior three-year period so that building occupants can see whether resource-saving improvements have been made or not. In summary, the European approach substitutes information for regulation.

2.4 Globally benchmarked, nationwide building energy use and GHG displays for the United States

Actual building energy use and GHG rating displays should be emulated in the United States. Without clear standards for new buildings and major upgrade requirements for existing buildings, the US will never be able to reduce the carbon emissions from residential and commercial buildings. All those procedures required to assess and rate the building's energy use should be nationwide. GHGs emissions and progress against resource and GHGs reduction targets annually on an objective global benchmarking scale should be tied to energy use of the UNFCCC carbon emissions counting and ranking. This is already partly practice in the United States with the Energy Star Portfolio program [14], but it is only a relative national ranking (the top 25%), as opposed to an absolute global benchmarking scale. If the US wants to get serious about reducing energy use in buildings and inducing energy-saving remodels, refurbishments, and renovations, it has to start comparing energy use per unit area per year by reliably linking local practice to global UNFCCC aims.

3 New studies on efficiency in buildings with global benchmarking

A new study on energy efficiency in buildings indicates that the global building sector needs to cut energy consumption in buildings up to 60% by 2050 to help meet global climate change targets. The World Business Council for Sustainable Development (WBCSD) recommends that worldwide governments, businesses, and individuals must start to aggressively reduce energy use in new and existing buildings in order to reduce the planet's energy-related carbon footprint by 77% or 48 Gigatons (against the 2050 baseline) to stabilize CO2 levels to reach the level called for by the UN Intergovernmental Panel on Climate Change [15]. Much further urgent work is needed to develop a 'common carbon metric' with an integrated resource master plan and diversified renewable energy portfolio for the measurement of the carbon footprint of buildings and cities. This would help to make smart infrastructure and new building choices, and ensure an economically, environmentally self-sufficient fossil-free infrastructure by 2050.

Global large-scale GHG benchmarking means that only systems directly applicable to reliably measure contributions to climate stability are valid. More specifically, these are approaches that embrace a 3.3 ton per annum per person of carbon dioxide by 2050 compared to 1990 levels. This globally benchmarked target is based on a fundamental equity calculation that on a per-capita basis, each person has only an annual 3.3 ton emissions allowance if oceans and forests are to be able to neutralize excessive carbon emissions. In contrast, Australia and the United States approach 20 tons per annum per person, while most developing countries, including India and China, will increase dramatically in the long run. European national governments have been far more willing to accept the conclusions of climate science than American governments and have been willing to develop practical public, socio-cultural, and economic policies for reversing the growth of carbon emissions. This includes subsidies, laws, and regulations to implement sustainability driven policies in order to significantly reduce GHGs as proposed by the UN Intergovernmental Panel on Climate Change (IPCC). To achieve this level of sustainability, it is necessary to develop a common language for carbon metric measuring.

In March 2009, the United Nations Environmental Programme and Sustainable Buildings and Climate Initiative (UNEP SBCI), and the World Green Building Alliance (World GBC), and members of the core groups (BRE Global/BREEAM, USGBC, CSTB, DGNB, FCAV, ITC, NIST, VTT) signed a memorandum of understanding to develop a common carbon metric, that is intended to accelerate the international adoption of Sustainable Building (SB) practices through the promotion of shared metrics of building performance assessment and rating [16].

3.1 Did the global climate summit in Copenhagen help to set a common language for final global benchmarking targets and guidelines?

The United Nations Climate Change Conference took place in Copenhagen, Denmark, between December 7 and 18, 2009. It included the 15th Conference of the Parties (COP 15) to the United Nations Framework Convention on Climate Change and the 5th meeting of the parties (COP/MOP 5) to the Kyoto Protocol.

In order for 9 billion people to live together on one planet in 2040, a circle of trust is required, one that rewards sustainability solutions and discourages the wrong economic activities of the past.

Recently, in Copenhagen an agreement on climate change was reached without any binding obligations. It is referred to as the Copenhagen Accord and aims towards an immediate action on climate change while guiding negotiations on long-term action. It also includes a political agreement to working towards curbing global temperature rise to below 2 degrees Celsius with efforts to reduce or limit emissions, and pledges to mobilize $100 billion a year for developing countries to combat climate change. U.N. Secretary General, Ban Ki-Moon stated, “The leaders were united in purpose, but they were not united in action,” to exhort world leaders to act in concert to ensure that a legally binding treaty is reached in the future. Nonetheless, he said that the talks “represent an essential beginning,” because without nations hammering out a deal in Copenhagen, the financial and technical support for poorer nations agreed upon would not take immediate effect [17].

The COP15 in Copenhagen was a critical and timely step that should have enabled the world to realize the unparalleled, cost-effective carbon mitigation potential of buildings, which account for around 40% of the world's energy use and 33% of global greenhouse gas emissions. However, there are no concrete goals formulated for reducing greenhouse gas emissions for 2020 and 2050 and there is no clearly distributed financing of the promised $100 billion in aid pledged to developing nations to adopt CO2-curbing green technologies to help pay for the damage caused to those countries by climate change. Unfortunately, there is no consistent monitoring of CO2 reductions and of how they are to be achieved. To announce a target of limiting global warming to an increase of 2 degrees Celsius is meaningless as long as there is no limit to the CO2 that humanity allows itself to emit by 2050 and such is close to 750 billion tons, according to the best available science. At the current level that is likely to be emitted by 2020.

It took governments from around the world 17 years of dialogues, countless scientific investigations and negotiations, political-ideological debates, delays and maneuvering, to come together for the Climate Summit in Copenhagen, since the last climate-related Earth Summit meeting in Rio de Janeiro in 1992. Seventeen years of searching for solutions to confront the threats resulting from climate change. The last drafts of the final declaration at COP15 included provisions not only for limiting the rise of global temperatures to 2 degrees Celsius above preindustrial levels by 2050, but also for how this could be achieved. There was mention of reducing greenhouse gas emissions by 80% by 2050 and even the possibility of a mid-term goal by 2020.

4 Conclusion

Without waiting any longer for better climate change agreements at the UN-COP16 in Mexico in December 2010, a political contract on the radical improvement of the Energy Performance of Buildings in the European Union was successfully agreed on between the European Parliament, the European Council, and the European Commission on November 17, 2009, to make all new buildings nearly Zero-Fossil-Energy by 2021. As a hopeful global leader in promoting energy efficiency, one key aspect is the requirement that all new sustainable buildings in the EU must be "nearly zero-fossil-energy buildings" and only renewable energy technologies will be accepted to operate buildings on January 2021. In addition, the agreed text does not prevent EU-Member States from setting even more ambitious targets and implementing the provisions of the Directive at an earlier date. In fact, there are many pioneering countries such as Germany, Swiss, and Austria, with leading city governments like Stockholm, Goteborg, Freiburg, or Stuttgart, where the national and regional targets are already more ambitious than the recast European Directive.

However, an area of concern is the fact that the agreed text seems to be under-ambitious in relation to the energy efficiency retrofitting of existing buildings which represents approximately 80% of the building stock in Europe. Despite signs of improvement, Europe's buildings remain a large energy consumer (40% of final energy use), of which too much is wasted in heating and cooling, and a carbon dioxide (CO2) emitter of 36% of EU CO2 emissions. The existing U.S. building stock is facing similar colossal challenges! Energy conservation, efficiency retrofitting of existing buildings, and the radical shift from non-renewable to renewable energy technology economies is the most effective and socio-economical approach to reducing 80% GHG's by 2050 compared to 1990 levels [18]. These changes are imperative for all countries in the world ranging from the most industrialized ones such as the U.S. to the most impoverished ones!

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References

[1] GEMIS, Life-Cycle-Software: Global Emission Model for Integrated Systems (GEMIS) Version 4.5, Oeko Institute Freiburg, Germany, http://www.oeko.de/service/gemis/en/
[2] UNFCCC, United Nations Framework Convention on Climate Change http://unfccc.int/ghg_data/items/3800.php
[3] WorldGBC, World Green Building Council Website, http://www.worldgbc.org/

[4] UNEP-SBCI: The United Nations Environmental Program and Sustainable Buildings and Climate Initiative, COP15, Copenhagen, Dec. 11, 2009. http://www.unep.org/sbci/index.asp
[5] UNEP-SBCI: The United Nations Environmental Program and Sustainable Buildings and Climate Initiative, COP15, Copenhagen, Dec. 11, 2009. http://www.unep.org/sbci/index.asp
[6] Pachauri, R.K. and Reisinger, A. (Eds.). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland. 2007, http://www.ipcc.ch/
[7] IEA (International Energy Agency), World Energy Outlook 2009, http://www.worldenergyoutlook.org/
[8] German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen DGNB) http://www.dgnb.de/
[9] White House Agenda on Energy and the Environment http://www.whitehouse.gov/issues/energy_and_environment/
[10] 2030 Carbon Neutral Challenge of the American Institute of Architects (AIA), http://info.aia.org/toolkit2030/
[11] Cathy Turner, Mark Frankel, Energy Performance of LEED® for New Construction Buildings, FINAL REPORT March 4, 2008 New Buildings Institute (NBI), http://www.newbuildings.org/measuredPerformance.htm
[12] The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) New Pilot Phase Building Energy Quotient Labelling http://buildingeq.com/
[13] Market Transformation (IMT): The Clean and Affordable Energy Act of 2008, and signed into law by District of Columbia Mayor Adrian Fenty on Aug. 4, 2008. http://www.imt.org/rating-dc.html
[14] U.S. Energy Star Portfolio and Environmental Protection Agency's (EPA's) Manager Tool, http://www.energystar.gov
[15] The World Business Council for Sustainable Development (WBCSD) http://www.wbcsd.org/templates
[16] UNEP-SBCI: The Common Carbon Metric for measuring energy use and reporting greenhouse gas emissions from building operations was officially launched at COP15 in Copenhagen on 11 December 2009. Website: http://www.unep.org/sbci/news/latestnews.asp
[17] UN-News-Centre Website: UN-Secretary-General Ban Ki-moon, Dec. 30, 2009, http://www.un.org/apps/news/story
[18] Bulletin Quotidian Europe No. 10022 Website, http://register.consilium.europa.eu/pdf/en/09/st17/st17472.en09.pdf

Section 7
Building technologies

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Eco-technologies for energy efficient buildings in Italy

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Abstract

The climatic context has an essential role in the building construction strategy: it represents the main benchmark to define criteria for energy-efficient buildings design. The control of external conditions through the building envelopment is essential for energy saving.

Environmental protection and energy saving characterize some strategic European experiences. Lots of European countries are promoting and sharing a sustainable building approach to be in compliance with the Kyoto Protocol and subsequent international agreements, such as those established at the last Copenhagen climate conference.

Assuming that buildings have a high environmental impact, in terms of energy and resources consumed, it is necessary to adopt different criteria in relation to climate zones. The design strategies in terms of new constructions and upgrading of existing buildings are based on the concept that building is a composite system, where the architecture, the layout of fronts and openings, the performances of the building shell and integration with the fixtures and fittings, also powered by renewable sources, must be efficiently balanced.

The Passivhaus standard, which defines low energy buildings with heating not dependent on fossil fuel, was originally developed in central European countries and recently it has been revised to adapt its criteria to different climate contexts, especially those of the Mediterranean.

In warm areas the energy efficiency is related to summer performances and passive cooling of buildings. Significant experiences are developing even in Italy, where the Mediterranean climate has different characteristics compared to the cold climates of central and northern Europe.

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Italian regions have more differentiated climates: according to the seasons, protection from summer heat and energy containment during the winter have differing levels of importance. In southern and central Italy the main factor is the heat control in the summer period, during which situations of overheating – which imply relevant energy consumption due to conditioning systems – shall be limited. It is possible that the energy required to cool the buildings exceeds the requirements for heating.

Keywords: ecology, energy efficiency, technology, passive house, Mediterranean architecture.

1 Introduction

The design strategy for energy-efficient buildings is based on climate analysis, the main benchmark to define criteria design. The Italian climatic context has predominantly Mediterranean characteristics, which differ from the cold climates of central and northern Europe, where major researches and applications concerning the containment of energy in buildings were conducted. In countries that have developed lots of experiences, such as Germany, Austria, Switzerland and the Scandinavian countries, the researches on energy efficiency and the concept of passive building refer to contexts characterized by harsh winters – where the priority is the containment of the heat dispersion – and summers with higher temperature conditions.

The buildings have mainly to ensure high levels of thermal insulation to contain the dispersion in the winter; the glazed surfaces should allow the

Figure 1: Historical building. The Italian traditional architecture is characterized by envelopes built with considerable mass materials.

incoming of solar radiation, which is useful for lighting and passive heating of the interiors, keeping down the overall transmittance of the building shell.

In these contexts issues related to summer heat and to the presence of moisture, typical of many areas of Italy, are less important. Italian regions have more differentiated climates: according to the seasons protection from summer heat or the energy containment during the winter have different levels of importance. In the alternation of seasons the buildings have to answer to cold winters and hot summers, often with high humidity, and provide adequate performances in different conditions.

In southern and central Italy the main factor is the heat control that regards just the summer period, during which situations of over temperature condition – that imply relevant energy consumption due to conditioning systems - shall be limited. It is possible that the energy required to cool the buildings exceeds the requirements for heating.

Figure 2: Typical buildings of the north-west Italian coast.

2 The national context

The Italian territory is characterized by different climates, variable from predominantly cold (Alpine) to warm (southern regions and islands), and areas with temperature variations related to significant seasonal cycles. The recent growing attention to the issue of buildings energy efficiency puts the stress on the technical and regulatory problems related to the search for solutions suitable for specific environmental conditions.

Therefore, it is necessary to define design solutions to respond to different climatic conditions, to contain energy consumption during the winter and to limit the interior over temperature during the summer. The main energy consumption in buildings regards the need of heating during the winter and/or cooling in the summer.

The national decrees, transposition of European Directive 2002/91/EC, providing different limits for indicator of energy performance for the winter climate, expressed in kWh/year per unit of area or volume depending on the climatic zone of reference, apply an early diversification according to the weather conditions.

Figure 3: Energy upgrading works of a historical monumental building. Bologna.

3 Guidelines for passive house

Having briefly outlined the national state of the art, characterized by significant climatic differences that have correspondence in regulatory requirements, it is interesting to note how the concept of passive house, born in the colder climates of central Europe, is developing with adaptive criteria in other countries.

In particular the research project Passive-On, sponsored by the EU SAVE Intelligent Energy, which aims to promote the passive houses in warm climates, is very interesting.

The concept, developed first by Passivhaus Institute in Darmstadt, has been deepened by researches and trials in Europe, such as the CEPHEUS - Cost Efficient Passive Houses as European Standards project on the potentials of an alternative approach to the issue of energy use in buildings, designing solutions and suggesting technologies for buildings that can consume minimal amounts of energy during their life cycle, without increasing the cost of construction.

The passive house consumes limited amount of energy for its management and doesn't use fossil fuels, using only minimal amounts of auxiliary energy: the original codification restricted the annual requirements for heating in not more than 15 kWh/m^2 and the total of domestic consumption (hot water, cooling, lighting, appliances) not more than 42 kWh/m^2.

Adapting the concept to the warmer climates it is necessary to take into account the specific needs for cooling, also using mechanical systems. Therefore the annual limits for heating were defined in 15 kWh/m^2, 15 kWh/m^2 for cooling and 120 kWh/m^2 for total primary energy for all consumption.

The experiments in progress on passive designing in hot climate, similar to what happened in cold climates, will be a reference to the development and application of more progressively efficient buildings.

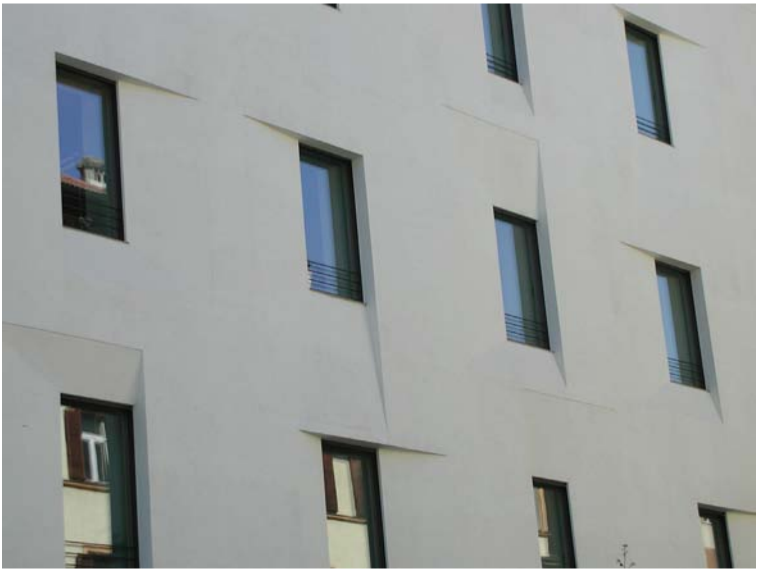

Figure 4: Energy retrofit of the new headquarters of the Autonomous Province of Bolzano. This is the first national public building with a consumption of only 12 kWh/m^{2}year for heating. It reaches the European standard of passive house.

4 Design criteria

The passive houses are characterized by design criteria focused on energy efficiency of the integrated building systems, pursing energy saving, minimizing the active fixtures and fittings, powered by energy.

Since the heat exchange between inside and outside carries out through the building envelope, it is important to use a compact building shell, and take advantage of opportunities to combine buildings, use a simple shell form, and minimize shaded areas in winter. It is fundamental the shape of the building and in particular the relationship between all dispersing surfaces and the heated or cooled volume. The passive standard provides that the limit of the S/V ratio, that is to say the index of compactness (the same also provided by national legislation), is not greater than 0.6. Buildings characterized by a compact form and a considerable volume imply a minor thermal exchanges. This consideration is valid in general even in hot context. While increasing the dispersant surface, the building form has to favor the natural ventilation, necessary for cooling during the night.

Figure 5: The design of the School of Children in Ponticelli, Imola is characterized by energy efficiency. The north facade is extremely compact; the south one is glazed and protected by a system of external shields. On the roof there are air extractors for summer free cooling.

There are several typological examples to refer, such as traditional “domus italic”.

The continuity of the insulation layer and the quality of shell components have a dual purpose: to avoid the spread of heat during the winter and over temperature during the summer. In relation to climatic conditions these functions, generally integrated, are important. In countries of central Europe and north Italy characterized by a hard winter, the dispersion control during this period is important, while in the Mediterranean areas the summer performances of buildings must be controlled. So, the designer has to determine insulation thickness of building envelope and avoid heat bridges.

To keep to Passivhaus standard (U-factor that does not exceed 0.15 W/(m²K) the components of the shell must have an insulation thickness of about 25 cm on the vertical walls, even more on coverage. The solution of isolation on the outer side of the wall, like a coat, avoids heat bridges (the transmittance of linear thermal bridge must be less than 0.01 W/mK) and protects the thermal mass of the structure, allowing the regulation of indoor comfort.

To complete the building shell also glazed surfaces must be extremely efficient: in cold climates to achieve the required standard (less than 0.8 W/m^2K) it is important to use windows with thermal insulated frame and triple-glazing with inert gas (argon, krypton), special low emissivity glasses, very transparent. In warm climates it is possible to obtain adequate results with insulating glasses and high performance frames (transmittance: between 1 and 1.2 W/m^2K, depending on the layout and size of the glazed surface). It is always necessary that the windows are applied respecting the continuity of the insulation layer, which must protect the same frame.

In general, the strict limits of thermal transmittance of the building shell are sufficient, in cold climates, to ensure high performances. In warm climates the integrative role of thermal inertia of the shell components should be considered. It is ensure by the high mass material that maintain an appropriate delay time (more than 12 hours) and mitigate, according to the thermal resistance of the structure, the effects of the external changes of temperature on the indoor microclimate.

In order to reduce heat transmission through the shell, subjected to direct solar radiation, to the inside layers, is appropriate to use ventilated solutions for

Figure 6: Wall construction sustainable system using straw bales. Hotel building as Passive house standard, Lana, Bolzano.

the walls and especially the roofs, which are subjected to excessive sunshine in the summer.

The passive use of solar energy depends on the right position and orientation of the site. South orientation of the main side (± 30°), and large south-facing window areas are important. South exposure is the most favorable as it receives the maximum sunlight in winter, when the sun is low in the sky and its energy contribution is significant (44 ° North Latitude, December 21th: the sun in high about 23° above the horizon). Instead in the summer when the solar energy is unfavorable because it tends to generate over temperature inside, the sun is high in the sky (June 21: about 70 ° above the horizon) and its beams hit on the vertical walls with high inclination. Therefore the facades are more protected from direct exposure.

However, since the exposure factors depend on conditions of the context the design criteria to define the size and orientation of the glazed surfaces should be defined with relation to the specific sites, regulating the conditions of solar capture.

South orientation of the main side receives the maximum radiation in winter, when the solar incidence is favorable, and a minor contribution in the summer. The experience has shown that on the south side the percentage of glazed surfaces in passive traditional buildings should not exceed 40% of the total facades, to limit the excessive losses due to the energy transmission. In warmer areas this value is to be significantly reduced depending on latitude, limiting glazed surfaces to 30% of the same façade. The exposure to solar radiation should be controlled by external shade elements. Particular attention should be pain at west windows, which contribute significantly to global over temperature. The north side, little sunny and exposed to cold winds, must be

Figure 7: Integration of the building with artificial basin of water, Parma. The presence of water helps to reduce the high temperature in summer.

closed as possible to avoid the dispersion of heat. It is important to use a building footprint that concentrates utility installation zones (e.g. bathrooms or kitchens and each other) or filter areas in this side.

To prevent heat loss and infiltration through the building envelope it is necessary to drastically reduce its permeability. Passivhaus standard requires a value of waterproof less than 0.6 volumes/hour of air chance measured with a pressure difference of 50 Pa between inside and outside. This is a very small value: in light dry constructive solutions is possible to apply a waterproof layer under the thermal insulation; for masonry solutions is important to require the continuity of plaster. Great care should be taken to assure that insulation layers are continuous, and without air pockets, to eliminate any discontinuity of different elements of the shell (it is important to have a building shell pressure test performed).

In warm climate areas the infiltration, even if negative, has less impact on energy loss, and the value of permeability can be increased to 1 volume/hour.

A passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems (Adamson 1987 and Feist 1988). The house heats and cools itself, hence "passive". Low energy consumption to maintain the conditions of comfort is ensured by highly efficient heat recovery from exhaust air using an air-to-air heat exchanger. The mechanical ventilation has a dual function: on the one hand contributes to heat and cool the interiors, on the other allows their ventilation, necessary for the

Figure 8: Low energy school in Imola. The plant system integrates solar wall, geothermal resources, solar cooling, etc.

comfort indoor, avoiding the heat loss due to opening windows, providing an air supply of 30-40 mc/h per person.

Solar collectors or heat pumps are used for water heating. In warm climate the production with solar collectors is also sufficient for the winter: you can also integrate the collector to the heating system, providing auxiliary heat to it. Generally the collectors are placed on the coverage, but the tendency foresees to integrate them into the building envelope components.

The electricity needed for lighting, home consumptions and for ventilation fixtures are extremely low: it is important to use light sources and low energy consumption equipment.

The installation of a photovoltaic system capable of transforming solar energy into DC (direct current) may contribute to the energy production: any unused energy quantity can be accounted for and placed in the network of distributors.

In summary the project strategy for buildings passive control in hot climates tends to minimize the internal and external heat gains and obtain appropriate levels of time lag and reduction.

All the strategies related to the removal of the summer heat are to be appreciated. If the waterproof of the envelope avoids accidental infiltration – which has a negative impact to the heat and energy balance, the exploitation of climatic context conditions in the appropriate seasons may cause considerable

Figure 9: Solar collectors system on the roof. It needs hot water and heating. In the summer it contributes to air conditioning inside the building.

free benefit of charge, contributing to the reduction of inside moisture. In particular the use of night ventilation, where the outside temperature falls to levels lower than that of comfort, can help to cool the thermal mass of the building, consisting of the massive structures in contact with the indoor environment, particularly if they are protected by insulation layer. This benefit helps to reduce high temperature during the following day. Alternative or supplementary forms consist of evaporative and geothermal cooling.

5 The importance of the mass for over temperature control

If the recent researches are primarily aimed to codify appropriate construction technologies for the energy saving in winter, it seems appropriate to focus attention on climate characteristics and in particular on the passive protection from the summer heat.

Figure 10: Traditional building typologies, "Dammusi" of Pantelleria and Apulian "trulli". The use of appropriate materials and the bioclimatic relationship with the context contribute to maintain a constant internal microclimate without integration systems.

To increase the heat capacity of building technological layers, you can use insulation with higher thermal mass, such as panels of wood fiber (with a density ranging from 130 to 190 kg/m^3), with very good hygroscopic performances. In general, lightweight solutions have not a considerable heat capacity, that is to say that they don't contribute sufficiently to delay the transmission of external thermal variations.

If the heat insulation is the most important and codified factor from the prescriptive point of view, in relation to different climates, in particular the warm ones, the role of thermal inertia of the building system gradually assumes importance. It is simple to define the concept but difficult to calculate this factor: at a glance it can be defined as the combined effect of the capacity of accumulation and heat resistance of the structure.

Traditional Italian architectures such as the Apulia "trulli" and "dammusi" of Pantelleria can represent simple but interesting bioclimatic reference models: they are able to maintain sufficiently constant temperature indoor, even without auxiliary fixtures and fittings, thanks to a correct architectural form, exposure, the relationship with the soil, and in particular to the thickness and mass of the envelope.

The coefficient of thermal lag allows evaluating the delay of transmission of the external thermal gradient changes inside. To obtain sufficient comfort conditions, lag should not be less than 8 hours, while optimal conditions are achieved with just 12 hours.

Therefore, especially in the summer, in addition to the transmittance it is important to assess the contribution of the massive materials, with higher heat capacity in order to reduce the effects of external thermal variations on the microclimate indoor.

6 Conclusion

The role of heat inertia, although extremely important in the characterization of energy efficiency of buildings in summer, cannot leave aside a more general design strategy aimed to a correct relationship with the environment. Among the main parameters the most important are the location, the shape and orientation of the building: southern orientation and shade considerations are some of the basic features that distinguish passive house construction. The ratio of dispersing surfaces and volume is an index of energy efficiency and it is considered a reference for regulations.

Other features of a passive house consist of an opportune distribution of rooms and functions, construction typology, use of energy-efficient window glazing and frames, application of solar shields. Particular important is natural or mechanical ventilation system - which may play an important role in summer cooling, encouraging the air change in the night (most of the perceptible heat in the exhaust air is transferred to the incoming fresh air) - and passive preheating of fresh air which may be brought into the house through underground ducts that exchange heat with the soil.

It is fundamental to integrate consciously energy-saving factors to realize buildings characterized by conditions of natural hydrothermal comfort with minimal energy use.

References

[1] AA.VV., *Costruire sostenibile: il Mediterraneo* (Cuore Mostra SAIE), Alinea: Firenze, 2001.
[2] AA.VV., *+Qualità–Energia. Per costruire sostenibile*, Be-ma: Milano 2008.
[3] Barucco, M.A., Trabucco, D., *Architettura_Energia*, Edicom: Montefalcone (Gorizia), 2007.
[4] Boeri, A., *Criteri di progettazione ambientale*, Delfino: Milano, 2007.
[5] Hendriks, Ch. F., *Sustainable construction*, Aeneas technical publishers: The Netherlands, 2001.
[6] Novi, F., *La riqualificazione sostenibile*, Alinea: Firenze, 1999.
[7] Smith, P., *Eco-Refurbishment*, Architectural Press: Oxford, 2004.

A global tool for the architectural and environmental quality of materials integrated into the architectural design process

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Abstract

In the very first phase of a design project the architect must choose both the materials and implementation processes. We propose in this work a global and cross-cutting design tool, "MaTerre'iO", to help the architect to make his choices based on environmental quality concerns. Firstly, we present the initial context of our work. Tools such as ours are still recent in the area of environmental architecture, and are often complex because they require a high level of expertise to be used correctly. This is why the objective of "MaTerre'iO" is to offer pragmatic information on the quality of materials starting at the beginning of the very first draft, in order to guide the various actors of the building project throughout the process of design. Then, we explain the principles of "MaTerre'iO": 1. to provide a global outlook, which is particularly needed in architecture; 2. to respect the design process phases (evolution of the nature of the requested input data); 3. to provide an easier comprehension to non-expert eyes on the environmental and technical aspects. A multicriterion grid provides a comprehensive view of the project. Next, we develop two of the criteria of our multicriterion analysis grid, and illustrate them through one example: (i) the physical pollution that governs the impact on the environment, on health and on the quantities of waste, and (ii) the footprint of energy consumption and resources consumption. The multicriterion analysis grid allows a multidisciplinary approach. It is based on three approaches: the global approach for architects, the awareness approach for the participating actors and the expert

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approach for engineers. Finally, we present its novelty and advantages, particularly its interdisciplinary and ability to ease the exchanges between the different actors of an architectural design process.
Keywords: environmental quality, tool, materials, architecture, footprint of energy consumption, physical pollution, multicriterion analysis grid.

1 Introduction

This work presents how the environmental quality of materials can impact the process of architectural design. In the traditional way of designing a new architectural project, the environmental impact of the components and of their assembly is approached in the last phases, when it is often too late to change the earlier choices. The alternative is to account for, or at least to be aware of, the environmental quality of the materials at the very first stages of the design.

We focus in this paper on numerical tools related to the choice of materials and the processes of implementation. Such tools are very recent in the domain of environmental architecture compared to those dedicated to energetic and comfort. We present first a brief review on the different kinds of tools available today, focusing more specifically on their ability to be integrated into the design process. Next the numerical tool developed in the frame of our research, “MaTerre’iO”, is presented. It consists on a multicriterion analysis grid that we illustrate through two criteria, before concluding on the advantages and the limits of “MaTerre’iO”. The two criteria that we chose in our multicriterion analysis grid are the physical pollution and the footprint of energy consumption.

2 Initial context: ability of current tools to be integrated into the design process

The tools related to the choice of materials and the processes of implementation have changed dramatically these past years, and particularly computer softwares. Three main families can be distinguished [1]. They are tools dedicated to helping the designers to learn more on the impact the materials and their implementation may have on an architectural project:

- database: this type of tool is widespread, they serve the quantification of the impact and aesthetic qualities of materials.
- environmental impact tools: the main objective of such tools is to help to exploit in a more easy way the data contained in the databases. They are not very much in use within the architectural community.
- tools combining materials and other environmental issues: this type of tool is rare.

Level of expertise:

The use of these tools requires a high level of expertise. Indeed the available data refer to specific knowledge such as technical data, mechanical details, health impact, environmental approach…The tools specialized in for example lighting, acoustics, heat transfer through buildings, are destined to experts of each field.

As a consequence information on the environmental impact of a material because of its interdisciplinarity is too complex for a non-expert. Because of that, they cannot be accounted for during the choices of design.

Materials data collection:
Today, data such as physical aspects of materials or constructive systems are relatively well-known and reliable for most of the studied criterion. As far as environmental aspects are concerned, the user must be extremely careful because the available data are on a self-declared basis. Therefore, experience and distance are required. In addition, economic aspects of the materials are difficult to account for. They are subject to exogenous factors in the sense that they depend on the geographical location of the construction, on the fluctuation of raw material, inflation, etc. Moreover, the collection of materials data raises the question of their regular update, of their homogeneity and objectivity. In sum, databases nowadays are very shallow and the information on their origin incomplete.

Integration of the design process phases:
The available tools require one to know the precise quantities of materials that will be used. In the situation of an architectural project, this means to be in an advanced phase of the design process, in order to be able to characterize the architectural proposal. Whereas today, the designer becomes interested in the material choices in the first phases of the project. Therefore it is difficult to use these tools.

It is important to notice that today, in order to be in phase with the different design process stages, some tools reason in terms of length of façade rather than in surface of materials. This tendency seems to be interesting because it allows a simplification of the input data requested to the designers.

A more global view is needed in architecture:

As far as the environmental quality of the materials is concerned, most of today knowledge and most of the tools focus on the energy footprint or on the carbon footprint. As far as the domain of architecture is concerned, it is essential to have a more global view when it comes to the choice of materials. In order to answer the designers' expectations, without minimizing the architectural quality, the process of architectural project must integrate a multidisciplinary approach.

The objective of "MaTerre'iO" tool is to inform the designer on the environmental impact of the choices of materials and processes of implementation. We focus on the different needs that we mentioned in order to offer pragmatic information on the quality of materials at the beginning of the very first draft, in order to guide the various actors of the building project throughout the process of design.

3 Principles of "MaTerre'iO"

MaTerre'iO tool is the result of the collaboration between a French environmental architecture laboratory and engineering research laboratory. The benefits of the exchanges come from the relationship between these two complementary professions.

3.1 The different principles of MaTerre'iO

The different principles that are in "MaTerre'iO" were derived from the particularities of the existing tools that we mentioned before, and from the discussions we had with specialists in environmental architecture and designers. We learnt from the specialists about the role of the different tools, their advantages and their limits. The designers informed us on the approach of the architectural project and especially on the choice of materials and processes of implementation.

3.1.1 A global view

In a design phase, designers handle the question of materials by combining simultaneously the constructive, environmental, aesthetic, economical, energetic and normative aspects of materials. To design means to account for different knowledge. We thought it would be interesting to reduce the number of architectural and environmental markers related to materials and devices of construction in order to be more global, pragmatic and efficient. Following a broad review on this topic, we gradually set up a multicriterion analysis grid. This grid is a structure of 3 levels. To date, the global vision level on the quality of materials is based on 7 criterions.

3.1.2 Respecting the design process phases and providing an easy comprehension to non-expert eyes

The question of materials and processes of implementation arises throughout the duration of the architectural project, but in various ways (Figure 1). Crucial choices are made during the very first phases of the project, whatever the project, the site and the work method used by the designers. In order to gain in

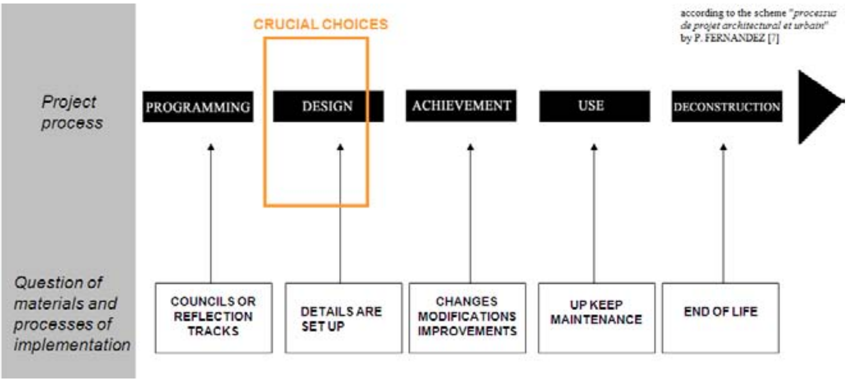

Figure 1: Design process phases and the question of materials and processes of implementation.

effectiveness, it is important to concentrate on this phase of the draft when developing future tools. This will allow easier optimizations during later phases of the project [2]. In addition, to be efficient and easy to use, the tool must be running fast and need to propose a convivial interface to integrate into the process of design.

3.1.3 Nature of the requested input data

The input data must be in adequateness with the needs of the designer in the first phases of the architectural design process. This is the reason why the proposed input data must be simple and in small numbers.

In “MaTerre’iO” tool, we propose only four input data (Figure 2):

- The city where the project will be built (for the climatic conditions)
- A simplified 3D drawing to see the morphology of the buildings, the volumes.
- The orientation
- The type of architecture devices: foundations, structures, partitions, envelope, openings, roofs. We propose to reason on materials devices and not on materials only.

The main idea is to compare the environmental impacts of the various choices at the very beginning of the draft, without going into any building detail.

3.1.4 Gathering of data on the environmental impacts of materials

In order to feed our tool, we set up a materials database, the most homogeneous and reliable possible. Today, our database centralizes and classifies all the

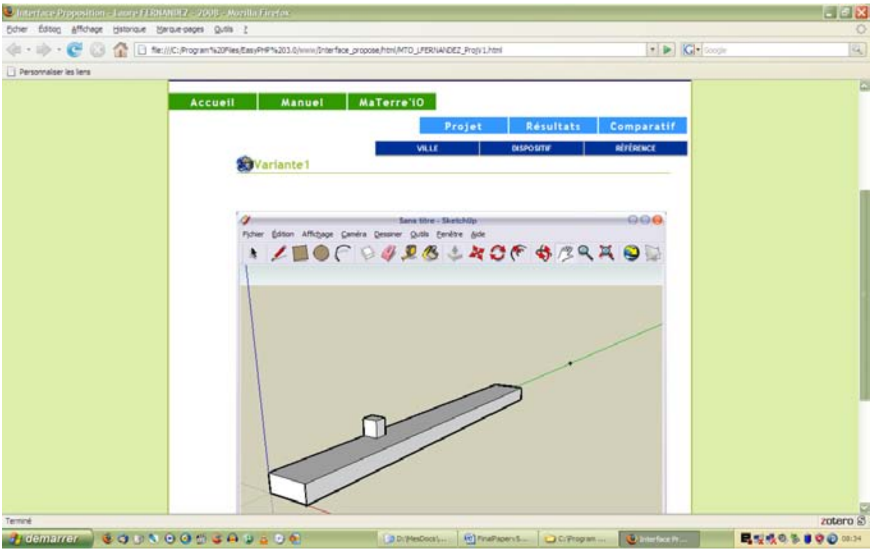

Figure 2: Example of input data in the MaTerre’iO tool.

characteristics of materials. It amalgamates physical, technical, environmental, economical and aesthetic data. It is as exhaustive as possible. It gathers information coming from various sources: Ademe, CSTB, inies, izuba, KBOB, Wufi, etc [3].

It is worth noticing that the environmental data harvesting is long and difficult mostly because such needs are recent or some parameters are unknown.

3.2 Multicriterion analysis grid

We developed in this work a multicriterion analysis grid in order to reduce the number of architectural and environmental markers related to materials and devices of construction. After a broad research on the subject, we set up a multicriterion analysis grid in 3 levels based on a tree structure.

3.2.1 Multicriterion analysis grid elaboration

At first, we were looking for a method that takes into account different criterion, without reducing at one [4,5]. The objective was to find an acceptable solution in an environment where the appreciation criterions are complex and plentiful.

A multicriterion analysis is better than a monocriterion one because it accounts for many criterions often conflicting. The multicriterion analysis seeks for compromises rather than an optimum result.

We developed a hierarchical structure with a top-down approach. The grid had to be exhaustive, irredundant, coherent, independent and readable. The objective of the multicriterion analysis grid was to propose a global glance on many criterions of materials and processes of implementation at the beginning of the draft phase. It was developed from an exhaustive bibliography on environmental knowledge on materials. Many fields were studied: the impact of the materials on health, on biodiversity, the life cycle of materials, their aesthetic cultural and technical aspects, their energy consumption, wastes….

Moreover, we used the results of a previous inquiry to complete our structure: first, we discussed with experts on the tools function in the design process. Second, we discussed with architects about their work method on the question of materials and processes of implementation.

3.2.2 Multicriterion analysis grid

To date, we reduced the global vision on the quality of materials and processes of implementation into 7 criterions (Figure 3). Each of the 7 criterions (global approach), is declined under different sub-criterions: indicators (awareness approach) which are declined in markers (expert approach) [6].

We propose different results according to the user's level of knowledge and to his comprehension level. The results at the levels of global approach and awareness approach are explained with indicators: very good – good - medium - bad – very bad. This makes the comprehension of the results easy. On another hand, the results at the level of expert approach are explained as precisely as possible through numbers. In sum, according to the user's level of expertise, it is possible to benefit from an increasingly precise and complete approach.

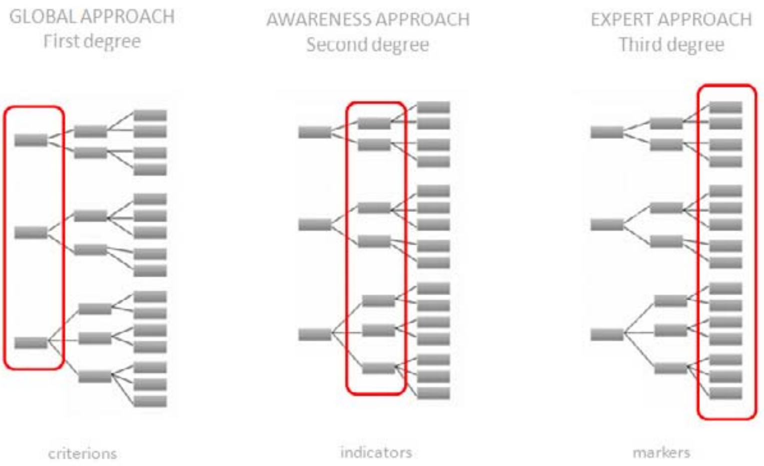

Figure 3: Multicriterion analysis grid, different approaches.

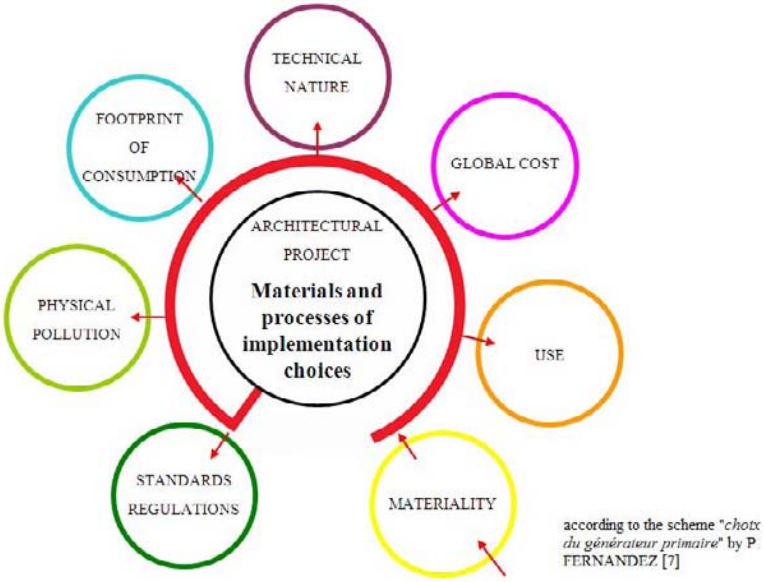

Figure 4: The seven criterions of the multicriterion analysis grid.

Even though it is necessary to study each criterion, the needs are different according to the context; designers, project, etc [7]. For example, the architect may be interest in the usefulness of a material before its physical pollution on the environment.

The seven criterions (Figure 4) are physical pollution, footprint of energy consumption, materiality, use, global cost, technical nature, and standards – regulations.

These criterions offer a global vision on the environmental questions of materials and processes of implementation for designers.

3.3 Illustration of the tool: Galopin's house in Seniergues (France)

To illustrate our tool, the "*Galopin's house*" project was chosen. This project is known as a great project about environmental architecture. It was presented in several books, as for example the book from Dominique Gauzin-Müller "25 maisons écologiques" [8].

The main features of the Galopin's house are:

- Orientation
- Implantation: semi-buried
- Choice of materials : local stone
- Ratio between windows and façades
- Room organization in the building
- …

We compared two architectural solutions from the point of view of the choice of materials and processes of implementation. The first solution is the solution chosen by the Gouwy Grima and Rames architecture agency. The architects used preferentially local stone for the envelope of the house with an approach (or thought process) that happened to be environmental friendly. Second, we proposed a more classical solution by using concrete and coating for the envelope of the house.

Our tool MaTerre'iO allows comparing the different solutions in order to improve the designers' choices.

4 Two criterion of our multicriterion analysis grid

In this work we chose to develop two criterions based on the following requirements:

- They concern the environmental qualities of materials,
- They are almost unknown to designers
- They correspond to the fields studied in our laboratories
-

We chose the criterions of physical pollution and footprint of energy and resources consumption. The data were found in several sources. Mainly the Inies database was used. This database stores FDES forms (environmental and health declaration form) [9].

4.1 Physical pollution

The physical pollution is the introduction in the environment of substances up to a level that their effects become harmful to human health, environment and/or climate.

The physical pollution criterion is declined into three indicators: environmental impacts, human impacts and waste impacts.

The environmental impact indicator is declined itself into several markers such as:

- climatic modification marker: it estimates the materials contribution in the greenhouse gases emission in the atmosphere. This marker amalgamates all the greenhouse gases emissions.
- atmospheric acidification marker: it takes into account the materials compounds which are transforming into acid. Note that these markers are hazardous for fauna and flora.
- air, water and soil pollution markers: they estimate the toxic and ecotoxic impacts of emissions in the air, water and soil. These markers amalgamate principally organic compound and metal.
- ozone layer destruction marker: it estimates the material contribution in the ozone layer destruction.
- photochemical ozone formation marker: it estimates the emissions contribution in ozone formation.

The human impact indicator is declined into five markers:

- moisture and microorganism marker: it estimates the materials sensitivity for moisture and microorganism development.
- fibers and particle produce marker: it estimates the fibers and particle emissions. Hazardous emissions depend on its physic-chemical characteristics and persistence in biologic tissues.
- VOCs marker: it estimates volatile organic compounds emissions.
- radioactive emissions marker: it estimates the quantity of radioactive emissions of materials.
- cancer risk marker: it classifies the materials according to cancer risk.

The waste impact indicator is declined into five markers:

- value waste marker: it accounts for all the wastes for which valorization is possible.
- hazardous, not hazardous, inert and radioactive wastes markers: they estimate the volume of waste to be abandoned. The waste classification is hazardous, not hazardous, inert and radioactive wastes.

4.2 The footprint of energy consumption and resources consumption

The footprint of energy consumption and resources consumption is the impact on all the resources: energy, consumption, etc. This criterion is declined into two indicators: footprint of energy consumption and resources consumption. These two indicators are declined into five markers:

For the footprint of energy consumption, the markers are:

- renewable energy marker: this marker takes into account the cultivated, naturally renewable or regenerable resources.
- non renewable energy marker: it estimates the fixed amount of resources existing on earth which cannot be renewed at human time scale.

For the energy consumption, the markers are:

- resources exhaustion marker: this marker takes into account the both resources consumption: energetic or non energetic resource, excepted water.
- water consumption marker: it estimates the water consumptions of the material during their entire life cycle
- territory consumption marker: this marker is difficult to evaluate. This is why we estimate only the area consumption by the architectural project.

4.3 Criterions, indicators and markers work method

In order to be in adequacy with the expectations of our multicriterion analysis grid, we present the results on our markers differently depending on the approaches. Thus the results on the expert approach are the sum of all the data on the materials used in the architectural project. The results are expressed in numbers. The awareness and global approaches results follow the expert results. We created boundary markers to explain the results by means of the following indicators: very good – good – medium – bad – very bad. Each markers and indicators are weighted according to their importance. The level-headedness depends on the existing knowledge.

5 Conclusion: advantages and limits of our research work

We proposed a tool which is compliant with the architectural process: a global view (multicriterion analysis grid), the respect of the design process phases, a tool providing an easy comprehension to non-expert eyes, an evolution of the nature of the requested input data… The exhaustive data base on environmental data about materials allows thinking in terms of device or assembly of materials rather than material itself in order to follow the process of design in the architectural project.

MaTerre'iO tool is innovative and we believe it is in adequacy with the designers expectations. To our knowledge, it is the only tool that is proposing simplified data on the environmental questions of materials and processes of implementation.

Difficulties and limits of this work are as follows:

- data access, mainly for some material families,
- data access, mainly for all material devices,

- objectiveness in weighting the indicators: these weightings are based on our readings and discussions with experts. We believe that they need more scientific validation as for example in the case of not cancer risk marker [10].

References

[1] Fernandez L., Bonneaud F., & Lorente S., *Environmental quality of materials: software tools of pertaining to architectural quality*, 25th Conference on Passive and Low ENERGY Architecture, Dublin, 22nd to 24th October 2008.
[2] Bornarel A., *Qualité environnementale des bâtiments – Manuel à l’usage de la maîtrise d’ouvrage et des acteurs du bâtiment*, Ademe edition, France, 2003.
[3] http://www.cstb.fr
[4] Schärlig A., *Décider sur plusieurs critères – Panorama de l’aide à la décision multicritère*, Presses polytechniques et universitaires romandes, Lausanne, 1985.
[5] Roy B., *Méthodologie Multicritère d’Aide à la Décision*, edition Economica, Paris, 1985.
[6] GRECO (EAT) & EAPB, *SAGACités: vers un Système d’Aide à la Gestion des Ambiances urbaines*, rapport d’étude, France, 2002.
[7] Fernandez P., *De l’architecture bioclimatique au développement urbain durable*, Habilitation à diriger des recherches, Institut National Polytechnique de Toulouse, France, 2007.
[8] Gauzin-Müller Dominique, *25 maisons écologiques*, edition Moniteur, Paris, 2006.
[9] http://www.inies.fr
[10] Déoux S. & P., *Le guide de l’habitat sain – les effets sur la santé de chaque éléments du bâtiment*, Medieco editions, deuxième édition revue et augmentée, Andorre, 2004.

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Planning the integration of new technologies for sustainability: case study of a school building's restoration project in Rome

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Abstract

The research for sustainability challenges us to reconsider the way we think about architecture and offers great opportunities to renew its formal language with new technologies, as it did in the beginning of the 1900s with the introduction of reinforced concrete, steel and glass in modern architecture. We need to transform the architectonic envelope in a smart skin, a selective filter with the capacity to control the energy fluxes between indoor and outdoor environments, to change its working according to different weather conditions and to fully exploit renewable resources. This can be done with new technologies that must be integrated in constructive systems in order to combine the enhancement of energetic efficiency with aesthetic requirements, which is even more important in building restoration, whose landmark preservation principles are more restrictive. Planning the integration is the theme of the research, performed on a school building restoration project, built during the 1980s in the periphery of Rome. This building is a representative model in terms of time of construction, typology, constructive technologies, dimensions and energy consumption; therefore, it can roughly describe 60% of Roman schools, whose total estate is of 13.5 million cubic meters in 1,296 buildings.
Keywords: green building technologies, BIPV, integration of photovoltaic, solar design, sustainable architecture.

1 Introduction

Almost 35-40% of energy consumption in Europe [1] is due to buildings and, in view of the technologies available, it forms the field with the widest room for improvement in energy savings. The enhancement of energy efficiency in

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buildings is therefore the most important field of research for a sustainable development of our society and also represents a great chance for architecture to renew its formal language through the integration of new technologies and new materials in building construction and the development of an environmental-friendly planning. This task involves the definition of new standards for the construction of new buildings and, even more importantly, the renovation of existing structures, with two different approaches: the managing of financial incentives for private buildings and the development of restoration projects for public buildings that are important not only because of their low energy rating, but also for their capacity to spread a new style of living based on ecological responsibility. In the public estate, excluding those building types dispensed from meeting energy standards (according to the Italian law Dlgs 311/2006: hospitals, prisons, barracks), 75% of energy consumption is due to schools [2].

School buildings are also interesting because of their need to strike a balance between cost reduction and high levels of comfort, necessary to create a warm and welcoming indoor environment in order to make children feel that the space is their own. As a matter of fact, it has been experimentally proved [3] that comfort conditions can play a key role for children in learning and developing their own capacities to the maximum, this influence can be even stronger than on adult office workers' performance. Finally, school building renovation projects can give us the opportunity to introduce environmental and energy information into the education process with a concrete example that can be easily experienced not only by children, but also by the whole neighborhood.

2 Defining the case study

The research has been performed on a school building, built during the 1980s in Tor Bella Monaca, a peripheral quarter of widespread and economic public housing in Rome, characterized by a deep urban degrade.

This building offers us a representative model of typology, constructive technologies, dimensions and energy consumption of roughly 60% of Roman schools, whose total estate comprises 13.5 million cubic meters in 1,296 buildings [4]. As a matter of fact, 60% of these schools have been built in the last 40 years in observance of standards set by the ministerial decree 18/12/1975 "Updated technical regulations concerning school buildings" (original title is: "*Norme tecniche aggiornate relative all'edilizia scolastica*"), published to achieve indoor comfort and cost reduction. Though this law exerted a positive influence on building design (of course, proportional to the technological and environmental knowledge of '70s), the lack of control in building construction and management (due to the weakness of the administration, interested only in reducing costs and not in broad-based projects), has led to the present situation in which even the high amounts spent on energy do not ensure the necessary thermal, visual and acoustic comfort. Therefore the building restoration project must recognize the potentialities of the existing construction and improve them in order to reach a new synthesis where comfort and reduction of energy consumption can be achieved.

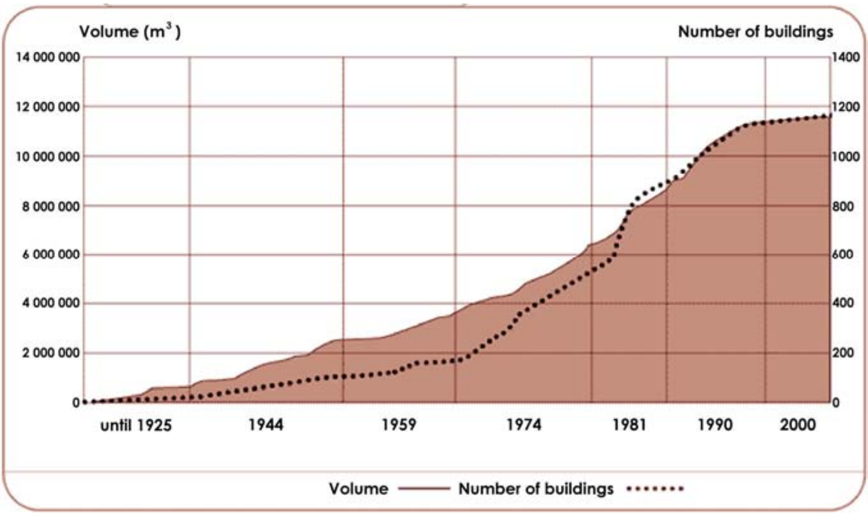

Figure 1: Trend growth of Roman public school constructions, in terms of volume and number of building; source: municipality of Rome, V department.

3 Objectives

The building chosen as object of our study presents many favorable aspects for a bioclimatic handling; this can be seen mainly in the almost exclusively south-facing orientation of the classrooms and laboratories and in the use of massive walls and large, windowed surfaces on the south façade. These solutions testify to the desire to take full advantage of solar radiation for the heating and illumination of the classrooms in the winter seasons and to limit it in the summer, through the heavy walls, capable of delaying the thermal wave until hours of non-usage of the school's interior, and of offering shade for the windowed surfaces.

The renovation project of the building thus should fully exploit these potentialities of the building, while overcoming critical factors, consisting mainly in the poor thermal performance of the building envelope and in the absence of effective shading systems. In fact, the only existing shading system, made of PVC roller blinds, does not allow for selective shading, capable of reducing the effects of glare in the winter season and the greenhouse effect in the summer. For this reason the roll-up shutters often remain closed, with an ensuing great loss of thermal energy in winter and of natural lighting throughout the whole year, resources which are free and – in the case of lighting – of better quality.

The project comprised common operations, such as the creation of a continuous external insulation, the replacement of windows and doors, the substitution of the boiler with a new, high-efficiency one and the fitting of

Figure 2: East view of the school.

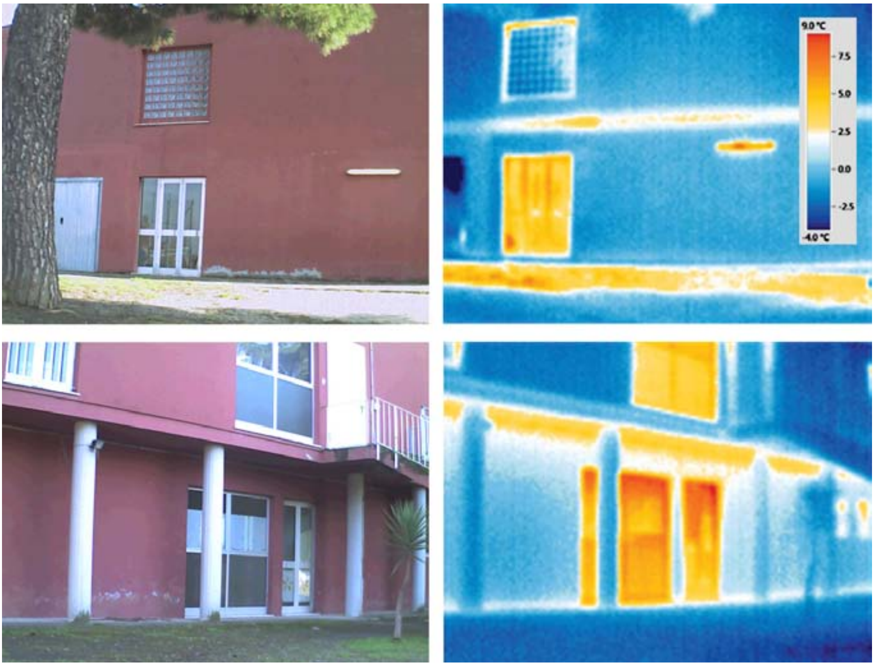

Figure 3: Infrared thermographic measurements of thermal bridges.

thermostatic valves for a better handling of the heating system. In addition, it focused on the project of the shading system, in order to obtain a selective filter that should regulate the incoming of thermal and luminous radiation.

The shading system, furthermore, could include in its interior the photovoltaic technologies for the production of electric energy. In this way we obtained a photovoltaic system fully building-integrated, both on the technological as well as aesthetic level, still guaranteeing the advantages proper to non-integrated systems, consisting in the optimized orientation of the modules (in this case we could even adopt a tracking strategy to optimize the radiation that hits the cells), in their easy maintenance and (if necessary) replacement and in the reduction of losses due to overheating, thanks to the optimal ventilation on modules' rear surface.

Today the insertion of these technologies seeks exclusively to reduce their impact, attempting not to disturb a pre-established situation. In this study, the potentialities of integration were explored, as a possibility to enrich the architectural language with new "architectural terms": in the case in question, the new structures should take up the rhythms of the façade, underlining them while enriching the external appearance with a light and technological element.

4 Planning the integration

Each intervention has thus been evaluated under a group of diverse aspects: technical, formal/aesthetic, economic and energy output.

The global improvement in thermal performance of the architectural envelope, accomplished through external insulation and replacement of the frames, achieved a drastic reduction of heat dispersion through the envelope (up to ¼ of the previous state) and guaranteed greater interior comfort by reducing the thermal gradient, the cold surfaces, and the draught. The installation of the external wall insulation has furthermore allowed us to redesign the façade, without altering its fundamental characteristics: underlining the internal division of spaces and the repetition of the tripartite rhythm, greater transparency and familiarity were sought, as well as a more recognizable appearance to the school building for the children, so that in this way they could recognize the spaces as their own.

Initial energy consumption, estimated by comparing calculations with measured data, and equal to 12.8 kWh/m^3 was reduced to 2.8, with a subsequent passing from energy class D to A+.

Regarding the summer season, the restoration project guarantees a better performance of the envelope in terms of phase displacement (from 6 to 10.5 hours) and damping (from 0.64 to 0.11) of the thermal wave, taking advantage of the pre-existing wall mass to delay until the off-hours, when the internal spaces are not in use, those peak charges, which can be disposed of using the openings already present in the skylights and internal courtyards.

The project of the shading system, the technological components with the strongest impact on the existing structure, was studied in particular depth through a comparison between the various options of two basic solutions: a

Table 1: Comparison of thermal performances of different architectural envelopes.

<table>
<tr><th rowspan="2"></th><th colspan="3">Medium values ante operam</th><th colspan="2">D.M. 18/12/75 minimum values</th><th colspan="2">Dlgs. 311 minimum values 1° jan 2010</th><th colspan="3">Medium values post operam</th></tr>
<tr><th>Mf (kg/m^2)</th><th>U (W/m^2k)</th><th>Tsi °C</th><th>U (W/m^2k)</th><th>Tsi °C</th><th>Mf (kg/m^2)</th><th>U (W/m^2k)</th><th>Mf (kg/m^2)</th><th>U (W/m^2k)</th><th>Tsi °C</th></tr>
<tr><td>Wall - east, west, north</td><td>164</td><td>1.04</td><td>17</td><td>0.81</td><td rowspan="5">14</td><td rowspan="5">230</td><td rowspan="2">0.36</td><td>249</td><td rowspan="2">0.28</td><td rowspan="4">19</td></tr>
<tr><td>Wall - south</td><td>465</td><td>0.88</td><td>18</td><td>1.09</td><td>585</td></tr>
<tr><td>Floor</td><td>479</td><td>0.93</td><td>18</td><td rowspan="2">1.00</td><td rowspan="2">0.32</td><td>560</td><td>0.32</td></tr>
<tr><td>Roof</td><td>670</td><td>1.45</td><td>17</td><td>682</td><td>0.28</td></tr>
<tr><td>Frames</td><td></td><td>5.60</td><td>8</td><td>5.50</td><td>2.40</td><td></td><td>1.6</td><td>16</td></tr>
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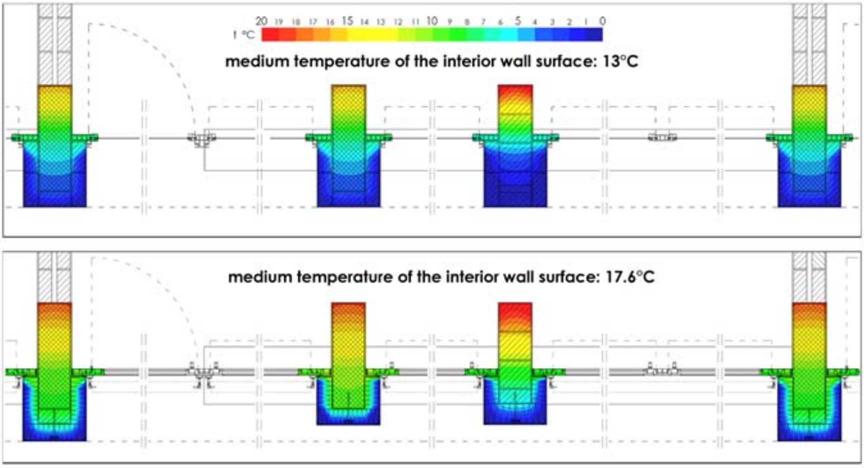

Figure 4: Temperature gradient in the south wall's depth before (above) and after (below) renovation.

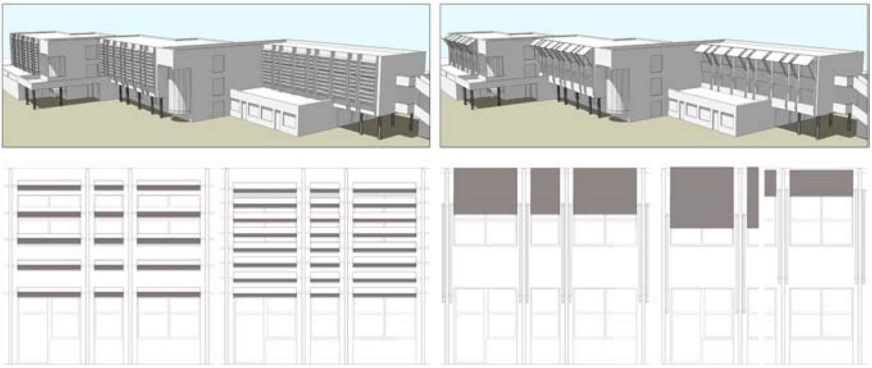

Figure 5: Comparison of aesthetic qualities between the "blades" (on the left, two different steps) and the "cantilever solar screen" (on the right, one fixed and one with tracking systems).

system of "blades" and one of a "cantilever solar screen" over each window; these different styles have been evaluated on the basis of their aesthetic integration, energetic output and shading performance from luminous and thermal radiation.

On the aesthetic level, in the first place the steps of the structure were defined in relation to the façade, with its tripartite rhythm of openings, in the second place, the comparison between the various systems has shown how the blade system adapts itself poorly to the building in question inasmuch as too sparse (and thus lacking its own formal dignity) or too thick and thus incapable of entering into dialogue with the façade behind it, and of guaranteeing the transparency required of a school building in order to offer an image of the school's openness and full accessibility to the urban context. The cantilever system, instead, is applied to the existing structure without denying it, and as an element possessing its own formal dignity that allows for a full visual transparency.

In regard to the energetic production, as well, the cantilever system guarantees a greater performance because it does not affected, as occurs with the blade system, from shade afforded by various wings of the building, which cause in the latter a loss of productivity of roughly 6% in terms of kWh/kWp or of 11% in terms of total active surface, should one decide to utilize only the best exposed surface of the blades as active. The cantilever system furthermore can also be applied to the north façade to obtain a covered pathway of access to the school, with an increase of the available area of roughly 30%, thus satisfying 53.6% of the building's total electric energy requirements.

The hypothesis of tracking systems – which in this case (W-E axis) can be daily or seasonal – has proven to be of scarce efficacy inasmuch as it offers reduced advantages, on the order of 3-5%, which corresponds roughly to the energy necessary to run the modules.

With regard to shading capacity, the cantilever system, performing in a less linear way between the winter and summer situations, guarantees a greater selectivity in transparency while the blade system has the defect of casting a heavy shadow even in winter, due principally to the fact that in order to optimize the energy output, the blades would be placed with a tilt of 30-34° and thus

Figure 6: Comparison of energy output between different shading systems.

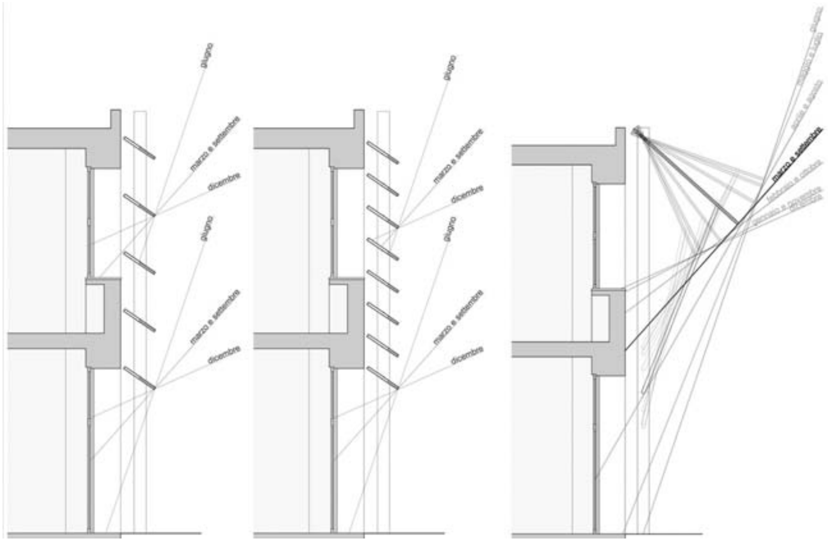

Figure 7: Comparison of shading capacity.

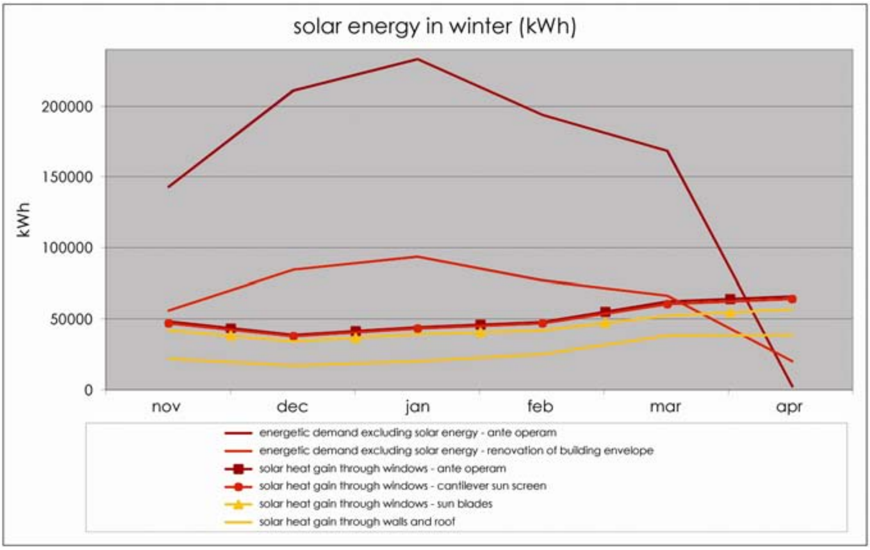

Figure 8: Importance of solar gain in winter.

would form with the sun's rays a greater angle of shade. The cantilever system has a slightly inferior performance in the months of April and August, due principally to the absence of shading on the windows of the lower level, which can be obtained with a secondary shading system necessary also in order to guarantee a complete darkening of the classrooms, if necessary. Should a tracking system be employed, there would be notable disadvantages in the winter season, because the need to favor the entrance of thermal radiation would conflict with that of optimizing the energy output: the first, in fact, requires blades parallel to the direction of the sun's rays, the second, perpendicular blades.

Regarding the shading of the luminous radiation, finally, we notice how both systems guarantee a decrement of the daylight factor due to a strong reduction of the direct component. This reduction becomes perhaps excessive in the cantilever solar screen, which in addition represents a poorer distribution of the illuminance which can lead to glare effect. For the purpose of limiting these critical elements – having chosen this solution as the best on the basis of the preceding analyses – it was decided to improve the transparency of the cantilever system (in order to increase the medium daylight factor) utilizing double-glass modules and to install an internal shading that can be accomplished through curtains, which allow the heat to enter and spread direct sunlight.

Table 2: Comparison of indoor natural lighting with different shading systems.

	Ante operam	Blades solar screen	Cantilever solar screen
Medium daylight factor (Dm)	5.8%	2.3%	1.7%
Minimum daylight factor (Dmin)	2.8%	0.8%	0.4%
Maximum daylight factor (Dmax)	17.8%	8.0%	7.5%
Uniformity factor G1 (Dmin/Dm)	0.48	0.35	0.23
Uniformity factor G2 (Dmin/Dmax)	0.16	0.10	0.05

5 Achievements

The intervention allows the building to reach a class A+ energy label, reducing by roughly 72% the consumption of energy used for heating, and to improve the comfort conditions in indoor environment during the school year, both in the winter as well as summer season. The requalification furthermore obtains a greater visual comfort, thanks to the improvement in the relation between diffused and direct components, which allows – along with the possibility of shading the thermal radiation in the summer and the luminous rays in winter, without completely closing the shading systems – to estimate a reduction of electrical energy use for lighting which is not exactly quantifiable.

The photovoltaic systems can produce roughly 53.6% of the building's total requirements, while the CO2 emissions in the atmosphere are reduced by 68%. The chosen solution furthermore restores the building's image, enriching it with technological elements that in this way are inserted into the didactic instruction as a daily experience of a sustainable lifestyle.

Figure 9: Rendering – south view.

Figure 10: Rendering – south view.

Figure 11: Reduction of CO_2 emission.

References

[1] European commission, Directorate-general for energy and transport, *EU energy and transport in figures - statistical pocketbook*, 2009
[2] Citterio, M. & Fasano, G., *Indagine sui consumi degli edifici pubblici (direzionale e scuole) e potenzialità degli interventi di efficienza energetica*, ENEA: Roma, 2009
[3] Wargocki, P. & Wyon, D.P., *Effects of HVAC on student performance*, ASHRAE journal, October 2006
[4] Source: municipality of Rome, V Department

Building maintenance: a technology for resource conservation

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Abstract

The Bruntland Report has for the first time formulated the concept of "sustainable development", defining it as "*development able to meet current needs without compromising future generations' ability to meet their own needs*"; such definition has emphasised not only the need to limit natural resources consumption and pollution emissions, but has also introduced the concept of (ethical) "responsibility" of man's action, both towards the natural environment and towards the anthropized one. Applying the sustainability objectives to the building process (project, construction, maintenance, management, decommissioning) – with the intention of reducing raw materials demand and wastes – forces one to reflect even on the maintenance process role. Maintenance can indeed be intended as a tool to build up a co-evolution project between man and nature, to be achieved by considering and managing maintenance-oriented buildings. Carrying out the maintainability requirement during the project phase becomes crucial since it guarantees, during the managing phase, that the maintenance intervention is carried out without any unforeseen or unpredictable collateral events characterized by a waste of financial and environmental resources. A number of researches and experimentations have been developed at the Department of Technologies for Built Environment in order to encourage the carrying out of the maintainability requirement during the project phase.
Keywords: building sustainability, design strategies, maintenance, maintenability, criteria.

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1 Introduction

Within the technological culture awareness has grown of the responsibility to give a contribution to the realization of a new development model, taking into account the delicate balances among *anthropos*, *physis* and *teknè*; in order to carry out such model, a crucial role is held by the capacity to activate a renewal based on a careful reflection upon the relationship between purposes and means.

In order to satisfy the needs, it becomes necessary to determine modalities that are not only effective but above all efficient, capable of optimizing the relationship between the employed means (natural, financial and human resources) and the obtained results (transformation/conservation of the built environment, safety, life quality etc).

The products of anthropic processes, more than being a collection of objects, are finally conceived – by dilating one's observation in space and time – as real energetic fluxes crossing our systems and creating unrulable processes.

The energy and matter flux crossing our systems to activate multiple processes is characterized by three critic phases: resource acquisition, production and use of goods and, at the final stage, disposal; if it is important to reduce the resource captation and the quantity of produced waste, it is also important to stop the current acceleration of the matter passage from resource to waste, by dilating as more as possible the good life time.

Within the architecture technology, with regard to the above three categories, the maintenance technology can give a fundamental contribution.

The necessity to stop, or at least to reduce, the waste of more and more limited and non renewable resources as well as to reduce the incalculable production of waste requires that technological research and experimentation should aim at the definition and control of compatible processes or at the achievement of sustainability goals by developing methods and tools directed to the implementation of an environmentally friendly building process (which guarantees a higher life quality by means of more careful planning in all the phases of resource absorption, to the realization and use of manufactures, and to their dismission).

In such a conceptual context, maintenance assumes a strategic role: the needs for a quality building basically find an answer in the maintenance approach, since it represents both the first tool for building knowledge (by means of which to carry out reliability and safety) and the strategic approach to sustainability (because it regulates the full life cycle). Maintenance can indeed act to slow down the passage from resource to waste, by dilating as more as possible the useful life time of components. The maintenance aiming at achieving a sustainable maximum system lifespan is substantially carried out by means of actions prolonging the life cycle. Indeed, the genesis and adjustment of a system should have as their primary objective the surviving of the system itself.

It is then necessary to define strategies, methods and tools meant to prolong the life cycle with a view to the resource preservation and to the maintenance/improvement of the building and still to build asset performances.

The maintenance and care concepts, intended to preserve and re-qualify building and nature, have a great cultural impact since they require a deep attention towards the building and natural heritage as a strategic choice of civilization and development.

2 Maintenance as a strategic vision

Maintenance technology aiming at sustainability can have a highly strategic role. Ferracuti [11] defined the importance of maintenance from an environmental point of view in a study dating back to the 90's: "*The recent interest in maintenance, which is new mainly within the many phenomena composing the physical-environmental changes of anthropized space, seems it has to be interpreted as an indication other from economical. On the contrary, it seems to acquire new meanings going beyond its current technical acceptation and significantly symbolizes a deep and apparently irreversible historical change. In such 'conjunction', somehow to be read as the end of the industrial age, maintenance and environment, or we should better say 'problematic maintenance' and 'problematic ecology', present many overlapping zones, almost until they identify and become each other's specification*".

Such convergence still hasn't been carefully evaluated and translated into managing politics recognizing the strategic role of maintenance for sustainability purposes. Maintenance and sustainability have a lot in common: they share a sort of 'platform' of values and objectives meant to assume a significant position within post-industrial ideology and culture.

Maintenance is then becoming more and more important against the simple materials management supporting the productive process; moreover, the awareness of the limited resources asks for the definition of a specific role for the maintenance economy.

In such perspective, the challenge of the care and maintenance-preservation of built environment inserts itself into the change processes which are typical of post-industrial society, and combines itself with sustainability and humanization.

An important aspect is the achievement of quality objectives. Looking for a global quality is certainly a synonym of care and maintenance. Mercedes Bresso [2] describes the real meaning of such quality: "*The way to give back quality to objects and to contrast (…) the tendency to disposability doesn't only consist in giving them back their beauty, but in another quality as well: permanence. Quality as a synonym of 'sense', which is care and maintenance. Not only movable assets are involved, but also real estate (houses, monuments) and the natural heritage: the richest societies in history have to guarantee maintenance to their own art towns and woods. Quality is strictly linked to the maintenance and care of the matters of the world*".

In order to develop a concept of quality related to the theme of duration and maintenance, the introduction of the principle of a legal responsibility for objects – defined as "*the seller's legal responsibility for damages caused by a defective object*" (D.E. del 26.7.1985) – requires a complex management (damage management and prevention) and, in the meantime, the concepts of risk,

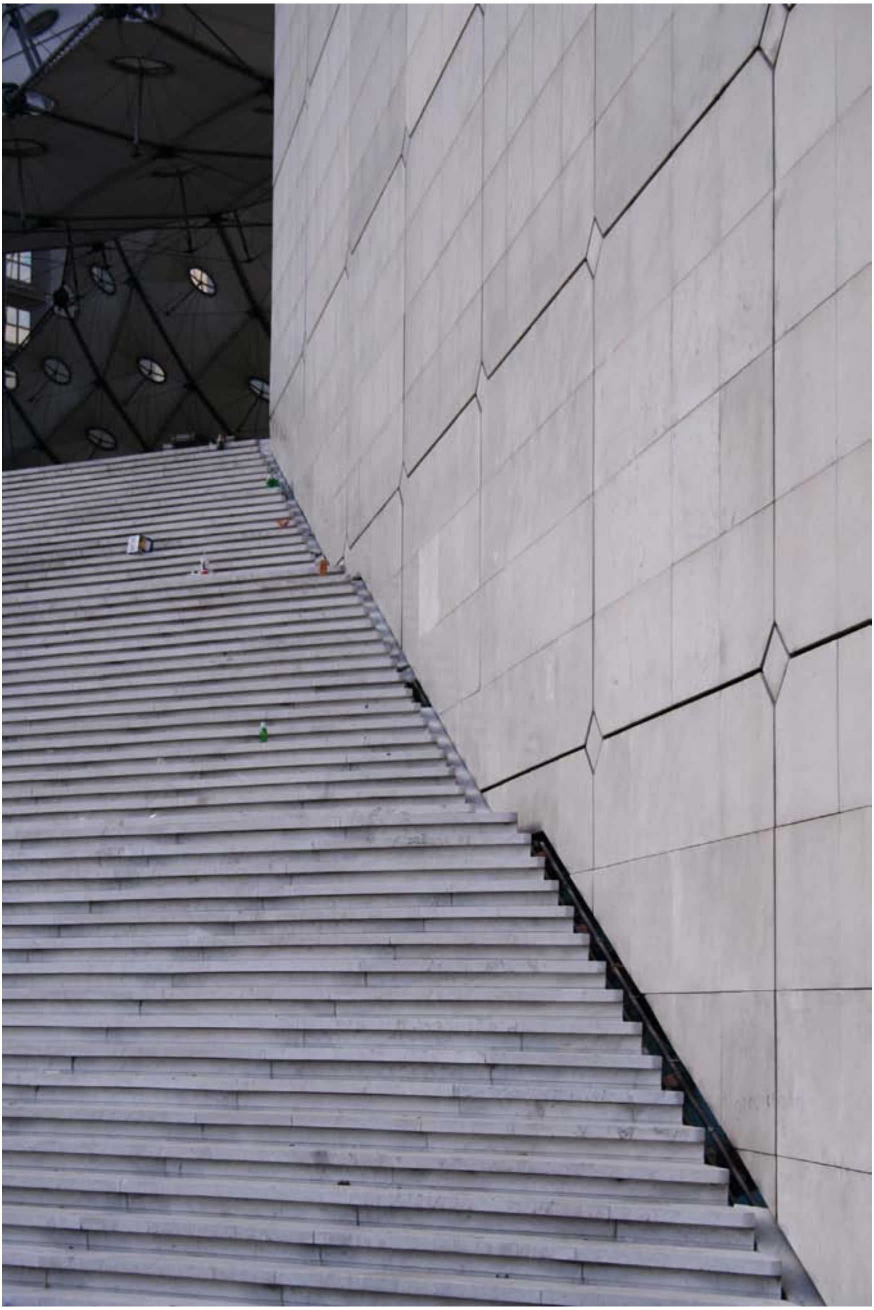

Figure 1: Paris, Grand Arche, self-cleaning capacity.

reliability and maintainability as project requirements. Such principle represents causes and effects of a higher and higher demand. It is evident an expansion of the production cycle, which tends to extend to the relationships with the product users in order guarantee the best usage.

Within the market, the concept of '*product-service'* has been more and more establishing itself having as a goal the quality maintenance even during usage. But, above all, a new role is taken by users – now considered as protagonists of the degradation process of used assets – who are now asked to undertake a direct responsibility in conservative interventions. The responsibility principle asks for the concept of service provided to users in order to increase the marginal utility of specific goods, in particular by means of maintenance interventions in as such way as they become 'excellence phenomena'.

In such a frame, maintenance should be interpreted as a complex process which replaces, and expands, the single random intervention. A great relevance is due not only to the purely technical aspects, but also to the interactions among users, so that the phenomenon assumes a socio-technical nature as well.

The same product to be maintained has to become a sort of socio-technical system because of the relationship to be established with users. Such a system expresses itself through a continuous process over time, explicating itself in different moments: the product realization, its conservation, its adjustment to the scenario where it typically stands.

Maintenance tends to become part of a "*new science*" which looks at the future highlighting the "purposes" in contraposition or, to better say, complementary to the "causes" determining the degradation phenomena as well as the obsolescence caused by use and ageing.

The time category can be considered as a context for analysing the possible convergences between maintenance technology and sustainability objectives. The research on the character of resource "permanence" and "conservation" guides us to re-discover the important care relationship with our environment, by means of a renewed approach to maintenance, intended as a crucial discipline to preserve the ecosystem balances.

Building maintenance represents a real strategy to govern complexity, aiming at the survival of all the built environment components; what is here underlined is that the maintenance approach represents the best it can be done for the care of building assets, being them traditionally different from the other assets because of a substantial specificity of their life-cycle: the service lifespan. Indeed, if the life-cycle of buildings is compared to the life-cycle of any industrial commodity or product, it is certainly among the longest; it is by exploiting this feature that maintenance can offer its most effective contribution to the macrosystems survival. If we consider a building and then evaluate, in terms of entropy balance, the phases of its life, it is possible to ascertain that the building reaches the highest positive entropy at the end of its construction, because of the great dissipation of energy and materials required; with time the building begins a transformation process whose velocity varies according to the varying physical characteristics of the constituting elements, of the environmental contest where it is set and of the use it is subjected to.

Figure 2: Madrid, Biblioteca de Usera, Facade access system.

If it is not prevented, the process of dissolution, began in its most vulnerable parts, extends to the overall sub-system, resulting in partial or total use inefficiency. To benefit from the sub-system it is necessary to rebuild it by increasing entropy by up to the initial one; instead, if during its life cycle maintenance cycles have been planned, by means of small increases in entropy it is possible to obtain a more than significant life extension.

Maintenance as a disciplinary context aiming at regulating the system life cycles can offer an important contribution by pursuing, at any scale, the system lifespan extension.

3 Integrating maintenance into the project

System duration, resource saving, waste production abatement: these are the objectives which can give an efficient answer starting by integrating the maintenance approach into the projecting phase.

Table 1: Maintainability general criteria.

Distinction between maintainability, lifetime and flexibility	Detailed and differentiated detection of the building elements (materials, components, sub-systems), on the basis of which to pursue the lifetime, maintainability and flexibility requirements.
Prevention from degradation, wear, physical obsolescence	Choice of building solutions suitable for preventing degradation, wear and physical obsolescence of the building constituting elements, according both to the external physical-environmental context where the building stands, both to its functions and use modes.
Lifetime congruence	Congruence assessment of the lifespan of materials setting up the building element or component.
Lifetime-flexibility coherence	Coherence test of the expected lifespan of elements with their needs and predictions of space use flexibility over time, and with the related consequences from a technical-operating point of view.
Technological obsolescence and flexibility	Flexibility assessment of technical volumes intended for housing fixtures and equipment, whose technological obsolescence is predictably quick.
Inspectionability	Inspectionability assessment of the drains - through which the technological network and the spaces housing fixtures and equipment to be periodically checked – pass.
Repairability, demountability, changeability	Repairability, demountability and changeability assessment of elements subjected to quick wearing or obsolescence process.
Functional non-interference	Non-interference assessment of the predictable maintenance activities presenting functions or actions to be normally performed in an office.
Technical non-interference	It is assessed if the single components (or networks) maintenance can be performed without impairing other systems or sub-systems functionality or integrity.
Demountability	Assessment of the building system and sub-system level of demountability, with particular attention to the "characteristics" and "state" on the part connections.
Testability	Assessment of the testability level of sub-systems (especially the networks), in order to allow the recognition of the "state" of functioning, degradation, use and failure.

The utility of such an integration results from the necessity to provide conceptual and operational tools aiming not only at minimizing the process and building object impacts, but also at regulating the duration dimension of the process itself. It is indeed necessary to implement a building and construction process aiming at controlling the building life-span in order to expand as much as possible the useful phase.

The relationship operationally linking the concepts of *duration* and *maintenance* is an "inverse" relationship: the higher the product capacity to maintain unaltered characteristics over time, the lower the exigencies of maintenance intervention. Being linked to this close relationship, duration and maintenance should be simultaneously projected starting from the planning phase.

Table 2: Maintainability sub-requirements.

Lifetime	It is the requirement which enhances the technological system or the sub-system to maintain its physical, performance and esthetical characteristics unaltered over time.
Non-soilability	It is the requirement which enhances the sub-system or the technical element to be hardly soilable, both for their intrinsic physical characteristics, both for any morphological-technical devices (for example, the pyramid trunk over the sixteenth century architraves of windows)
Self-cleaning capacity	It is the requirement which enhances the sub-system or component – especially with regard to its form and project characteristics – to provide autonomously, by using it or by means of the intervention of predicted or projected factors, to its own cleaning (for example, the steps of external stairs using rainwater to convey dirt to lateral drains).
Self-maintenance capacity	It is the requirement which enhances the sub-system to provide by its own to the maintenance exigencies (for example, the self-lubrification).
Cleanability	It is the requirement which enhances the sub-system or component to be easily cleaned, according to its morphological characteristics (for example, a curve fitting instead of a sharp bend, or a tile instead of plaster).
User maintainability	It is the requirement which enhances the component or sub-system to be maintainable by means of intervention which can be directly performed by the user.
Inspectionability	It is the requirement which enhances the sub-system, system or component to be easily inspected, even if periodically, in order to prevent or, in case of failure, to verify the state of conservation or functionality and so to permit repair or substitution (for example, networks of domestic fixtures).
Repairability	It is the requirement which enhances the sub-system, component or system to be repaired by a user, an enterprise or an external maintainer.
Demountability	It is the requirement which enhances the component to be easily demounted and removed from its usual collocation within the system it is part of, in order to be repaired somewhere else; such a requirement can be complementary or alternative to the requirement of "in situ" reparability.
Replaceability	It is the requirement which enhances the sub-system or component to be easily replaced in case of irreversible failure or in case of functional or technological obsolescence (for example, special attention should be paid to the projecting of technical spaces intended for housing fixtures or equipments prone to quick obsolescence.

A correct design should indeed makes choices which are conscious of the alternative - proposed for each material, component, sub-system - between a “long” life time (involving low maintenance) and a “limited” life time (involving higher levels of maintenance intervention). In this case, the project should also define modalities and contents.

A correct design should then formulate: conscious choices for each technological element of a manufactured, “project lifespan” (pre-valuable accordingly to the corresponding time and performance specifications) smartly integrated each other and systematically integrated with the corresponding predictions – which are project predictions as well – of the predictable maintenance interventions (in other words, of the maintainability characteristics of the product). For the purpose of the building system demounting and re-use/re-cycling of its constituent materials - once ended its life (or its usefulness, it is better to say) - it becomes convenient to predict the system constructive reversibility. In other terms, the asset design should include since its beginning a careful prediction of the morphologies and correlations which simplify demounting (which aims to maintenance and deconstruction, then to recycle or re-use).

Table 3: Maintainability and process variables.

Process fragmentation	Related to the organization of building production process, as well as the possible responsabilization of the protagonists of the different process phases (promoter, designer, builder, owner, user and maintainer) in relation to maintenance needs.
Legal-trial-like frame of the process	Related to the procedure and contract specifications on how to set and manage the productive process, and on how to evaluate and explicit the impact anyone of the chosen legal-trial-like frames can have from the point of view of future building asset maintainability .
Productive context	Related to the economic, productive and technological characteristics of the territory context, aiming at guaranteeing a concrete and contextualized maintainability to the designed product, in other words at guaranteeing that the product can be easily and economically maintained in that context.
User profile	It represents the set of variables - enjoyment title, spaces for private and public use, user activity related to use - which highlight the building product use modalities. All these variables involve a different attention to the maintainability requirement (during planning and construction) and different hypothesis for the user responsabilization during the definition of the maintenance project.
Physical-environmental context	It represents the set of variables caused by natural external agents (rain, hail, snow, lightning, sun, organic agents, earthquakes, etc), by intrinsic agents (moisture, chemical interaction among materials, etc), agents due to the building use and management (physical-technical loads and over-loads, fire, etc.) and by combined agents (rain and snow, acid rains, ultraviolet radiations and rain etc), which can all represent a factor of degradation, wear and physical obsolescence of the system or of the building technical elements.

In comparison with the optimization of the building life cycle, implementing the requirement of maintainability represents one of the fundamental contributions that maintenance approach can give to a sustainability-oriented project.

Several researches and experimentations have been developed in Department of Technologies for Built Environment in order to achieve such a requirement during the project phase: indeed, the "*general maintainability criteria*", and the maintenance requirement resulting in "*operating sub-requirements for the* project" - to be adopted according to the internal characteristics of the project and to be joined to and used together with the "process variables" - represent a useful tool to give an ethical dimension to the building systems design.

In such a study approach it becomes evident not only how the sub-requirement of maintainability represents the feature without which it is not possible to actuate solutions of use flexibility or to implement processes of constructive reversibility aiming to re-use and/or recycle at the end of the service life, but also how the concept according to which a maintenance intervention can be performed without having to develop other collateral unpredictable activities (characterized by depletion of economic and environmental resources) is part of the maintainability approach itself.

4 Innovation scenarios

In determining and controlling the extension of the building useful life cycle, the implementation of the maintenance process plays a crucial role, since its task is to prevent or remove degradation and obsolescence in order to guarantee functionality.

During the project phase, a *maintenance-oriented* approach in governing the life cycle duration requires, both for a new realization and for a re-qualification intervention, the implementation of the fundamental requirements of reliability, durability and maintainability.

The component *reliability* and the material *durability* allow one to reduce any possible failures and degradation, while *maintainability* facilitates the future interventions of maintenance without having to intervene upon close elements not subjected to failures. While projecting high levels of reliability and maintainability, in the managing phase the prediction will not be followed by a strong necessity of building maintenance interventions, simultaneously with an adequate maintainability level.

The implementation of the *maintainability* requirement permits to promote any possible re-qualification interventions necessary in case of an unbalance between the technical element performances and the users' changed exigency levels, allowing to make quick adjustment interventions upon the new levels of attended quality. The reversibility of the connections postulated by such a requirement also permits to decrease those impacts caused by building dismissal, since it allows to demolish with disassembling, and consequently to separate the constituting parts and the materials in order to their possible re-use or recycle.

In the maintenance approach, it is implicit the concept that a maintenance intervention can be performed without any collateral predictable or unpredictable activities characterized by the waste of financial and environmental resources. In comparison with the building life cycle optimization, the implementation of the maintainability requirement represents one of the crucial contributions which the maintenance approach can give to a sustainability-oriented project.

Within the government context and within the building elements life cycle extension, it is evident the presence of numerous and important new paths toward product and process innovation.

With regard to products, the necessity to contain the maintenance intervention frequency requires a renewed interest in the implemented materials lifespan, whose knowledge is really little, as well as in the innovation of building components functional to the constituting parts lifespan congruence. The relationships among the constituting parts have to be consistent with their own maintenance life cycles, so that interventions on components characterized by a shorter lifespan don't have to necessarily involve interventions upon those components having a longer lifespan; in such a way, all components could be replaced only at the end of their own life cycle.

The improvement of the overall lifespan performances, for example in an attic, can be obtained by verifying the single layers performances and the study of alternative techniques to optimize synergies and relationships.

In addition to paying attention to the relationships among materials, it is relevant their number reduction as well: the existence of materials each of which characterized by a specific lifespan and maintenance mode multiplies the forms and frequencies of intervention; a reduced variety of materials reduces and simplifies the number of replacement cycles.

Another interesting theme, often queued, is given by the necessity of a substantial re-thinking of the connection modes between the building parts and components, in order to guarantee their own reversibility in a manner that facilitates both the maintenance and the re-qualification interventions. The development of clean execution technologies can allow "*the possibility of linguistic flexibility and the building reversibility as well, both of them to be considered as fundamental paradigms in a building vision which considers the overall building life cycle - from the project phase up to the management, maintenance and disposal - its constituting components and materials*." (Campioli [3]).

An innovating process context concerns the development of methods and tools based on low cost technologies for diagnostic and monitoring processes supporting decisional processes related to interventions on buildings which require a deep knowledge of the material and constitutive nature and of any possible changes undergone over time.

Having such information can allow one to optimize the decisional processes and minimize superfluous actions or interventions that are not useful.

5 Conclusions

The research of the “permanence” and “resource conservation” character leads us to re-discover the important care relationship with our environment by means of a renewed approach to maintenance, conceived as a crucial discipline to regulate complex anthropic systems, and aiming not only at their own efficiency but also at the ecosystems balance preservation.

The necessity to implement a more careful lifespan regulation represents the main element, which is more associated with the maintenance culture than with the sustainable one, within an ideological and ethical dimension.

System lifespan, resource saving, waste abatement are the goals which, within the building system, can find an effective answer in the adoption of a maintenance approach during the project phase.

(Di Sivo Michele is the author of Sections 1 and 2; Ladiana Daniela of Sections 3 and 4)

References

[1] Ashby, W. R., Introduzione alla cibernetica, Einaudi, Torino, 1971.
[2] Bresso, M., Per un'economia ecologica, Nis, Roma, 1993.
[3] Campioli, A., Il contesto del progetto, Franco Angeli, Milano, 1993.
[4] Ciribini, G., Introduzione alla tecnologia del design, Franco Angeli, Milano. 1979.
[5] Ciribini, G., Tecnologia e progetto - Argomenti di cultura tecnologica della progettazione, Celid, Torino, 1984
[6] Directorate General for Development Evaluation Unit, Commission of the European Communities, Project Cycle Management Handbook, Geneve, March 2002.
[7] Di Sivo, M., Ladiana, D., Sicurezza e manutenzione dell’ambiente costruito, Alinea Editrice, Firenze, 2007.
[8] Di Sivo, M., Manutenzione Urbana, Alinea, Firenze, 2004.
[9] Dioguardi, G., I sistemi organizzativi, Bruno Mondadori, Milano. 2004.
[10] Dioguardi, G., Manutenzione d’eccellenza come strategia d’innovazione, In XX Congresso Nazionale AIMAN (Bologna, 20-21 February), 2003.
[11] Ferracuti, G., Tempo, qualità, manutenzione. Scritti sulla manutenzione edilizia, urbana e ambientale, Alinea, Firenze, 1994.
[12] Ladiana, D. (a cura di), Manutenzione e gestione sostenibile dell’ambiente urbano, Alinea Editrice, Firenze, 2007.
[13] Ladiana, D., Pianificazione della gestione e manutenzione delle infrastrutture urbane. L'approccio top-down e bottom-up, Alinea Editrice, Firenze, 2008.

Addition of polymeric wastes as pore formers in ceramic lightweight bricks

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Abstract

In the Argentine littoral region, ceramic brick masonry is generally used, with common bricks of 0.15 m thick for walls constituting the exterior of homes. This thickness is insufficient to achieve adequate hygroscopic and thermal isolation conditions because this area requires that such walls provide a minimum thickness of 0.30 m, considering the brick and plaster on both sides.

The objective of this work is to develop alleviating bricks, decreasing their density by the incorporation of macroscopic pores in the mass of the fired brick through solid wastes consumed during heat treatment, using conventional manufacturing procedures. In this way, the thermal insulation capacity will increase, without risky reductions in the resistance to compression or excessive increases in costs, and the amount of natural land use will be reduced.

Samples of 24 cm x 12 cm x 5 cm were obtained, from mixes of clays, like those used in traditional brick production (soil), with the addition of different waste materials: cinder and crushed expanded polystyrene of two different granulometries.

The utilized raw materials were characterized by several techniques: particle size analysis, optical and scanning electron microscopies and X-ray electron dispersion analysis. From the sintered bodies, parameters such as density, porosity, thermal conductivity and compression resistance were determined. A better behavior was observed when polymeric waste was used in respect of cinder utilization: greater resistance to compression and less thermal conductivity.
Keywords: wastes, ceramics, construction.

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1 Introduction

In the Argentine littoral region, ceramic brick masonry is generally used, with common bricks of 0.15 m thick for wall cladding and the exterior of homes. This thickness is insufficient to achieve adequate hygroscopic and thermal isolation conditions because this area requires that such walls provide a minimum thickness of 0.30 m, considering the brick and plaster on both sides.

For that reason, this work attempts to develop alleviating bricks, decreasing density by incorporating macroscopic pores in the mass of the fired brick through solid wastes consumed during heat treatment, using conventional manufacturing procedures.

Different combustibles and organic compounds have been used as pores formers in the commercial brick industry [1, 2]. Ducman and Kopar [3], for example, have carried out essays on clay bricks with 30% in volume of sawdust and paper industry mud as porosity generators. The bricks obtained, with a heat treatment of 920°C, resulted in structural ceramic materials, highly porous and with good properties for their specific use.

In previous works [4, 5], experiences that helped to determine the feasibility of incorporation of wastes into the brick structure, yielding a material with characteristics similar to commercial bricks were presented. In these experiments the possibility of incorporating up to 61% of waste, such as crushed expanded polystyrene and cinder, without significant changes in manufacturing procedures applied in local brickworks was determined.

One of the utilized wastes, expanded polystyrene (EPS), is a petroleum by-product that is usually applied in the construction industry for lightweight concrete, improving its characteristics in terms of thermal insulation, or as fuel for electricity generation or heating. While the EPS can be arranged in landfills without risk of contamination of soil or groundwater, this alternative disposal has the serious problem of generating excessive volumes. Another important source of polystyrene waste is from commercial or home use as protective packaging, both compact or pellets, and all the material that emerges in the process of cutting plates.

The cinder, on the other hand, is the disposal of furnace production of charcoal that is precariously sieved or shaken in brickworks, in order to separate the fraction of coal used as fuel to burn in the oven between layers of adobes. This separation is carried out with a metal mesh with an opening of about half an inch. This waste is available in abundant quantities and without charge. The cinder incorporation emerged from observing the techniques of assembling the oven, because it is used between layers of adobes to achieve a uniform temperature. The incorporation of these wastes allowed in all cases, to obtain bricks with increased porosity and reduced bulk density, which resulted in increasing the capacity of thermal insulation [4]. There were, also, reductions in resistance to compression, which can be explained by the relationship between this property and the porosity for brittle materials such as ceramics [6].

Figure 1: Photograph of the oven used for firing bricks in the study.

Bricks studied at different stages of this research were fired in traditional brickworks ovens, which are called “anthill” and which are formed by stacking of the bricks to be fired. Figure 1 shows a photograph of an assembled oven for firing the samples under study. Depending on where the mud is placed in the oven, the bricks acquire different tones: those from the top are clearer and more prone to collapse, those in the middle are of better quality and the bricks in the bottom are burned by excess heat and appear glued, twisted, dark color and are used for stuffing or grinding.

This work attempts to determine the influence of the incorporation of waste and the heat treatment, on the morphological and structural characteristics and mechanical properties of bricks made in pilot scale.

It is important to take into account, from the environmental point of view, that during the fire process of these mixtures, particulate and gaseous emissions from organic compound combustion can occur.

The emissions characterization from polystyrene combustion was carried out by S. Durlak et al [7]. They established that an important number of organic species are formed, when this material is heat treated in the range of 800°C to 1200°C, besides the expected combustion products such as CO, CO_2, and particulate matter. They also observed that there was an exponential decrease in the total number and mass of these organic species with the temperature increase.

In this work, the emission products (gas and particulate matter) produced during the heat treatment of clay and polystyrene mixtures were analyzed.

2 Experimental

Three samples were prepared using three different aggregates: polystyrene, milled polystyrene and cinder with average particles sizes of 2.5 mm, 0.5 mm and 30 μm. Mixtures of clay and aggregates were obtained with a dose volume of clay aggregation like 1:0.60, 1:0.65 and 1:0.95, respectively. Bricks without addition of any waste were also produced to be taken as patterns. The samples are identified as follows:

B: brick without aggregates

BC: brick with cinder addition.

BPc: brick with polystyrene with average grain sizes of 2.5 mm addition.

BPf: brick with polystyrene with average grain sizes of 0.5 mm addition.

The procedure of preparing the clay, molding and firing the bricks is described in a previous work [1]. All the bricks were shaped in the usual measures of commercial bricks of the area, which is 24 cm x 12 cm x 5cm.

During the firing of the bricks with waste incorporation, it was necessary to reduce the amount of wood burned in furnaces, because an excessive amount of stuck and twisted bricks was detected in places where usually bricks with acceptable characteristics were found. After this reduction, the bricks showed no major superficial defects, but in the interior of some of them, dark zones, indicative of high temperature firing, were still observed.

The powders to be used as raw material for the compact bodies' production and the fired samples obtained were characterized by several techniques: optical and scanning electron microscopies (SEM), particle size analysis, and Vickers microhardness measurements, among others. The samples granulometries were determined by optical and scanning electron microscopies.

Physical and mechanical properties of the bricks such as resistance to compression (IRAM 12586), apparent density and porosity (IRAM 12510), and thermal conductivity were evaluated on the obtained bricks.

The SEM analyses were carried out through a Phillips 515 scanning electronic microscope with an X-ray detector (EDAX-Phoenix).

The optical observations were made with Zeiss-Axiotech equipment with a Donpisha 3CCD camera and an image scanner.

The microhardness analyses were made with a Vickers indenter in a HMV-2000 Shimatzu equipment, using loads of 100 g during 10 sec in all cases.

The firing processes were characterized in relation to the possible gases and particulate matter emissions. This characterization was carried out in a lab oven analyzing the air quality in the superior exit of it, in the range of room temperature to 1100°C.

For this, air quality analyzer equipment, with laser technology for particulate matter analysis and electrochemical sensors for gases was used (XILIX-EPA 2001). It was located so that the emissions were analyzed a few seconds after they were produced. The contaminants determined were hydrocarbons in general (HC), carbon monoxide (CO), and particulate matter with particle size inferior to 10 μm (PM_{10}). The HC sensor detects all present hydrocarbons and calculates the concentration on the basis of four carbons in the molecule.

3 Results and discussion

In Figure 2 waste materials used as aggregates for obtaining the alleviating bricks, cinder and expanded polystyrene, are observed.

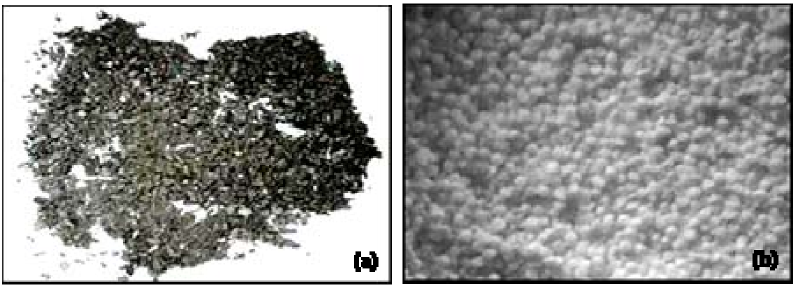


Figure 2: Photographs of the aggregates: (a) cinder (b) polystyrene.

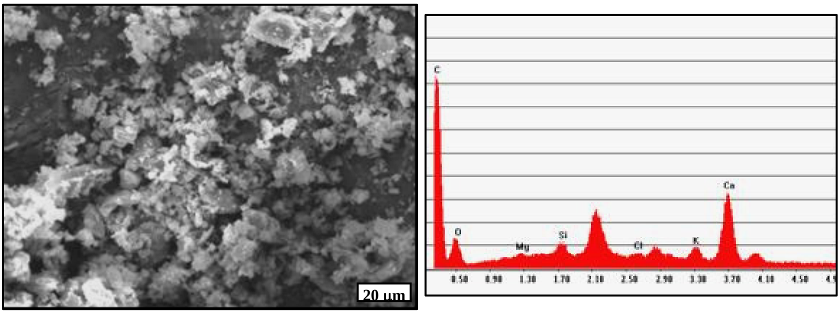


Figure 3: SEM photograph and EDS analysis of cinder.

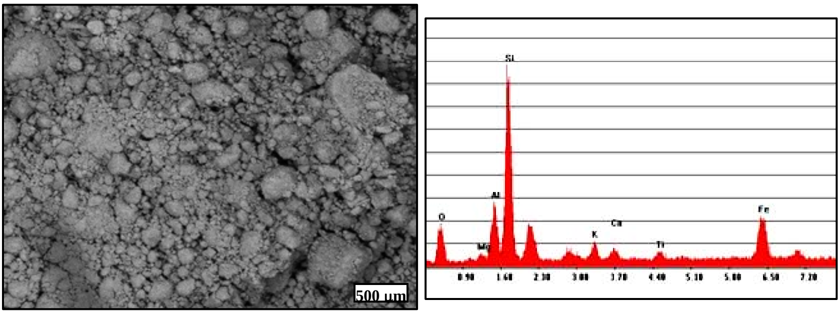


Figure 4: SEM photograph and EDS analysis of the used soil.

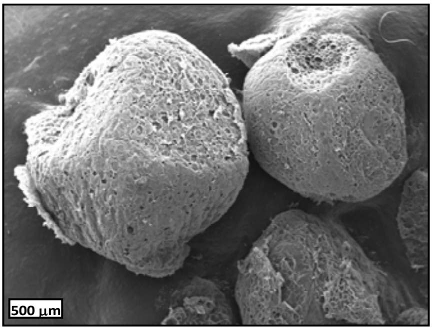
SEM and EDS analysis of the starting materials including the used clay (soil) are presented in Figures 3 and 4 and in Table 1.

As noted in these studies, the cinder material has approximately 70% of C, component that is removed during the firing of the brick, generating porosity in the resulting product. The remaining components will be incorporated into the brick structure in the great majority as oxides during the firing process.

It is observed that the base material used, is a common silicoaluminous soil, with a significant content of Fe, and smaller quantities of Mg, Ca, K and Ti. The high content of Fe gives intense reddish to the fired brick.

Table 1: EDS analysis of raw materials used: cinder and soil.

Oxide	Cinder [%]	Soil [%]
C	70,88	---
O	21,5	33,75
Mg	0,75	2,75
Si	1,03	32,04
Cl	0,46	---
K	0,87	2,29
Ca	4,5	1,68
Al	---	10,51
Fe	---	15,47
Ti	---	1,5



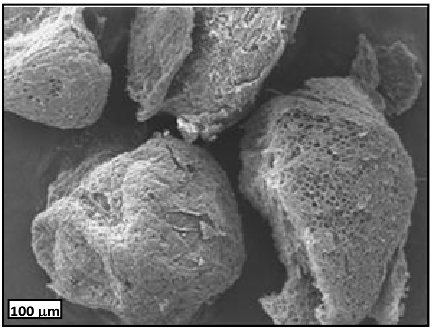


Figure 5: SEM photographs of the EPS particles of two different granulometries.

The other aggregate, polystyrene, was added in two different granulometries, average particle sizes of 2.5 mm and 0.5 mm. The larger aggregates have rounded homogeneous shape, while the smallest are heterogeneous in shape, as broken spheres, because of the milling process made for further use. This can be seen in the photographs of Figure 5, which presents the SEM analysis of both materials. The internal porous structure of both wastes is similar, and can be seen in Figure 6.

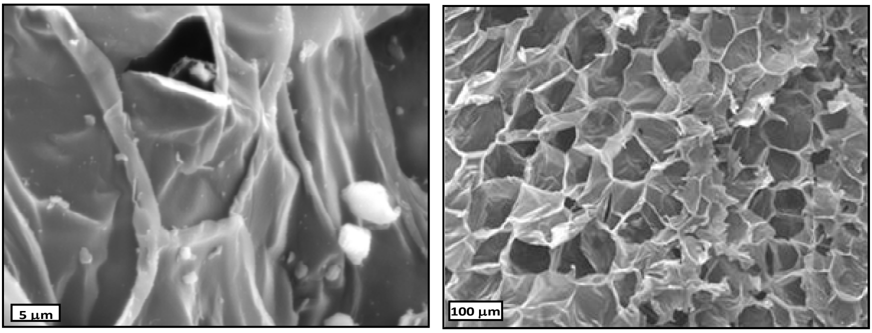


Figure 6: SEM photographs of the internal structure of polystyrene particles.

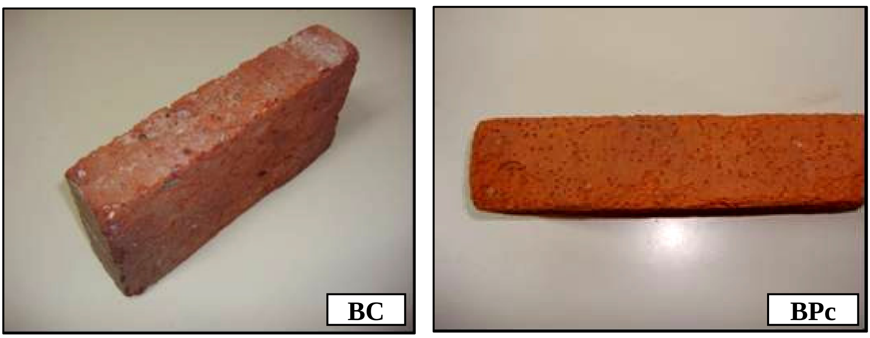


Figure 7: Brick obtained with cinder (BC) and polystyrene (BPc) aggregates.

Obtained bricks (Figure 7) have good external characteristics, with defined edges, without losing edges or corners. The bricks with the addition of polymers have an intense reddish coloration while those with added cinder have a more uneven coloration with darker areas.

These samples were cut for microscopic observation in order to determine differences in the morphology, distribution and internal structures of the pores formed.

Figure 8 shows SEM photographs taken in the three samples of bricks BC, BPc and BPf. As it can be seen, the samples BP have pore sizes according to the size of the added material, which suggests the idea of base structure densification simultaneously or before the combustion of the material, because otherwise, if the densification were later this would lead to a decrease in pore sizes and hence a shrinkage of the final product. For the BC sample, the internal morphology obtained is similar to those seen in common bricks without aggregates, with the presence of irregular pores.

By comparing the fine structure of the bricks, it can be detected in both samples of bricks BP, areas with different sintering degrees of the material which could be mainly grouped into two regions, those analyzed in the internal walls of the pores, and those studied in the rest of the brick, on the dense areas of the material.

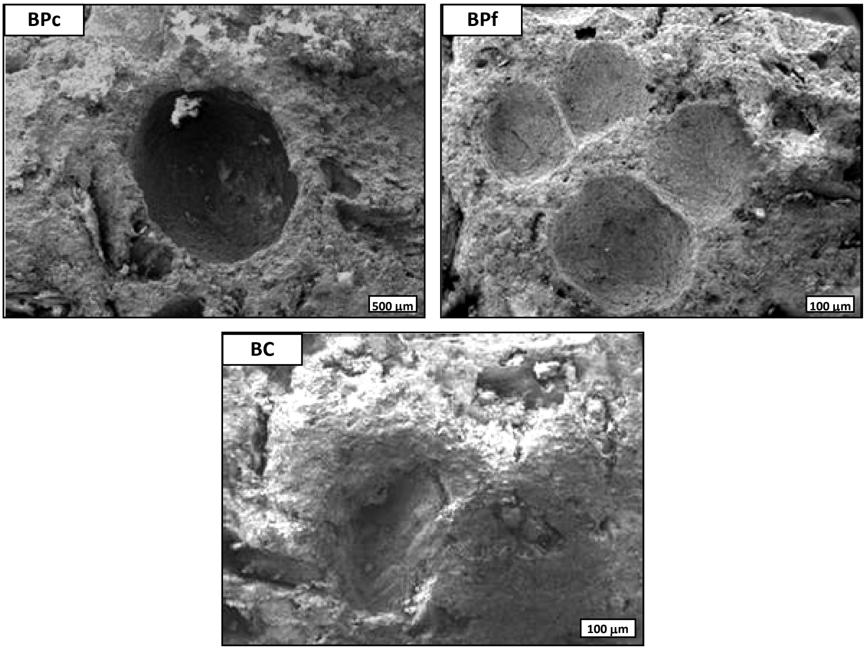
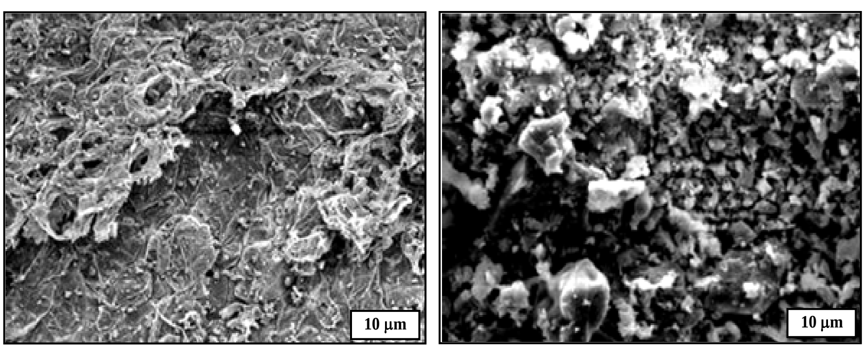


Figure 8: SEM photographs of the morphologies in samples BPc, BPf and BC.



(a) (b)

Figure 9: Analysis of the sintering degree of different regions of BP bricks. (a) Pores internal surface. (b) Dense material area.

Figure 9 shows the sintering characteristics found in these two regions. A higher degree of sintering in the internal areas of the pores is determined, which indicates the probable presence of higher temperatures in these regions. The internal surface of the pores presents the same aspect as the surface of EPS particles, like a superficial replica. This reinforces the mentioned idea that the clay matrix sintering is a previous step to the complete burning of EPS particles.

The tests carried out to determine the properties of the obtained bricks are shown in Table 2. This table summarizes the average results obtained for each of the specimens tested. These results are very encouraging because density was reduced from 1.50 g/cm^3 in common bricks to 1.03 g/cm^3 in BC bricks and for bricks including polystyrene densities of 1.09 and 1.15 were determined.

The local IRAM 12566 standard defines various categories of bricks according to their resistance to compression. For common bricks the value of compressive strength between 3.5 and 9.0 MPa classifies them as type 2, between 9.1 and 15.0 MPa as type 3 and type 4 corresponds to values greater than 15 MPa. Therefore BP bricks, according to this, are classified as type 2.

The parameters presented in Table 2 indicate that the compressive strength is lower in the bricks with the addition of wastes, while the porosities obtained are quite superior. It succeeded in getting brick with lower density, and hence the definition of "alleviating".

Table 2: Properties of the studies samples.

Brick	**Apparent density** [g/cm^3]	**Resistance to compression** [MPa]	**Thermal conductivity** [Kcal/hmºC]	**Porosity** [%]	**Hv** [Kg/mm^2]
B	1,50	10,4	0,568	26,5	---
BC	1,03	1,9	0,355	59,7	180
BPc	1,15	3,8	0,420	52,5	248
BPf	1,09	3,8	0,469	53,3	260

The macropores generated by the cinder calcination, as seen in the SEM analysis, show an angular and irregular shape, and branched cracks occur at the ends, that weaken the area. These angular shapes may also be a major focus of stress. On the contrary, in the case of macropores resulting from the calcinations of crushed expanded polystyrene, the cells have a regular spherical shape, with well defined boundaries and without cracks.

In the Vickers microhardness tests, well-defined indentations, without cracks, have been obtained, indicating the presence of tough structures [5]. In the case of sample B, cracks developed around the Vickers indents are observed, and it was impossible to determine a reproducible microhardness value. The obtained values show behavior consistent with the resistance to compression determined in the samples.

In relation to the thermal conductivity, the standard brick without wastes presents the higher value, and the lesser one corresponds to BC sample. The bricks BP show intermediate values. These values are in inverse correspondence with porosity values obtained.

The air quality analyses were carried out during heat treatments of samples obtained in the same conditions as the original bricks studied, but in pieces of small sizes. Figure 10 shows the results of PM10, CO and HC analyses, in two probes, one corresponds to sample B (soil) and the other corresponds to BPc sample. The highest levels of contaminants for sample containing EPS waste are observed, as it is expected. In the case of HC pollutant the maximum concentrations were determined in the range 470°C – 680°C. The observed values don´t reach in any case the standard legal values for these substances [9].

It is important to mention that the average levels of these compounds in the lab environment, without heat treatment process in course, are habitually 0.05 mg/m^3, 0.02 ppm and 0.1 ppm for PM10, CO and HC respectively.

Taking into account the results of these studies, it is possible to conclude that the incorporation of discarded EPS in clay mixtures, in the studied proportion, leads to obtaining alleviating ceramic bricks, with an adequate porosity, improving the superficial hardness and heat conductivity properties in relation to bricks obtained in the same experimental conditions but without wastes.

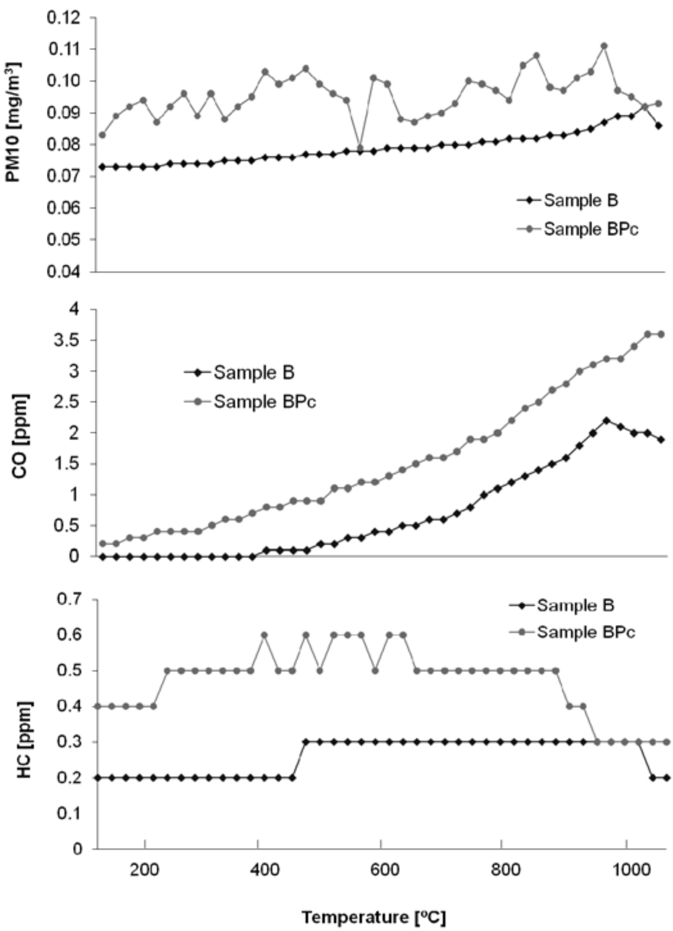


Figure 10: Air quality analyses during samples' heat treatment.

4 Conclusions

Alleviating bricks have been produced, by incorporating discarded cinder and wastes of expanded polystyrene in two different granulometries to ceramic bricks. The bricks obtained with addition of polymers show better characteristics than the bricks with carbon addition, due to the spherical shape of the macropores formed within the brick and the absence of cracks in its perimeter.

In order to determine the sintering degree of the material, the internal structures present on the bricks have been studied. A clear difference between the inner surfaces of the pores, with higher sintering degrees, in relation to the characteristics of the dense areas of the material, with less degrees of sintering is observed, suggesting the development of higher temperatures in regions where the burning of the waste material took place.

The addition of discarded EPS in clay mixtures during standard bricks production leads to obtaining alleviating ceramic bodies, with the formation of pores in an adequate proportion to improve the toughness, hardness and heat conductivity in relation to bricks without waste incorporation. The porosity values obtained classifies this material as ceramic bricks type II (local standard). The resistance to compression is lower than the standard products but its value is in the required commercial range.

The emissions of gases and particulate matter during the firing processes were characterized and they are below the standard legal values for these substances established in local norms.

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References

[1] Turgut P. and Algin H., Limestone dust and wood sawdust as brick material, *Building, and Environment* **42**, pp. 3399-3403, 2007.
[2] Demir I., Effect of organic residues addition on the technological properties of clay bricks, *Waste Management* 28**,** pp. 622-627, 2008.
[3] Ducman V. and Kopar T., Sawdust and paper making sludge as pore-forming agents for lightweight clay bricks source, *Industrial Ceramics* 21 **[2]**, pp. 81-86, 2001.
[4] Citroni J., González A., Carrasco M.F., Avendaño M., Botterón A., “Ladrillos cerámicos alivianados elaborados a partir de la utilización de residuos” en *VIII Congreso Latinoamericano de Patología de la Construcción y X Congreso de Control de Calidad en la Construcción*

(CONPAT 2005), Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de las Construcciones (ALCONPAT), (2005): pp. III.221 a III.227, Asunción. Paraguay.
[5] Citroni J., Rodríguez M., Carrasco M.F., Avendaño M., Sota J.D., Franzoy M.L. y Baldó E. "Desarrollo de ladrillos cerámicos alivianados a partir de la utilización de residues". *En IV Reunión PROCQMA.* San Rafael, Mendoza. ISBN 950-42-0056-7.
[6] Mindess S. and Young J. *Concrete*. Prentice. Hall, inc. Englewood, Cliffs. New Jersey. (1981) pp. 194-197.
[7] Durlak S., Biswas P., Shi J. and Bernhard M. *Environ. Sci. Technol.* (1998) 32, pp. 2301-2307.
[8] McColm I. Cracked Indent – Friend or Foe? Their Use in Toughness and Brittleness Characterization (Chapter V). *Ceramic Hardness, Ed. I. McColm*, Ed. Plenum Press, pp. 145-207, 1990.
[9] Environmental Polity Secretary *Decree 3395/96, Law 5965,* modified by *Resolution 242/97.* Argentina.

Ubicomp, urban space and landscape

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Abstract

This article discusses the use of Ubiquitous Computing (Ubicomp) systems in the design of urban revitalizations and refurbishments, using a specific methodology that considers Information Technology (IT) as one more instrument to harmonize the urban scene with the landscape, minimizing the impacts that those processes can bring. The hypothesis is that when IT components and services are strategically deployed – respecting the structure of the places – they can introduce computational resources that will allow human activities to better harmonize with the landscape. This hypothesis is based on Heidegger´s thoughts, when he reflects about the concept of "circumspection", meaning that when a technological apparatus works fine, its presence recedes in the human consciousness.

When components and services of *IT* are deployed strategically in a place – respecting its topological structure – those devices and services can add computational capabilities that improve human activities and make them integrated with the natural environment in a coherent and continual gradient of meaning, functionality and technological availability.

Human activities can better harmonize with nature by means of the use of ordinary objects and spatial elements that act as interfaces to access computational services, supporting the activities of a place, making them more efficient, producing less pollution, reducing their cost and energy consumption.

Mark Weiser's idea about the evolution of Ubicomp also reinforces that main hypothesis. According to him, the spread of computational resources in the environment through Ubicomp will bring a new era of calm technology in which human dwelling will be supported by intelligent environments. To test that hypothesis, a theoretical framework was developed and applied by architects in three urban projects, in cities of the United Kingdom and South Korea. Focusing on the potential within IT components to promote qualities such as territoriality, privacy, identity and ambience, three case studies were described and analyzed. There are reasons for appropriately deploying IT based on the nature of the place and the activities that happen within it. The results show that a less physically

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interfering design can be achieved. Therefore, the projects become more ecological and sustainable, with more chances to harmonize with the landscape. Conclusions are drawn and possible new research is suggested.

Keywords: ubiquitous computing, urban project, architecture.

1 Introduction

Ubiquitous Computing (Ubicomp) is the model of human/computer interaction in which a computational capacity and its resources are accessed through the devices and services of Information Technology (IT) integrated in the environment. They are integrated by means of being embedded in ordinary objects and spaces that are tuned into interfaces so as to allow interaction with people in order to detect, respond and represent some of their needs. The most common devices and services in a Ubicomp System are microprocessors, sensors, displays, actuators and links, among others. Due to this new paradigm of integration with the space, the activities can be accurately scrutinized in terms of types of users, frequency of use, origin and destiny, personal preferences, special needs and other characteristics. This information can trigger different types of arrays of spatial elements and equipments so as to promote quick changing in the built environment, for instance, to adapt the function of the environment to new activities, or to save energy, or to improve the security, the user´s satisfaction or merely to monitor the equipments.

2 Mark Weiser and the disappearing of technology

In the middle of the 1990s, Mark Weiser coined the term Ubiquitous Computing to refer to the conjoint of technologies that would allow that, in the near future, the computing resources would be installed in the environment and used by people within the places. That usage, according to Weiser, would not happen by means of stressing and complicating interactions, but, instead, it would be an intuitive and intelligent manner to use the components, with lots of computer spread to support the user in her/his activities, every time, everywhere. Using as interfaces the quotidian objects and spaces to access the spread computing resources, the user could thus concentrate himself better and easily in her/his main activities, putting in the periphery of her/his attention what would be out of the original focus in that moment. Weiser summarized that idea, deeming that one day computing would spread and embed in the environment. About this, he commented: *"The most profound technologies are those that disappear. They weave themselves into the fabric of the everyday life until they are indistinguishable from it"* [1]. He exemplified that comment using nowadays trivial facts as the use of machines that are integrating our lives, such as cars, phones and other gadgets, which we do not pay attention to. He named this technological era "Calm Technology", a future mentality, where interfaces would be designed to be intuitively used because of the existence of new technical achievements, of a massive miniaturization of components, a cost reduction and an intelligent design of those systems.

3 Disappearing is a psychological condition

However Weiser, despite all the reasons of industrial design, recognized that that new era of calm technology was a consequence from a human need. He commented that: “*Such a disappearance is a fundamental consequence not of technology, but of human psychology. Whenever people learn something sufficiently well, they cease to be aware of it. (…) Computer scientist, economist, and Novelist Herb Simon calls this phenomenon ‘compiling’; philosopher Michael Polanyi calls it the ‘tacit dimension’; psychologist TK Gibson calls it ‘visual invariants’; philosophers Georg Gadamer and Martin Heidegger call it ‘the horizon’ and the ‘ready-to-hand’, John Seely Brown at PARC calls it the ‘periphery’. All say, in essence, that only when things disappear in this way are we freed to use them without thinking and so to focus beyond them on new goals.”*[1]

4 Weiser cites Heidegger: the transparency of the ready-to-hand

This conceptual similarity with others thinkers allow us to understand, specifically through Heidegger´s thoughts, the consequences of a common vision about technology, at the same time helping us to review other spatial implications [2] for the human being associated with the natural and built environment. To Heidegger [3], the term “*ready-to-hand*” points out a kind of entity that was turned into an *equipment* by means of human labor. So, elements of nature are “*present-at-hand*”, which means they are not for a specific purpose, but when human being applies over them some labor, they are turned into *equipment*. The essence of equipment is being for something, which means, its essence is its finality. Heidegger observed that when we use equipment, our consciousness becomes subordinated to its function and it starts to integrate its usage itself. He called this “*manipulating*” which means a primeval understanding that we can have about the entities “*ready-to-hand*”. This way to understand the world differs far from the second hand way to understand, when we know something but without ever having tried it.

5 Characteristics of equipment in Heidegger

To Heidegger, the meaning of an object ready-to-hand emerges from its links to others objects ready-to-hand which provides support to the human being. Since those objects are called equipment, he called these links among objects as the “*equipmental nexus of the things*” [3], meaning that what is an object will depend upon of its contextual functionality more than its cultural meaning, given in the time or in the space. When we are using a ready-to-hand object, we are more concerned and absorbed with our goal than with the equipment itself. Thus, when ready-to-hand objects are genuinely effective, they become “*transparent*” [4] and unnoticed for us. In this situation, we are not busying our mind with their immediate presence and our consciousness becomes a whole with the utensil we are using exactly by means of the usage. However if, instead, it breaks down and stop functioning, it starts occupying again our mind and becomes visible for us, conspicuous, requiring our attention to fix it. Our *equipmental nexus of things* also causes in our existence a kind of daily perceptual experience about the environment. Heidegger called it "*circumspection*" which means a kind of careful vision of things that do not imply in a deliberated attention in what is being done. It provokes in the subject a mental attitude where the perception of herself/himself is indistinguishable from the totality she/he makes with the action itself and the use of the equipment. This mental state is similar to the attitude that many professionals can have due to the accumulation of knowledge or skill with the time. That gives them not the mechanical appearance of a robot but, instead, extreme simplicity while operating equipments. At the same time, they will look as they were forgotten of themselves [4].

6 Natural and built places as equipment

By using those concepts it will be reasonable understand that both architectural spaces [5] and urban spaces [6] can be grasped as an identical category of concepts, that means, they are linked equipments which last goal would be to permit to the human to dwell on earth. Natural landscape is, in this way, a background composed by "*present-at-hand*" entities, over which built spaces are understood as figures. Concerning to architectural and urban studies Norberg-Schulz emphasized that the symbolic value of the built space, related to the landscape [7] is a relation similar to the *figure and background,* concept which he borrowed from Gestalt. It means that the idea that of the totality of the human environment is much more complex than the simple idea that that totality is an addition of those two terms. Norberg-Schulz pointed out that was necessary to understand that the structure of the environment is similar to a universe of linked vertices, which would be the natural and the human built places. The links among both domains represent a continual graduation from the natural to the built environment. Thus, the concept of harmonization would be much more related to a gradual and continual link of values given by human being from natural to human environment structures than a quest for a new kind of aesthetic research. We need now to understand how such universe of links can be integrated by components of IT in order to better strength and improve the continuity from the natural to human domain using Ubicomp.

7 Ontology of natural and built places

Maybe the first step to understand how natural and built places could be taken as having the same structure is asking about their similarity in their ontology. When we consider places as equipage to dwell, we should realize about them as equipmental nexus (Fig. 1).

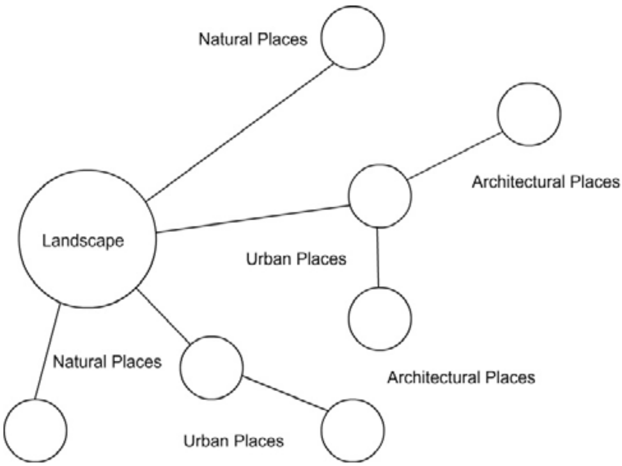

Figure 1: Equipmental nexus of places.

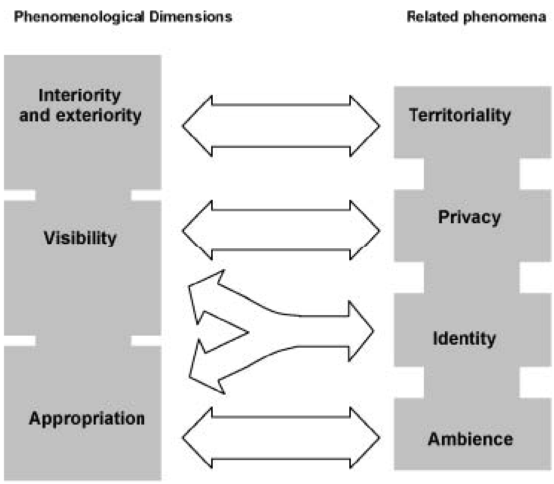

Figure 2: Ontology of places according to Malard [5].

Through the *equipmental nexus* analysis, natural landscape can be taken as a bigger group that are linked to other more complex structures which, by their turn, are linked to natural and built places (those formers as architectural and urban places). To all those spaces inhabited by human beings, maybe it is possible that the ontological principles pointed out by Malard [5] would be useful to explain how people differentiate spaces into places and attribute them their qualities (Fig. 2) as territoriality, privacy, identity and ambience, which are common to natural and built places. When there is no way to the humans to remain within the natural landscape, being it unfit to live on, we will call them as uninhabitable areas, but we can take them as frames to natural and built places [8].

If it is right to assume, as Heidegger did, that when equipments broken down then they start occupying with more visibility our attention, reflecting about places, it would be the absence or dysfunction of the spatial elements of a place what will affect those mentioned qualities [5]. Then, detecting which spatial elements are broken down is a necessary task to improve the qualities of places and detecting them can reveal common categories related to those qualities. We need now to clarify what are the spatial elements of places and how they are related to territoriality, privacy, identity and ambience.

8 Topology of natural and built places

The interiority of a place is defined when *enclosures* (5) delimitates an *internal area* (2), which has a *centrality* (1). These elements qualify the place, turning its interior in a *territory*. Simultaneously, the association of *enclosures* plus the *entrances* (6) controls the manner through which the place is connected to the exterior, specifying its *privacy* and the way it can be visually *identified* from outside. Human actions inside the delimited internal area in both horizontal and vertical directions would define simultaneously the *identity* and the appropriation, showing off how people care about that place dedicating it attention and making it with an *ambience*.

That topology explains how natural and built places can have their elements analyzed through the similar categories in a manner that that analysis puts out how those elements can be correlated to the qualities as *territoriality, privacy, identity and ambience*.

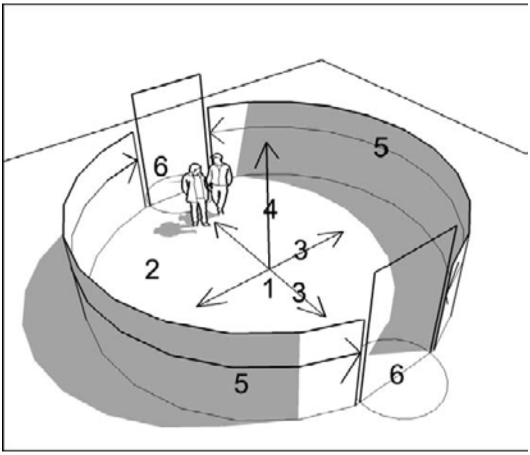

Figure 3: Topological elements of a place studied by Souza [9]: 1) center; 2) internal area; 3) horizontal directions; 4) vertical directions; 5) enclosures, 6) entrances.

9 Environmental discontinuity

It is necessary now to clarify how natural landscape and natural and built places can harmonize through which other. Norberg-Schulz [7] pointed out the need of a conceptual definition similar to what Heidegger called the equipmental nexus, meaning a connection between the internal world of a place and its coherent transition towards the outside natural world. So far we have mentioned that that transition can be grasped as a coherent and continual transition that can be classified according at least three categories: symbolic, functional and technological. Through those categories one can see and analyze the places coherently, graduating from their interior to their exterior but always supporting their main function that is being places to dwell. Thus, we can understand that the harmonization between natural and built places, between landscape and city, would depends upon that graduation, which means it would be the coherency among their symbolic elements, their functional factors and resources, their building resources and technological scene. The whole environment, when we are craving for integrity, would propitiate that the built places, in this way, give us fruition, functionality and would permit being arguable about its build resources while providing a meaningful connection with the natural world. The environmental discontinuity would be the main problem which results in pollution, visual chaos, disorientation and lack of identity in the great urban centers. In the private life nowadays that discontinuity id given by the stylish of the houses of the *parvenu,* with their interiors looking as museums, detached of the world and isolated, demonstrating the quotation which says *"my home is my castle"*. Those insulars portions of disconnected places, scattered over the world, would obstruct the environmental continuity as nodules of contrast, framed by meaningless spaces as tiresomely long high-ways and uninhabitable areas with landscapes destroyed by human exploitation.

10 Architects concerned with better places through Ubicomp

According to John Thackara [10] we live, from some years to nowadays, in a technological dilemma where the most of what is being produced by industries is a response to the fact that the technology allow it to be made, more than a response to real demands of the society. Regarding the truth supporting that point of view, we can say that the focus of the technological development should be the value that the industrial development add to our life more than the innovation it can introduces, showing off itself as a "*genial solutions*". In other words, our industries are more concerned in how to make things than answering why those things were made, the meaning of those in our daily life.

Reflecting about the use of IT in the last 10 years, some authors considered its influence over the society, some emphasizing internet resources, wondering whether that connectivity would shorten physical distances [11] and create a generalized interactivity based in the pervasiveness of the technology [12]. Using metaphors based in the common sense about *space* and *place,* those authors referred to the web connection interfaces as an electronic space or cyberspace, that will dissolve the physical place and the city [11]. With the *Virtual Reality Technology,* those authors imagined that cyberspace would finally offer the subtleness of immersive communication, possible so far in the real world, making unnecessary the real places. Mitchel [13] formulates that there was, in that moment, a crisis in the physical dimension of the place, the region and the city: "Net negates geometry", he said. However, some years later, many of those deterministic predictions did not happen and, instead, at present IT is being studied as part of the material production of spaces, reinforcing the importance of localities and recursively interfering over the design of places. In this sense, reversely the idea of Mitchel, McCullough stated that [14] "*contextual computing starts from physical geometry*" of the places. Searching for real demands to be responded with the usage of IT applied in the places, architects and environmental designers now are concerned simultaneously about the improvement in the physical conditions and in the communications that support activities in the places. The framework that we are introducing here tries to justify the use of Ubicomp as a search of harmonization between places and landscape. To do so it will need to focus on an ecological view of information.

11 Conclusion: the framework

Using the paradigm that the modifications that living systems do in the environment belongs to a linguistic domain [15], we understand that the term "*information*" should not be used as its mechanical conception in Shannon [16] to whom it was conveyer of meaning. Quite the opposite, spatial organization created by living beings, in the natural environment or built one are tied up with their skill to co-operate among them and adapt themselves. The language, a human privilege, depends upon the concrete environment to create meaning, it means, *space is itself information* [9]. Humberto Maturana [17] has exemplified the linguistic domains of living systems in the environment as the following picture.

Thus, it is possible to infer that, by an external observer point of view, the physical characteristics of the environment, summed up with the history of its transformations, could be considered as part of a linguistic domain. The skill of a living being to modify its environment to adapt it and survive could be

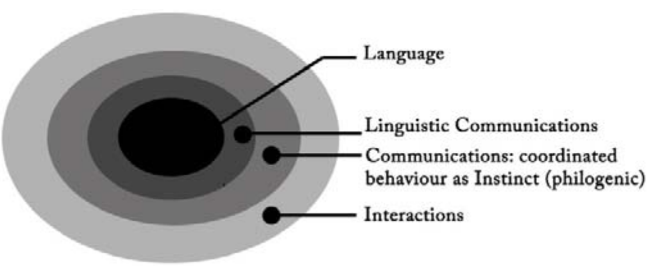

Figure 4: Linguistic domains in the interaction between living systems and their environment [9].

understood as a particular kind of communicative behavior, specified through the spatial interactions. Since the environment is modified by the systems that live on it, also could be said that this situation is also communication. But does not mean that the space conveys information: a spatial element is, itself, information.
Analysis

Thus, it would be possible to wonder how the spatial elements are correlated to an IT component aiming to reinforce the qualities of places. An analysis [9] has demonstrate that the components of IT, as the sensors, microprocessors, electronic tags, communication links, among others, can be regarded in relation of topological situations which interferes over the qualities of the places. That permitted describing the IT components by means of their positive potential to support local qualities. The following table is part of that analysis [9].

	Territoriality	Privacy	Identity		Ambience
	Interiority and exteriority	Visibility	Visibility	Appropriation	Appropriation
Sensors detect action, measure physical quantities such as temperature, pressure or loudness and convert it into an electronic signal of some kind.	Related to interiority, for instance, when they are able to sense whether a moveable element is inside or outside a pre-established territorial delimitations.	Sensors are related to privacy by sensing proximity, invasion, thus permitting surveillance, and informing when an action is needed to react against invasion.	Sensors could permit Identification of visible users according their tag. They could also Permit users to identify specific elements according to specific concerns.	By the use of 'gesture sensing' technology, they could Sense mechanical movements, adjustments in order to tune the system, distinguishing how the user appropriates the place.	These could integrate systems in order to sense changes in temperature, pressure, light, when the user tunes the system, allowing information about how the user appropriates the place to be gathered. These would permit the creation of collections of info about those variables in order to trigger actions.

Figure 5: Table of correlation between the IT component and the qualities of a place [9].

Using the previous concepts, a framework was created to help the design of the use of IT by architects in the project of urban places. That framework consisted by asking the architects to identify conflicts between spatial elements malfunctioning and the activities they should support. Thus, using the scheme showed in, they explained how the missing or broken down elements were interfering in the four qualities (Fig. 2). Detecting the missing element and interpreting how its interferences were related to spatial attributes, the architects established how a component could be articulated to the space in a system to support the affected activities, using the table above.

By the years of 2005 to 2007, three urban refurbishments were made by architects in UK using the framework described to support the design of the use of IT in the place. It was studied which limits were imposed to qualitative solutions when the approach was used partially or in its integrity. A first tem (team A) tried to find pragmatically local problems to given solutions based only in the reflections related to the qualities of place (Fig. 2) without any other theoretical frame. The second team (team B) identified the missing or broken spatial elements in conflict with the activities, given solutions with IT but partially using the framework, which in that time ended with the distinction of elements and services of IT able to be applied in the place (elements to sense the place, to act in the place and to represent the place). The third team (team C) used the whole framework here described, deploying IT components and designing complete systems of Ubicomp. The analyses of the projects before mentioned has demonstrated that team C used less physical interfering solutions, while team A provided the most intrusive solution, with many physical and expensive recasts.

Those experiments confirmed Mark Weiser's ideas, observing that when an Ubicomp system is designed according to the logic of activities and spatial structure of a place – as the solution of team C – then physical interferences can be minimized and the technology applied tends to disappear, not being perceived. When otherwise this not happen, as in the solution of team A, the solutions look only as an attempt to exhibit the technological apparatus without a correct concern with local qualities, imprinting a feeling of discontinuation in the environment, making that the function and fruition of the place were stuck in the place.

Reflecting about those experiments, we concluded that when we design creating an environmental continuity with the discrete use of Ubicomp, the harmonization between built elements and the landscape probably is improved by means of the graduation of technological, functional aspects and symbolic value. In this manner, Ubicomp could participate of this process of harmonization between the human and the natural, demanding new research where, instead of posing itself between those former two universes separating them, IT will act as a bridge, and linking the human presence with the world.

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References

[1] Weiser, M., *The computer for the 21st Century*, in *ACM SIGMOBILE: Mobile Computing and Communications Review.* 1999.
[2] Malpas, J., *Heidegger's Topology - Being, Place, World*. 2007: MIT press.
[3] Heidegger, M., *Being and Time*. 1962, London: SCM Press.
[4] Dreyfuss, H.L., *Being-in-the-World: A Commentary on Heidegger's Being and Time*. 1991, Massachusetts: MIT Press.

[5] Malard, M.L., *Brazilian Low Cost Housing: Interactions and Conflicts between Residents and Dwellings*, in *Architectural Studies*. 1992, University of Sheffield: Sheffield. p. 239.
[6] Souza, R.C., *A rua e a sua habitabilidade: Moradores e Espaço Urbano em Situação de Conflito*, in *Curso de Mestrado em Arquitetura da Escola de Arquitetura da Universidade Federal de Minas Gerais*. 1998, Universidade Federal de Minas Gerais Belo Horizonte. p. 172.
[7] Norberg-Schulz, C., *Genius loci: towards a phenomenology of architecture* 1980, New York: Rizzoli.
[8] Norberg-Schulz, C., *Existence, space and architecture* 1971, London: Studio Visa.
[9] Souza, R.C., *A place-theoretical Framework for the development of IT in urban spaces*, in *Architecture*. 2008, The University of Sheffield: Sheffield. p. 315.
[10] Thackara, J. *The design challenge of pervasive computing*. In *Computer Human Interaction Forum (CHI 2000)*. 2000: The Hague.
[11] Virilio, P., *The third interval: a critical transition,* in *Rethinkin Technologies*, Andermatt-Conley, Editor. 1993, University of Minnesota: London. p. 3-10.
[12] Stefik, M., *Internet dreams: archetypes, myths and metaphors*. 1996, Cambridge: MIT press.
[13] Mitchel, W., *City of Bits - Space, Place and the Infobahn*. 1995, MA: Cambridge: MIT press.
[14] McCullough, M., *Digital Ground: architecture, pervasive computing and environmental knowing*. 2004: Massachusetts Institute of Technology - MIT Press.
[15] Maturana, H., *Biology of Language: The Epistemology of Reality*, in *Psychology and Biology of Language and Thought: Essays in Honor of Eric Lenneberg*, G.A. Miller, and Elizabeth Lenneberg, Editor. 1978, Academic Press: New York. p. 27-63.
[16] Shannon, C. and W. Weaver, *The Mathematical Theory of Communication*. 1949, Urbana: University of Illinois Press.
[17] Maturana, H., *Autopoiesis and Cognition: The realization of the Living*. 1980, Boston: Reidel Publishing Co.

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Evolution of the American Zero Energy House

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Abstract

Interest in reducing energy use in buildings began in the U.S. in the 1930s with work on solar heated structures at the Massachusetts Institute of Technology. With the energy crises in the 1970s, efforts were made to reduce energy use in U.S. homes. Passive solar design involved insulated south oriented glazing systems, Trombe walls, sunspaces, flat plate collectors, thermal mass, and optimally designed overhangs. It was discovered that by reducing building cooling and heating needs through energy conservation while implementing passive solar strategies the lowest energy use at a lower incremental cost could be achieved. Super-insulated homes were successful at minimizing heat loss and gain and the subsequent load on mechanical systems, but interest subsided as energy prices dropped in the 1980s. The passive solar homes and super-insulation movements addressed passive heating and cooling, but other home energy end uses were not addressed. Throughout the late 1980s, the cost of solid state solar electricity production with photovoltaic cells declined and become affordable for individual house distributed generation. This paper is a survey of the evolution of the Zero Energy House in the U.S. and the related technologies from its experimental beginnings to its realization in several recent projects.
Keywords: energy efficiency, sustainable buildings, ZEH, solar, renewable energy.

1 Introduction

Today's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Of the millions of buildings in the U.S. most were built in 1979 and prior, providing us the tremendous opportunity to reduce the nation's energy consumption by increasing the efficiency of aging buildings through retrofits or replacements as needed.

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Additionally, to address the projected increase in new construction it is essential that we improve the techniques and strategies of how we design, build, and operate our buildings for the future. In 2006, the Residential Sector consumed 37 percent of all electricity produced in the United States. The Commercial Sector consumed 36 percent and electricity expenditures made up 67 percent of total Buildings Sector energy expenditures. According to the US Department of Energy, electricity energy consumption in the sector is increasing while natural gas and petroleum energy consumption are declining and less than 2 percent of annual Buildings Sector energy consumption has been from renewable energy, each year since 1997. Space heating, lighting, and space cooling are the largest energy end-uses in the building sector with water heating and electronics in the next two spots. From this data it is clear that the design and construction of energy efficient buildings offers tangible benefits to building owners and occupants and the U.S. as a whole. Building owners can lower their energy costs by 50 percent or more while lessening maintenance and capital costs. In the process, building occupants will realize increased comfort, health and productivity and the country will conserve energy resources and enjoy cleaner air and a healthier environment [1].

2 Energy efficient buildings in the U.S.

Attempts at reducing energy use in buildings began in the U.S. just before World War II with work at the Massachusetts Institute of Technology on solar heated structures. The MIT Solar IV built in the late 1950s was the third test house designed by a group of engineers known as the Space Heating Committee of the Solar Energy Conversion Project, which was founded in 1938. Unlike modern photovoltaic solar cells, the cells on the MIT house were not designed to generate electricity. A 640-square foot collector tilted at a 60 degree angle provided for 57% of the building's heat during winter. Heat was stored in two basement water tanks of 1500 and 275 gallons: during the winter, the larger tank was heated by the circulation of solar heated water from the roof collectors. Water from the tank circulated through the coil of a heat exchanger to warm air blown through the house. Water from the smaller tank was heated by an oil burner and used for supplementary heat on extra cold or cloudy days. When summer came, the smaller tank was connected to the roof collectors to provide hot water for domestic use, and a low capacity refrigerator cooled the water in the larger tank to provide air conditioning. After collecting data for three heating seasons, MIT decided to sell the house to a private owner in 1962. Since no knowledgeable service organization existed to maintain the unique solar heating system, the unit was removed, and a conventional heating unit was installed. [2]

During the energy crises of the 1970s, for the first time, a concerted effort was made to reduce energy use in U.S. homes. Books like Ed Mazria's *Passive Solar Energy Book* were written to make the concepts of passive solar design accessible to professionals and the average person alike. Mazria writes in the acknowledgements that at the time he began writing the book in 1975 that "information concerning passive solar design was virtually non-existent". Passive solar design utilized insulated south oriented glazing systems, Trombe walls, flat plate collectors and sunspaces. Roof overhangs were once again thought of as a necessary feature requiring precise design. The properties of materials, their thermal mass, and reflectivity became important considerations as did the natural circumstances of the site and its micro-climate.

The 2100 sq.ft. Kelbaugh House built in Princeton, New Jersey [40^0 N. Latitude] is representative of passive solar buildings of that era. The house features a Trombe wall solar collection system consisting of a 15" concrete wall, painted black with two sheets of double strength window glass placed in front of the wall. Heating is mainly accomplished by radiation and convection from the inside face of the Trombe wall. Vents located at the top and bottom of the wall also allow for daytime heating by convection over the warm outside facing side of the wall. According to data gathered over a one year period from 1975 -1976 the passive system reduced space heating costs by 76%.[3]

At about the same time researchers at the University of Illinois were trying to reduce the heating and cooling loads in buildings by constructing a highly insulated envelope. The "Low Cal House" designed by Wayne Schick stood for "low calorie." Schick did a computational study of how much energy you could save with high levels of thermal insulation, airtight construction and heat recovery ventilation using air-to-air heat exchangers. The proposed insulation values were R-60 ceilings, R-30 walls and R-20 crawlspace floors. The Lo-Cal house was designed to illustrate how good planning and construction detailing could reduce residential energy consumption. Although never built, the Lo-Cal House attracted a great deal of national publicity and was influential in subsequent built projects like The Leger House in Pepperell, MA, one of the first double-wall super-insulated houses in the world. The 1979 heating bill for the Leger House was $38 and remained less than $50 per year for at least the next 10 years. [4]

The sudden influx of accessible information about passive solar design and super insulation coupled with the sudden high price of petroleum set off a temporary energy efficiency movement among architects that spread to a small counter culture but never acquired the momentum necessary to make it a popular movement. By the time the oil crisis ended and energy prices returned to an affordable level the construction of passive solar buildings all but died out. If anywhere, a lasting effect was felt in the arid western regions of the US where passive solar design is so well suited to the climate. The solar houses of the 70's had a certain functional aesthetic that was largely rejected during the historicism of the postmodern 1980's. The lack of a perceived energy crisis seemed to deal a lethal blow to the short lived energy efficiency movement in the US. While there was particular success in the reduction of heating energy [except for certain climates] cooling was not effectively dealt with nor was many other home energy end uses. Photo voltaic panels were beginning to be discussed at that time but their cost made them impractical in most applications.

3 The Zero Energy House

Throughout the late 1980s, the cost of solid state solar electricity production with photovoltaic panels declined in price such that the possibility of using PV for individual house, distributed generation became increasingly feasible. In the state of Florida where the climate defies many passive solar design techniques the affordability of PV technology opened the door to active solar systems that would take advantage of the state's wealth of insolation that ranks second in the country only to Arizona. In 1998 the Florida Solar Energy Center began its Zero Energy Homes research program in collaboration with the City of Lakeland municipal utility and builder Rick Strawbridge.

The team constructed a 2400 sq.ft. energy efficient photovoltaic residence (PVRES) and a standard model (the Control) and tested them for more than a year. In one year, the PVRES home used 6960 kWh of electricity and had a PV system production of 5180 kWh. For the same year, the control used 22,600 kWh. The yearly energy savings due to differences in energy efficiency of the two homes is 70%. Putting the PV system production into the numbers shows that the PVRES house's net energy use for the entire year was only 1780 kWh. When comparing the PVRES house energy, including the energy it produced, against the standard house, the PVRES house had a 92% utility energy savings compared to the standard house. Perhaps even more important than annual energy use is the fact that during periods of peak electric demand, the PVRES home, due to the PV system, placed nearly zero net demand on the utility system. Both test homes have R-30 fiberglass insulation blown in the attic, but there are major differences in the building envelope and mechanical systems of the two buildings.

The building envelope of the PVRES house features a white mission concrete "S" tile roof. The control home's roof is conventional popular gray-brown asphalt shingles. The solar reflectance of the white S-tile tested at 77% while the reflectance of the gray-brown architectural asphalt shingle was only 7%. When the outside summer air temperatures were at their peak the coincident peak attic air temperature difference was 40^{o}F lower in the white tile test cell (91.4^{o}F) than the construction with black asphalt shingles (131.5^{o}F). For solar control on walls and windows, the PV home has a 3 foot overhang around the perimeter of the building while the standard home has one and a half foot overhang. At 11:10 AM on October 1st, 1997 the standard home, with a 1.5 foot overhang casts a shadow length of just 36 inches. At the same time, the shadow cast on the PV home is nearly 72 inches long. The overhang shades most of the wall and at least 75% of the south and east window area. In conventional residential construction in Florida, walls are insulated with R-3 to R-5 insulation on the interior of the masonry walls. However, the concrete block walls of the PVRES home were insulated on the exterior both in order to assist with reducing the cooling system size and to utilize the thermal mass inside the building. An exterior application of 1¼" *Tuff-R C* [isocyanurate insulation] was used to encapsulate the building in R- 10 insulation so that the masonry portion of the building could be pre-cooled during the daytime hours when solar availability is high and the PV system output is at its maximum to utilize the thermal capacitance of the building and its masonry and help to reduce air conditioning needs during the late afternoon and early evening hours. The windows in the PVRES home are PPG Industries' *Sungate 1000* solar control, low-E glass product with Argon gas fill. with a SHGC of only 0.38, but with a daylight transmittance of 73%. The center-of-glass U-value is 0.24; white thermally broken vinyl frames reduce U value (overall U-value = 0.35). The improved glass reduces the size for the air conditioning system. With 384 square feet of glass in the floor plan there is a 7,700 Btu/hr difference (0.64 tons) in the required size of the air conditioning system.

The mechanical systems of the two buildings also had marked differences. The HVAC systems of the two buildings were designed based on a 95°F [35^{0}C] outdoor design temperature with a 75°F [24^{0}C] interior temperature. The calculations indicated a 3.88 ton cooling system for the standard home (4 tons) and 1.73 ton (2 tons) for the PVRES house. The Trane two-ton heat pump and a variable speed indoor air handler with a combined Seasonal Energy Efficiency Ratio (SEER) of 14.4 Btu/W were selected to provide optimum efficiency, humidity removal and quiet operation. For the standard home a standard efficiency 4-ton Trane heat pump with a SEER of 10.0 Btu/W was used.

In conventional houses the ducts and often the air-handler are located in uninsulated attic space. In Florida, the attic sometimes reaches 130^o F and studies show that heat transfer to the duct system can reduce the cooling capacity of the air conditioner by 30%. In the PVRES house the ductwork is placed within the conditioned space of the building. Any heat gained by the duct system is removed from the conditioned space itself so there is no reduction in cooling capacity of the air conditioner. To avoid problems with leakage, the duct system was carefully sealed with mastic and tested. The duct system was oversized to provide better air flow across the evaporator, reduce air handler fan power, improve system efficiency, and reduce noise.

The PV generation system was sized to provide power that would offset most of the daytime household electrical loads. Based on the predicted loads for a peak day, it was determined that a 4kW solar array should be installed. As a *Utility Interactive System,* the photovoltaic system is owned and maintained by the electric utility company and the power generated is supplied to the utility side of the meter. The output of the system is monitored by the utility company to evaluate the system performance and to troubleshoot problems. Systems installed such as this one increase the capacity of a service provider and can help reduce the total operating hours required for fuel-burning generators. Siemens SP75 single crystalline solar modules with a maximum power rating of 75W were selected for installation on the roof of the house. The photovoltaic arrays were installed in panels, comprised of three modules each and connected in series. Thirty-six modules or 12 panels make up the south-facing sub-array and 18 modules or six panels were installed on the west face of the roof. An AC power inverter was selected to convert the array's DC power to AC for interaction with the utility grid.

The PVRES home uses a solar water heating system with propane back up. The system consists of a forty square foot *American Energy Technology AE-40* solar collector mounted on the south side of the home's roof. The collector is rated at an energy production of 45,600 Btu/day at the low temperature (95°F) rating. The Control home contains a standard electric resistance 52 gallon storage tank in the garage, rated to use 4,828 kWh/year. The PVRES water heater has a rated energy factor of 0.65 with the measured tap hot water temperature 130°F. Approximately 66% of the system's water heating is solar and the remainder is supplied by propane gas. Daily hot water use averaged 37.8 gallons per day against a daily propane consumption of only 3.2 ft3 - about 0.09 gallons per day [6].

The Lakeland project was instrumental in the formation of the U.S. Department of Energy's Building America program which has led to many zero energy home and near zero energy home projects around the country. The Building America Program is responsible for reengineering new and existing American homes for energy efficiency, energy security, and affordability. Building America works with the residential building industry to develop and implement innovative building energy systems—innovations that save builders and homeowners millions of dollars in construction and energy costs. This industry-led, cost-shared partnership seeks to reduce average whole-house energy use by 30%–90% and reduce construction time and waste, improve indoor air quality and comfort, integrate clean onsite power systems [leading to Zero Energy Homes], and increase the energy efficiency of existing homes by 20%–30%. The DOE has posed the "Builder's challenge" to the homebuilding industry — to build 220,000 high performance homes by 2012 [7].

4 Zero energy communities and beyond

With several successful examples of ZEH built across the country, the focus in recent years has become ZEH communities. In 2003 San Francisco Bay area production builder Clarum Homes partnered with Building America to build Vista Montana, the nation's largest zero-energy home community, in Watsonville, California. The development of 177 single-family homes, 80 townhouses, and 132 apartments opened in August 2003 and sold out in its first year. Clarum initially advertised prices of $379,000 to $499,000 but some units sold for as much as $600,000. Every home that Clarum offered at Vista Montana features energy-efficiency measures throughout plus a package of zero energy features including a 1.2 to 2.4 kW photovoltaic system on the roof. Clarum partnered with ConSol and others to develop its *Enviro-Home* package of energy efficiency and solar power features, designed to reduce homeowner energy bills by up to 90%. Each Enviro-Home has been professionally designed, certified, and inspected to reduce energy consumption and use sustainable resources while improving comfort. The program has also earned the U.S. Environmental Protection Agency's ENERGY STAR® seal, ConSol's *ComfortWise* designation, and the California Building Industry Institute's California Green Builder certification. In addition to a solar electric home power system, each *Enviro-*

Home in the Vista Montaña community features a tankless on-demand water heater, and a high-efficiency furnace as standard features. The homes also feature a foam-wrapped building envelope, increased insulation, radiant roof barrier, advanced HVAC technology, tightly sealed ducts, and low-E energy-efficient windows. Ceiling fans, fluorescent light bulbs, water conserving plumbing fixtures, and water conserving landscaping are also incorporated, providing homeowners further utility savings. The *Enviro-Home* incorporates sustainable building materials, such as engineered lumber, recycled decking material, and fiberglass doors, and offers recycled content carpet, bamboo flooring, cork flooring, and environmentally friendly paint as optional items. According to the developers, the *Enviro-Home* features that are included as standard equipment will provide more than $20,000 of added value to homebuyers at no extra cost to them. Clarum works with Building America to use their cost and energy savings analysis to point to the most cost-effective combination of features for the climates it builds in. Once a cost-effective combination is chosen, economies of scale can be achieved through volume purchasing and training of subcontractors. Clarum is building four super-efficient demonstration homes in Borrego Springs, California where temperatures routinely soar past 100°F 6 months of the year. The homes are equipped with cutting edge wall, cooling, heating, water heating, ventilation, and PV systems.

On an even more holistic level, the NREL is assessing the feasibility of developing "renewable energy Communities" with sustainable planning, net zero-energy homes, advanced vehicles, and innovative utility interconnections that could significantly decrease energy use, as well as its associated emissions and climate change impacts, both in the U.S. and worldwide. Although there have not been any of these communities developed yet in the US, The *Beddington Zero-Energy Development (BedZED)* in England, is being designed to be carbon neutral, with strong emphasis on roof gardens, sunlight, solar energy, reduction of energy consumption, and waste water recycling. BedZED includes a green transport plan that promotes walking, cycling, and the use of public transport, including a car pool for residents [8].

5 Emerging technologies

The sustainability movement in the U.S. and world wide has stimulated research and development of many new materials and products that will be useful in building the zero energy house of the future. With the US government's pledge to invest in renewable energy and energy conservation the list of new and innovative technologies is sure to grow quickly in the near future.

In early examples of ZEH, photovoltaic technology has been the primary source of site generated renewable energy. Hydrogen batteries and fuel cells also hold the promise of clean renewable fuel with abundant domestic sources although they are still in the development stage. Projects are currently under way at the DOE and the NREL to develop Hydrogen fuel cells for various uses from vehicles to large scale power generation to the grid and localized power generation for buildings. At Florida State University an Off Grid Zero Energy Building [OGZEB] demonstration utilizes Hydrogen batteries for power storage and Hydrogen production. The Hydrogen can then be used in Hydrogen burning appliances and electricity generating hydrogen fuel cells. These technologies are not yet commercially available but are nearing that stage.

To minimize the need for energy in buildings, insulation systems are critical and several promising materials are on the horizon. *Aerogel*, a material first discovered in the 1940s, is made by drying a gel of its liquid contents without collapsing or shrinking its matrix structure. Referred to as solid smoke, an aerogel consists of more than 96 percent air and resembles a hologram, appearing to be a projection rather than a solid object. The remaining four percent is a wispy matrix of silica (silicon dioxide), a principal raw material for glass. Aerogels, consequently, are one of the lightest weight solids ever conceived. Despite their lack of substance, these materials are the world's best solid insulator, transmitting only one hundredth the heat of normal glass. Made of inexpensive silica, aerogels can be fabricated in slabs, pellets, or most any shape desirable and have a range of potential uses. By mass or by volume, Sandwiched between two layers of glass, transparent compositions of aerogels make possible double-pane windows with high thermal resistance. Aerogels are a more efficient, lighter-weight, and less bulky form of insulation than the polyurethane foam currently used to insulate refrigerators, refrigerated vehicles, and containers. Products utilizing aerogels including roofing, glazing, insulation, and exterior wall and roof panels are currently in commercial production [9].

In terms of energy efficiency, windows are one of the biggest contributors to heat loss from buildings. A thermos insulates by separating the contents from the outside temperature with a vacuum. Heat is conducted by three modes, conduction, convection, and radiation. A vacuum prevents conduction and convection, and a reflective coating serves to reflect radiated heat back to its source. Compared to a standard double-pane window with an R-value of 3 or 4, windows with double-pane glass and a vacuum between the panes have the potential to provide insulation values comparable to a standard insulated 2×4 stud wall [R-13].

Advances in PV thin film technology have made building integrated PV systems a reality in recent years and this technology is poised to become even more pervasive in the near future. Thin film materials that replace or become a part of traditional roof or wall coverings, while maintaining and improving their insulation and protective properties are now available. While producing renewable energy from the sun, these systems go beyond photovoltaic panels by integrating design, efficiency, aesthetics and functionality. One company’s product is suitable for shingle-type roofing on a wooden frame or on concrete beams with or without protective sheathing. The roof surface can be walked on with complete waterproofing for slopes up to 18°.

As one of the top three building end uses efficient lighting systems are critical to an energy efficient building. A Light Emitting Diode (LED) is a semiconductor device which converts electricity into light. LED lighting has been around since the 1960s, but is just now beginning to appear in the residential market for space lighting. LEDs are small in size, but can be grouped together for higher intensity applications. Although efficacies of up to 100 LPW have been created in laboratory settings, the efficacy of a typical residential application LED is currently approximately 20 lumens per watt compared to,. Incandescent bulbs with an efficacy of about 15 LPW and ENERGY STAR® qualified compact fluorescents at about 60 LPW. LED lights have a longer life, and are more rugged and damage-resistant than compact fluorescents and incandescent bulbs.

Hundreds of millions of dollars have been invested in OLED lighting, especially in Europe, the US and Japan. Currently, more than 130 companies and universities, and over a dozen organizations are working on OLED lighting. Compared with the other major lighting technologies in the market – incandescent, fluorescent, high intensity discharge (HID) lamps, LEDs and electroluminescent (EL) – OLED lighting has several advantages. OLED lighting devices emit from the surface, can be made flexible/rollable, and even transparent like a window or reflective like a mirror. OLED lighting is thin, rugged, lightweight, and has fast switch-on times, wide operating temperatures, no noise and is environmentally friendly. The power efficiency of OLED lighting has also improved dramatically recently. The unique features of OLED lighting are inspiring the imagination of designers, who are exploring various OLED lighting applications: windows, curtains, automotive light, decorative lighting, and wallpaper. OLED lighting can have very attractive designs, can be rigid or flexible, white or color, or tunable. OLED lighting does not have ultraviolet or infrared in its spectrum, and does not generate heat during operation.

In hot humid climates air conditioning is the largest energy end use**.** Absorption cooling is the first and oldest form of air conditioning and refrigeration. An absorption air conditioner or refrigerator does not use an electric compressor to mechanically pressurize the refrigerant. Instead, the absorption device uses a heat source, such as natural gas or a large solar collector, to evaporate the already-pressurized refrigerant from an absorbent/refrigerant mixture. This takes place in a device called the vapor generator. Although absorption coolers require electricity for pumping the refrigerant, the amount is small compared to that consumed by a compressor in a conventional electric air conditioner or refrigerator. When used with solar thermal energy systems, absorption coolers must be adapted to operate at the normal working temperatures for solar collectors: 180° to 250°F (82° to 121°C). The development of micro-scale compact-type absorption chillers for residential and light commercial buildings in 2003 represents the maturation of the absorption chiller industry. The first generation of micro-scale compact-type chillers is a series of two-stage, water-LiBr based, and natural gas direct-fired systems with cooling tower. Four types of compact absorption chillers, categorized by their cooling capacity, are now on the market. Although, as of 2003 only 1% of the total installation capacity of absorption chillers was micro-scale compact-type systems, an increase of installations is expected in the future.

6 Conclusion

With the exception of a few individuals with a broader perspective, the energy efficiency movement of the 1970's was largely a response to an economic crisis. As such, it lacked a broad backing after economic conditions improved and fuel prices returned to affordable levels. However, because it is based on a broadly acknowledged worldwide environmental crisis, the current sustainability movement is fundamentally different from its predecessor. Unlike the passive solar building movement, the sustainability movement has permeated all sectors of society and has broad acceptance and support. Even within the broad perspective of a sustainable world, buildings are being singled out along with transportation as the largest consumers of energy and contributors to CO_2 emissions.

Since the proliferation of Central heating and air conditioning in the mid-20th century the thermal comfort range of the average American has changed several degrees making it difficult for people in extreme climate zones to live in passively heated or cooled homes. However, the principles of passive solar design can compliment highly efficient mechanical systems to greatly reduce the energy consumption of buildings. There is also evidence that comfort levels can be gradually altered when standards are placed on heating and cooling levels in buildings. In Japan, for example, the Koizumi administration fixed air conditioning in public buildings at 28 degrees Celsius and not less during the hot summer season. On a recent trip to Japan I found the warmer temperature in buildings was noticeable compared to what I have experienced there previously and what I have become accustomed to in the U.S. Although this represents a dramatic change from inside building temperatures in the 1980s [when Japan was in a bubble economy] people seem to have adjusted to the new standard with little inconvenience or discomfort. Lower building energy demand through conservation and more efficient, building envelopes, mechanical systems, appliances and passive solar strategies coupled with on-site, grid interactive, renewable energy generation through PV, fuel cells and other emerging technologies is a proven formula for net Zero Energy Buildings that will almost certainly become the norm in the U.S. in the very near future.

References

[1] National Energy Technology Laboratory, "2008 Buildings Energy Data Book", D&R International, Ltd., November 2008 http://www.netl.doe.gov

[2] "Solar houses: Solar IV" MIT Libraries, Cambridge, MA http://libraries.mit.edu/guides/subjects/architecture/architects/solar/solar4.html,

[3] Edward Mazria, "The Passive Solar Energy Book", Rodale Press, Emmaus, Pa, 1979

[4] Joseph Lstiburek, "Westford House", Building Science Insight, Building Science.com, 5/22/09 http://www.buildingscience.com/documents/insights/bsi-018-westford-house/,

[5] Katrin Klingenberg, “Passive House –a Positive Net Energy Home”, ISTC PDF, Illinois Sustainable Technology Center, Urbana Champaign Ill, 10/28/2008 http://www.istc.illinois.edu
[6] “ZEH: Lakeland Fl.” Florida Solar Energy Center, Orlando Fl., 2007 http://www.fsec.ucf.edu/en/research/buildings/zero_energy/lakeland/
[7] National Renewable Energy Laboratory, “Whole-House Approach Benefits Builders, Buyers, and the Environment”, PDF, U.S. Department of Energy, Washington DC, 10/2004 http://www.nrel.gov
[8] Bill Dunster Architects, “BedZED – Beddington Zero Energy Development, Sutton” , The Government’s Energy Efficiency Best Practice programme, Crown, March 2002
[9] Jeffery Kahn, “Aerogel Research at LBL: From the Lab to the Marketplace”, Berkeley Lab science Articles Archive, Berkeley Ca., 1991 http://www.lbl.gov/Science-Articles/Archive/aerogel-insulation.html ,
[10] Jennifer Colegrove, “OLED lighting set to take off in 2011,” LEDS Magazine, Pennwell Corporation, Tulsa, Ok., May/June 2009 http://www.ledsmagazine.com
[11] Danny S. Parker, “Very Low Energy Homes in the United States: Perspectives on Performance from Measured Data”, Florida Solar Energy Center/University of Central Florida, Cocoa Fl., August, 2008 http://www.fsec.ucf.edu
[12] Benjamin Stein, John S. Reynolds, “Mechanical and Electrical Equipment for Buildings”, John Wiley and Sons, New York, NY, 2000
[13] Fred Mitlitsky (Primary Contact), Jim McElroy, Karla Conmy, “Low-Cost Co-Production of Hydrogen and Electricity”, 2008 Annual Progress Report, DOE Hydrogen Program, Washington DC, 2009 http://www.energy.gov
[14] Danny Parker, David Hoak, Alan Meier, Richard Brown, “How Much Energy Are We Using? Potential of Residential Energy Demand Feedback Devices”, Florida Solar Energy Center/ University of Central Florida, Cocoa fl., August 2006 http://www.fsec.ucf.edu

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Smart architecture contribution to achieving sustainable architecture realization

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Abstract

In this article we consider the ideologies that affect modern human life and smart architecture contribution used as tools to enable those ideologies. It is considered that the technological impact on human life is undeniable but, as well as making use of the technology environment, consideration is really required. Therefore, this study explores the role of smart structures and materials to create new buildings with sustainable architecture.

First, such terms as green architecture and sustainable architecture are identified. Then, using smart technology in buildings and what it would be like, are defined. Various smartness used in the buildings, their outcomes, performances and roles are evaluated. Smart buildings' role in sustainable architecture is explained.

Keywords: smart architecture, sustainable architecture, green buildings, building technologies, smart materials, ecological design, sensors, actuators, biomimetics, efficient design.

1 Introduction

Nature always inspires man in engineering. Smart buildings and materials are not exceptional for this rule. Zuk and Clark in their book "Kinetic architecture" suggest that "life is a kind of movement, which begins from a single cell to the most complex organisms. Movement, dynamism, changeability and compatibility are signs of life. Additionally, survival depends on these factors. It implies that they can feed biological process, remedy its pains, restore it, and

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finally adjust the biological mass with its environment.” In fact, this ideology represents the beginning of smart buildings plan. The main goal is to facilitate such biological functions as sensing, controlling, and reacting by what is called smart building. This exact idea is the first motivation and development factor in the new path, called “smart buildings”.

Building Smart Alliance, a council of the National Institute of Building Sciences, define the smart building as follows: “smart building with its four components: systems, structures, services and management as well as their interactions, creates an efficient and low cost environment. The single common characteristic of all smart buildings is a design such that it responses to changing environment with a low cost and efficient way.”

The multitask components of a smart structure take the responsibility of diagnosis, control and operation processes. In fact, smart structures resembles human body metabolism. Biological systems are a kind of smart structure that imitates nature. These systems are smart structures as well as economic which are able to be used as a main reference for smart structure design. We will discuss the details later.

Smart materials with two functionalities of sensing and system operation are used to build a smart structure. In the other words, smart structure reacts properly to any changing in the environment including changing in its own circumstances. Such a structure is properly and usefully predesigned. Proper reaction implies that two or more motives are received but based on the design there will be only one reaction.

Smartness involves optimum behavior in different conditions. Though some smart structures were designed in the long past, what makes present activities more interesting is the high level of development in materials used, information technology, measurement instruments, sensors, operators, signal processing, nanotechnology, cybernetics, artificial intelligence and biomimetics [1].

Smartness in building is shown in these fields: a) building management systems such as heating and cooling control systems, lighting control system, fire alarm and fire fighting system, emergency power control system, earthquake alarm system, etc.; b) monitoring systems such as closed circuit system of digital cameras; c) access control system such as door automatic open-close system and anti thief system; d) communications systems: TV and satellite signal distributor system; e) safety structure systems such as absorption tools, warning tools, etc.

We seek to address smart structures in this paper. Smart structures provide flexibility and adjustability for the building in order to be aligned with its environment. Inevitably, regarding to environment concerns and higher concern for sustainable architecture in modern world, smart buildings take an efficient step towards sustainability by improving in construction process and proper impact on building maintenance and by lowering the energy and cost of reconstruction.

We address smart buildings function to provide a healthier environment and higher efficiency for building based on sustainable architecture.

2 Smart structures formation basics

The smart structure idea was first addressed early 1980s [2]. A smart building was first defined as a building which makes use of new technologies but later (1991), flexibility was added, which means that the building is able to change in function. Then environmental considerations and economical conditions of users were added to the definition. In 1998, Kroner suggested that smartness was evaluated based on some criteria: building which is equipped with electronics to provide a convenient place for the inhabitants [3]. Arkin and Paciuk modified the above definition as smartness doesn't mean to be content with only specific technology in order to improve some functional systems (as lighting or air conditioning) but it addresses whole systems integration [4].

In summary, smart building evolution was as follows: 1981-1985 (old view): smartness is seen as building management, communication and automation with help of new technology to provide convenient office affairs. 1986-1991 (guided view): smartness in building management, office affair automation, communication and providing proper reaction to organizational change by means of new technology. 1992-1995 (advanced view): smartness in building management, environment management and management over economical fields in order to provide proper and efficient as well as supportable reaction to economical change. Since 1995 (wholeness view): smartness provides conditions to use all before mentioned fields, including followings:

- Economical field: lower cost, high productivity, lower dangers.
- Environmental field: lower gas pollutants and improvement in energy use.
- Social field: higher quality life and healthier building inhabitants.

3 Sustainable development, sustainable architecture

The UN conference on sustainable development in New York (1987) gave the following definition: The development which responds to human demands without destroying potentials, may be used to respond to human future demands [5].

Based on the above definition, the final purpose of sustainable architecture is to provide health and convenience of both present and future generations. The definition attracts one sided and immoderate minds of builders. Considering the future generation interests represents social position establishment for such discussions among different nations so that sustainable development is put into the agenda for governments (even the third world) as well as international conferences.

Certainly, any effort to protect and sustain Earth is acceptable. Smart building, specially, smart structure by use of technology has transformed present architecture definitions and will remove a lot of limitations for sustainable architecture.

3.1 Green building and ecological design in architecture

According to Ken Yeang:

- Ecological design recognizes nature and environment restoration and respects its borders.
- Ecological design seeks to repair and maintain ecosystems.
- Ecological design seeks symbiosis between manmade systems and natural systems.
- Ecological design must gain a predicting view [6].

As you see, ecological design must be closer to natural systems as much as possible, so it must gain higher level of smartness, never violating natural ecosystem rule. An unelectable element in design of a building is consideration of the building as a living organism, effective on nature as well as an inter structure ecologic goal.

If architects have enough knowledge of smart buildings, they can remove the negative effect of building on environment ecology and it will be decreased very much.

4 Inherent smartness and artificial smartness

Three main components involve how to live: man, nature and machine. Machines are functioning biologically by improving their smartness. As this phenomenon advances, the distinction between inherent and artificial smartness will be more ambiguous. Smart artifacts will dominate, will adjust, will repair themselves and will be developed.

If smart structures are to gain comprehension, learning and decision making ability should be provided for them. It involves data collection.

The human brain is smarter than computer, because man can process a lot of data simultaneously. A brain bears 10^{11} neurons; the human brain is the most intelligent model of data processing.

Artificial neural networks (NNs) simulate the human brain model. They can dynamically and simultaneously learn system structure without previous knowledge. Artificial neural networks (NNs) involve a large number of processing elements (PEs) and are designed to use of a considerable combined behaviors without relying on each element behavior [1].

5 Smartly designed structures

The terms such as “smart”, “comprehensive”, “compatible” and other terms are used for explaining and grouping smart buildings and materials, representing the fact that the given system has sensor, and control and measuring hardware. According to one of the proposed definitions for smart materials and smart buildings, they have compatibility with extrinsic actuators such as forces because of their inherent smartness.

So, smart building components integrally and logically adjust with their environment.

Smart configuration addresses natural loads in natural conditions. If necessary, operator systems encounter with abnormal loads actively. For example, smart structure mast be able to operate actively when earthquake occurs in seismic zones like Iran.

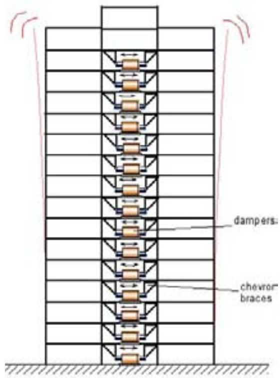

Figure 1: Inclusion of dampers in this high building provides its stability when an earthquake occurs. Dampers are filled with magneto rheological fluid (MRF). The fluid is solidified when facing magnetic forces but it restores its fluidity when vibration occurs. So it remains stable during quakes. The picture shows how the dampers operate during earthquake.

It should be noted that dampers are not only suitable for critical events (abnormal loads, such as earthquakes), but also they are used for resistance against normal, long term loads, corrosion and other parameters of oldness which endanger even safety. If we include widely sensors and permanent monitoring systems into the design, it could be possible to repair on time, decrease the costs and ensure higher safety.

6 Smart structures evolution

Man made structure evolution paths are as follows:

- Actively smart structures (sensor + feedback + enhanced actuator action).
- Very smart structures (sensor + feedback + enhanced actuator action + one or more other biomimetic features).
- Intelligent structures (actively smart structures endowed with a learning feature, so that the degree of smartness increases with experience).
- Wise structures (moral and ethical decisions).
- Consciousness in smart structures.
- Collective consciousness. The Internet is already playing the role of a collective consciousness for the planet earth, and much more is still to come.

- Man-machine integration. Immortality through repeated repair or replacement of worn out or unserviceable parts (both animate and inanimate)[1].

Of man-made items, the main source is the human brain and it involves machines compatibility with the human nervous system. The properties of an intelligent man's brain may be summarized as follows:

- Perception of location and conception of space;
- Knowledge of past and having imagination and dream;
- Ability to focus on a significant job;
- Ability to predict various event and to plan for future;
- Decision making;
- Emotions and feelings.

Most robots are designed to provide at least one of these properties. Emotions and feelings modeling in robots may seem unachievable dream.

7 Smart structure's behavior

There are two kind of smartness in structures: closed-circuit and open-circuit. Closed-circuit smart structure percepts changes and distinguishes the nature of problem, initiates to decrease the severity of problem and saves the related data to refer to them later [1]. Open-circuit smart structure is designed to be integrated more only if needed, otherwise it functions normally [1].

Smart structure is a combination of sensor, actuator and control system. In addition to using sensors and actuators with good performance, a more important part of smarter structures is the development of optimum control algorithm to lead actuators for better performance after the sensor sense the changes.

Adaptronic structures are another term for smart structures. Rogers clarifies the nature of adaptronic structure design: "the main assumption for adaptronic structures is that they are designed for a proper and optional purpose and they must be able to transfer the energy and their behavior in order to create a set of performances…" It implies that smart structures can help architecture and create flexibility in architectural spaces.

7.1 Biomimetics

Structures or biological systems are the smartest or the most cost effective ones. Figure 2 shows main configuration of a biological system and its components are: sensors (nerves), actuators (muscles), distributed control center (brain) and host material (body). Of course, a power source is needed.

Living system sense changes in the environment. Then sensors data are sent to the brain (control center). Living organism needs to have a goal (for example, survival or stability). The brain sends signals to muscles or actuators based on the given goal in order some essential actions are performed. For example, if it exceeds a predetermined value in the environment there is a continuous feedback between sensors, actuators and decision making center.

Smart structures more or less imitate biological systems so that they can be defined as structures with properties close to or possibly above biological structures.

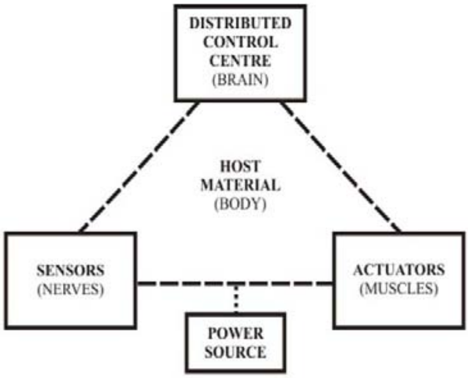

Figure 2: Main configuration needed for a living system [1].

As mentioned above, biological structures common properties include: sensors, actuators, adoptability, self repairing, self replication or reproduction. Smart structure designers try to provide these properties with lower cost. Very smart structure benefits from most of these properties. Future smart structure may be so advanced that could design themselves. Smart structures copy biological structures and make use of online sensors, actuators and microprocessors. They try substitute online adaptability requires various factors: one of which is how materials of structure so called smart materials react to intrinsic and extrinsic forces. Smart materials I.Q. is evaluated according how they reaction rapidly to the motives in environment.

Smart materials can be classified in to three groups: a) single-phased material; b) double-phased material; c) smart buildings.

Ferroic materials and those which are based on few anomalous rules, and related to phase change phenomenon, belong to the first group. In fact, the third group is a combination of sensor, actuator and a control system, imitating the body metabolism and it is designed to do the tasks of adoptability to change in environment and self repairmen. These three levels cover general definition of smart structure and material.

7.2 Sensors

As it is shown in figure 2, sensing is essential in smart structure. There are various outputs for sensor in biological systems. But electrical signal is the most convenient sensor output for smart structure. So, sensors convert a form of input energy into electrical signal. Optical fibres are commonly used for sensors in smart structures.

7.3 Actuators

Actuators like sensor are essential parts for most smart structures. Actuator transduces other forms of energy into controllable mechanical movement. They are made of ferroic materials.

8 Future of smart structures

We will witness the combination of four ultra technologies:

- Advanced material
- Nanotechnology
- Information technology
- Bio technology

Nanotechnology is connected properly with smart structures. The purpose is to manipulate individual molecules and atoms and place them where they should be or to motivate them to do that integrated [1].

With nanotechnology, an object, a building, in different place and time, behaves differently and its behavior is well field-oriented or performance-oriented. They will be able to adopt smartly with temperatures, weather conditions, energy consumption and other climate conditions, geological change and load change. All these are included as data in computer programs for building or structure to be executed if needed to achieve an adoptive and convenient environment [7].

Our machines will be advanced and inherent-artificial smarts distinction as well as living-nonliving or nature-technology distinctions will be decreased.

9 How smart structure helps sustainable architecture and green architecture

Green and sustainable architecture goals are classified into three fields:

1. Environmental goals: higher quality environment, using less transformable and more restorable materials.
2. Economical goals: reduced costs, reduced energy consumption and convenient production and performance.
3. Social goals: attaining security and adoptability with environment [5].

The conditions of a building which will lead to the goals of green and sustainable architecture may be following in summary:

- Nontoxic materials which do not affect on environment.
- Efficiency in energy: construction process which consumes less energy.
- Quality and durability: higher quality building with longer time lasting.
- Designation for reuse and restore materials and systems [8].

Van Der Ryn and Calthrope (1986) in “sustainable societies”, introduce sustainable environment as follows: A sustainable human environment provides minimal physical and psychological problems for its inhabitants. For example, disproportion between spaces and needs, demands or user behavior patterns, higher cost for required repair, replacement or maintenance, not meeting environment requirements, demanding minimal resources such as ground, water, soil and fuels (non-renewable) resulting minimal load on its environment [9].

Urban environment is expending and new construction methods are introduced. So, it is not surprising that construction industry has turned to be very enormous and it is very important in three dimensions: economical, social and environmental.

Table 1: Sustainable architecture profile.

Meeting ecological requirements		
Human health protection	Environment protection	Resource protection (energy/materials)
In all stages of building life cycle		
During the end of building function: • During removing the building • During functional change □ During building demolition	**During use of building** • In exploiting • In maintenance • In reconstruction □ In rebuilding	**In building construction process:** • During material collection • During material production • During structure construction □ During other stages of construction

Today, commercial, public and residential buildings must meet multi aspect requirements: from resistance to fire, water flood, natural disasters and terrorist attacks, to energy efficiency, less environmental impact, providing access to web networks, as well as meeting the needs of elders and disables.

Quality of building directly affects human life quality. From an ecological viewpoint, the construction industry uses an enormous part of natural resources and produces very large amounts of wastes and pollution. In addition, this industry uses energy and produces destructive gases. Itu, Iso, Iec standards encourage smart buildings all over the world, including standards on efficient use of energy, ecological reforms, environmental performance and gas evaluation.

Designers, architects, engineers, industry owners, public authorities provide smart building development upon these standards. These international standards ensure not only safety requirements and high quality in buildings but also lead to develop new technologies in construction and making use of smart and sustainable buildings.

As mentioned above, smart buildings are designed to help man in economical, environmental and social fields. So, they are instruments for attaining sustainable design since they help sustainability concept both during construction and use of building and during the end of its functionality.

Sustainability depends on ecological protection plus all mentioned above:

1. Smart structure imitation from natural processes and systems, represents a kind of continuous adaption instead of one-phase design and construction and thus provides sustainability requirements.

2. When smart structure uses building, reconstruction and maintenance, helps sustainability aspects. For example, sensors installation in buildings, provide continuous monitoring. Therefore failures and faults are diagnosed and are repaired very soon. Thus, safety increases and the costs decrease, both are related to sustainable architecture concept.
3. Smart structure concept helps architecture to provide flexible spaces for various usages. In fact, the ability to be reconstructed, replaced and change, makes smart structure an active and non-permanent one which is able to solve many architecture non-adaptability problems.

This study shows that smart structures can provide healthier buildings with higher efficiency and higher life quality for the inhabitants. According, it is expected that smart buildings turns to be the most important solution for improving human living condition and human environment and ultimately leading to green and its higher role in human life, as well as change of demands level.

References

[1] Wadhawan, V.K., *Smart Structures and materials*, Resonance, pp 27–28, 36, 38, 40, July 2002.
[2] Behzadi, B., *Smart control systems in building*, Abadi Mag., vol. 43, p.68, 2005
[3] Kroner, W.W., *The new frontier: Intelligent architecture through intelligent design*, futures, 9, vol. 21, no. 4, pp 319–333, August 1998.
[4] Arkin, H., Paciuk, M., *Evaluating intelligent building according to level of service systems integration*, Automation in construction, vol. 6, no. 516, pp 471-9, 1997.
[5] Ahmadi, f., sustainable architecture, Abadi Mag, vol. 40, 41, p. 95, 2004
[6] Yeang. K., *The Green Skyscraper: The Basis for Designing Sustainable Intensive Buildings*. Munich. London. New York. 1984.
[7] Abasalipour, S., *Nano houses, the houses of future*, Fine arts Mag., vol. 30, p. 86, 2008.
[8] http://www.green building supply.com
[9] Farhoodi, M., Sustainable architecture concept review, Architectural & construction Mag., vol. 12, p. 39, 2007-2008.

Improving the shear resistance of adobe masonry for rebuilding and new construction purposes

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Abstract

Adobe is a common building material used all over the world, especially in low cost housing. The areas in which this material is utilised also happen to be regions prone to experiencing earthquakes. Adobe masonry has a comparatively low shear resistance and fails, due to its brittle limitations resulting in virtually no ductile capability. It is therefore very susceptible to earthquake-induced loads.

The present studies focus on the improvement of the shear resistance of adobe masonry by adding reinforcements in form of natural fibres to the clay bricks and enhancing the bond between mortar and stone by optimizing the surface of the clay bricks and mixing additives to the clay mortar. Furthermore, the fibre reinforcement should enhance the energy absorption capacity of the clay and therewith the ductility and earthquake resistance of the masonry.

Keywords: adobe masonry, historical masonry buildings, earthquake, energy absorption, fibre reinforcement, clay, Arg-e Bam.

1 The historical citadel of Arg-e Bam

Built before 500 BC and used until 1850 AD, the ancient citadel of Arg-é Bam (Iran) was the largest adobe building in the world. On December 26, 2003 a major earthquake struck Bam and the surrounding Kerman province with a magnitude of 6.3 on the Richter scale. The earthquake destroyed about 70 percent of the buildings in Bam city and more than 80 percent of the historical Citadel itself.

Bam and its cultural landscape were inscribed on UNESCO's World Heritage List and on the World Heritage List in Danger in June 2004.

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Figure 1: The historical Citadel in Bam before and after destruction.

A team from the Faculty of Architecture at the TU Dresden, under the direction of Prof. Jäger, has been participating in several projects in close collaboration with the Recovery Project team from ICHHTO concerning the restoration of the Citadel since 2006.

2 Shear resistance of masonry

Buildings under seismic loads are mainly exposed to horizontal forces, which have to be primarily transferred as shear stress by walls, loaded as diaphragms. These shear loads have to be superposed with vertical forces resulting from permanent loads of the structure as well as from the live loads. The behaviour of masonry walls subjected to shear and compression forces has been described by the failure theory of Mann/Müller [1], also forming the base for the shear verification according to the German masonry code DIN 1053 [2]. This theory distinguishes four failure criteria for masonry; gaping of the units, friction failure of the horizontal joint, tension failure of the bricks and crashing of the masonry (see Figure 2).

In short, it can be assumed, that this theory is also valid for adobe-masonry under shear loads. The typical damage modes of the mentioned failure criteria can also be found on the adobe-walls inside the historical Citadel in Bam which were destroyed by shear forces resulting from the earthquake in 2003.

According to the theory of Mann/Müller [1], the shear resistance of masonry walls depend from the following material properties:

- Compression strength of the masonry
- Tensile strength of the bricks
- Initial shear strength and friction coefficient mortar-brick
- Adhesive tensile strength mortar-brick

The subsequent tests (herein described) were orientated to improve the shear strength and with it the earthquake resistance of adobe masonry. Therefore it was intended to increase the tensile strength of the bricks and in this way the compression strength of the masonry by adding fibre reinforcement to the clay bricks. Furthermore, additives to the clay mortar and the optimization of the brick-surface should additionally improve the bond between mortar and brick.

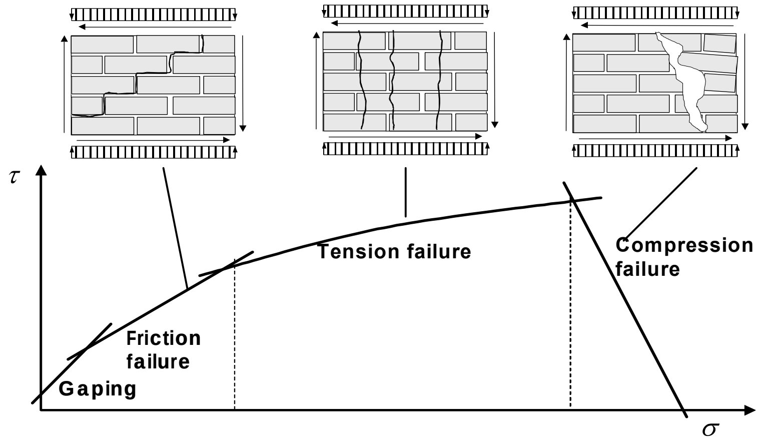

Figure 2: Failure criteria for masonry subjected to shear loads according to Mann/Müller [1].

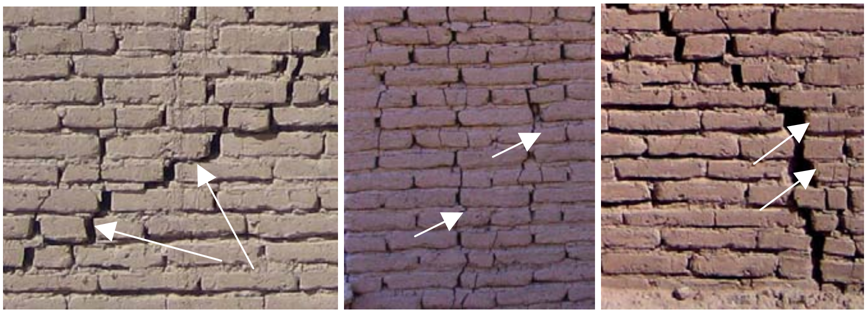

Figure 3: Friction (left), tension (middle) and beginning of shear-compression failure (right, crashing) of the adobe-masonry.

3 Fibre reinforced adobe-bricks

The traditional adobe construction uses clay as a natural, easy reusable and local available material which incurs low costs. It was therefore decided to add exclusively natural fibres as reinforcement to the row brick material in order to complement the tradition, as well as to meet the requirements of the common charters and guidelines for restoration and conservation of architectural heritage buildings in case of the world heritage site of Bam.

Initial tests have been executed with Sisal-, Flax-, Hemp-, Coconut- and Coco-palm fibres. Following the first expedition to Bam, the fibre of the Date palm (Phoenix dactylifera) which is widely available in the region due to the date production and traditionally used for the fabrication of ropes, was included in the research program. To investigate the suitability of the different natural fibres, tension and compression tests were carried out on the fibre reinforced clay bricks. The maximum strength of the various bricks was measured as well as the energy absorbed by the test specimen until the point of failure. This can be assessed as criteria for the energy dissipation capacity in case of earthquake actions.

While the test specimens without reinforcement show a sudden, brittle collapse, the fibre reinforcement of the bricks can continue to absorb tension load even after the failure of the clay itself (see Figure 4).

Figure 4: Failure process of reinforced clay bricks under tension.

It was found out that the unreinforced clay and the industrial produced bricks achieve the highest tensile strength, due to the undisturbed clay matrix, but have virtually no post-peak behaviour. The fibre reinforcement, however, reduces the content of clay in the test specimens and influences the inner cohesion of the row clay material negatively what results in a decrease of the tensile strength. As visible in Stress-Deformation-curve in Figure 5, the Sisal fibre achieves the best post-break results in terms of fibre-absorbed-tension, maximum deformation and energy absorption, whereas the performance of the Date palm fibre, favoured for the application in Bam, is considerably lower (see Figure 8).

Under compression the cross-section area of the unreinforced test specimens is reduced by cracks resulting from transverse tension, causing a brittle failure. In reinforced clay bricks cracks also occur due to transverse tension, but do not cause a reduction of the compression absorbing cross-section area, because the debris continues to be held in place by the fibres. Therefore the specimens maintain their shape during the test and display a ductile failure.

Similar to the tension tests, the unreinforced test specimens achieve a higher compressive strength than the bricks with fibre reinforcement. However, the strength degradation in the post break process is more significant and the failure is less ductile. Again the Sisal fibres attain the best results with a comparatively low decrease of the maximum compressive strength and a high energy absorption.

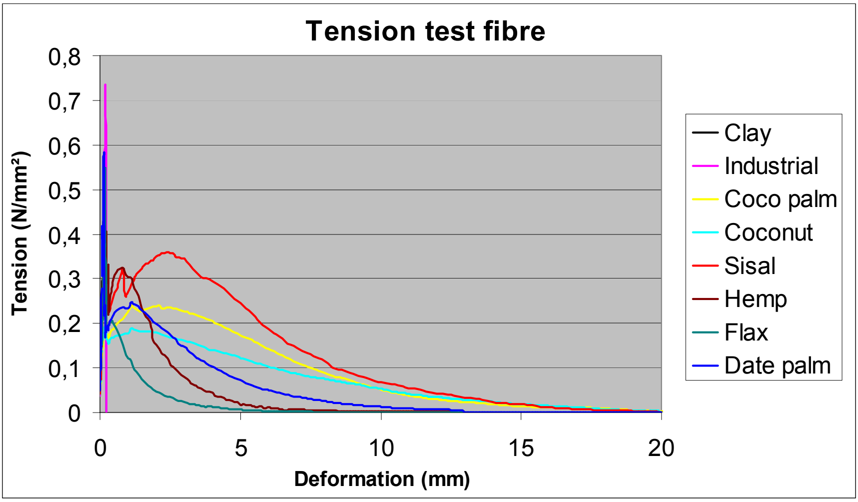

Figure 5: Stress-deformation curves of fibre reinforced clay under tension.

Figure 6: Failure process of unreinforced and reinforced clay bricks under compression.

As indicated by the displayed Stress-Deformation curves, the application of natural fibres as a reinforcement of clay bricks causes a marginal reduction of the tensile and compressive strength, but significantly increases the capacity to absorb energy. From the selection of tested fibres, Sisal was determined as the best suitable natural fibre, whilst the application of locally sourced Date-palm fibres also demonstrated a considerable enhancement of the energy absorption.

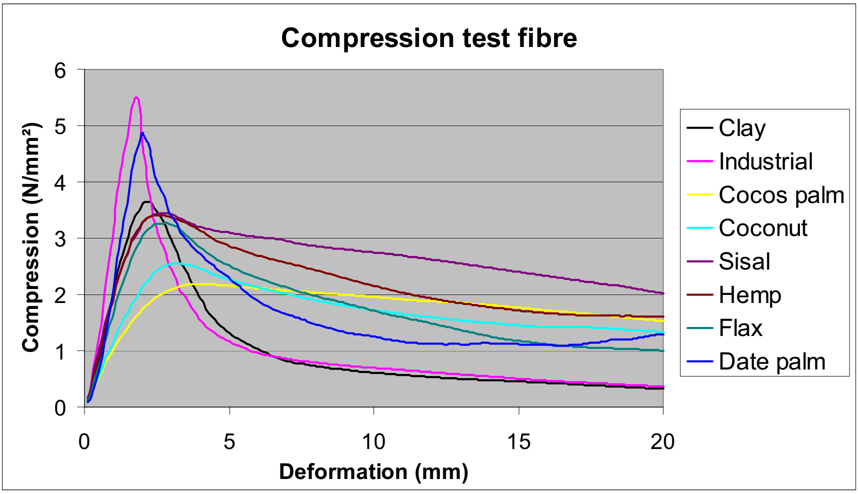

Figure 7: Stress-deformation curves of fibre reinforced clay under compression.

Fibre	Tension				Compression			
	Tensile strength		Energy absorption		Compressive strength		Energy absorption	
	N/mm²	%	Nmm/mm²	%	N/mm²	%	Nmm/mm²	%
Clay	0,668	85,62	0,06420	2,93	3,7313	65,32	20,0702	38,52
Industriell	0,780	100,00	0,07625	3,48	5,7125	100,00	22,0627	42,34
Cocos palm	0,233	29,86	1,76744	80,63	2,2056	38,61	36,0978	69,28
Coconut	0,213	27,29	1,43011	65,24	2,5621	44,85	34,2444	65,73
Sisal	0,508	65,05	2,19206	100,00	3,4828	60,97	52,1024	100,00
Hemp	0,643	82,36	0,86360	39,40	3,4565	60,51	43,4880	83,47
Flax	0,630	80,78	0,34017	15,52	3,3394	58,46	35,0070	67,19
Date palm	0,690	88,37	1,05470	48,11	5,0562	88,51	33,7245	64,73

Figure 8: Tensile/compressive strength and energy absorption of fibre reinforced clay under tension/compression.

3.1 Analysis of fibres

The differences in the performance of the various fibres could result either from inherent variable tensile strength of the fibres or from different bonding conditions between fibre and surrounding clay. The tensile strength has been determined for Sisal and Date-palm fibres. While the Sisal fibres proved to be very homogenous with diameters ranging from 0.18 and 0.22 mm, the thickness of the Date-palm fibres varies considerably. Consequently, the Date-palm fibres were subdivided for the test into fine (0,15-0,30 mm) middle (0,31-0,60 mm) and coarse (0,61-0,90 mm) fibre categories.

The average tensile strengths for the fibres determined by tests are:

Sisal fibre	840,09 N/mm²
Date palm fibre – fine	164,15 N/mm²
Date palm fibre – middle	139,87 N/mm²
Date palm fibre – coarse	115,27 N/mm².

Figure 9: Sisal fibres (left) as well as fine, middle and coarse Date palm fibres.

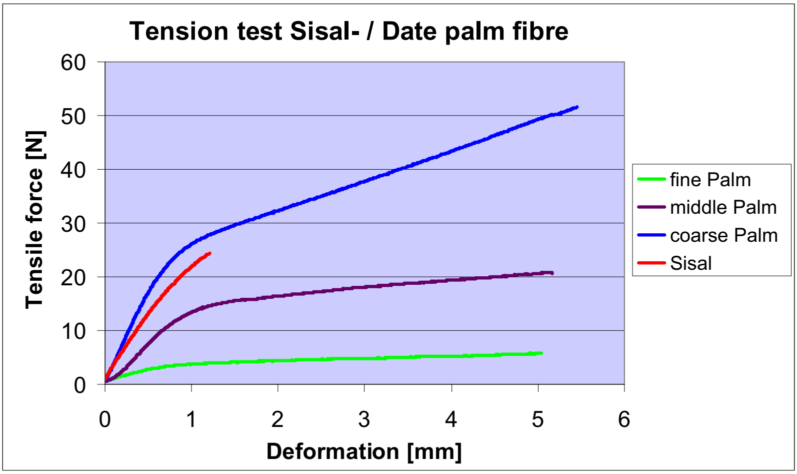

Figure 10: Stress-deformation curves of Sisal and Date palm fibres under tension.

The differences in the tensile strength of the fibres can be explained by aid of the differing functions the fibre plays in the plant. While the Sisal fibres stabilise the leaf structure of the agave plant, the Date-palm fibres mainly have a protective function.

Information regarding the bonding conditions between fibre and clay has been gained by investigating the fibre surface and the integration of the fibre in the clay with the use of an electron microscope.

While the Date palm fibre displays a relatively smooth surface, the Sisal fibre is strongly marked by the remnants of leaf structure. Further scans investigating the integration of the fibre in the clay matrix, display a interlocking of the Sisal fibre surface and clay crystals. Conversely, the clay crystals were obviously unable to interlock in the same degree with the smooth surface of the Date palm fibre.

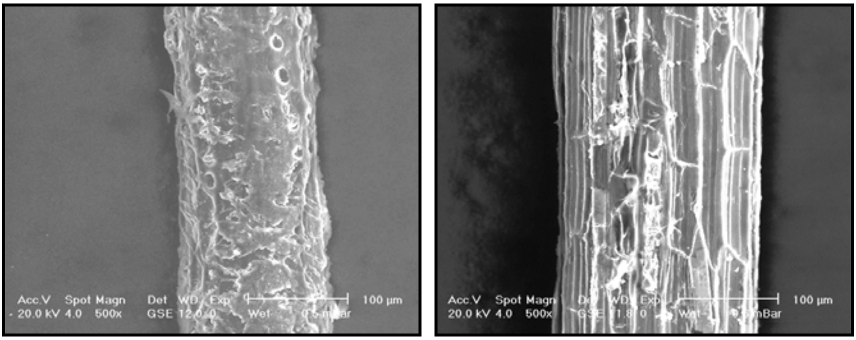

Figure 11: Electron microscope scans of Date palm (left) and Sisal fibres (right).

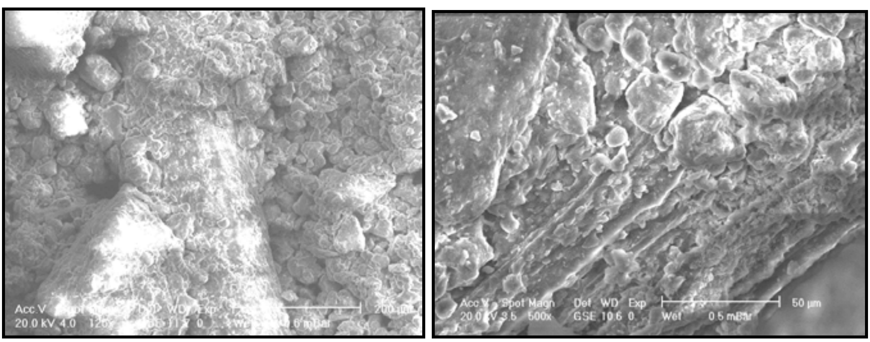

Figure 12: Integration of Date palm (left) and Sisal fibres in the clay matrix (right).

The favourable bonding conditions between Sisal fibre and clay, along with the high tensile strength this achieves provides the basis for the superior tension and compression results achieved with Sisal fibre reinforced clay bricks.

4 Improving the bond between clay mortar and clay bricks

A further method to enhance the shear resistance of masonry is to increase shear and tensile strength as well as the friction coefficient between mortar and brick. Therefore several tension and shear tests of two- and three-stone-specimens with different surfaces and varying additives to the clay mortar were performed on clay brick structures. In addition to the traditional sandy and finger-scratched roughened brick surfaces, smooth, steel-brushed and two different scrapper-prepared surfaces of brick were tested. As additives, cement, lime and gypsum were chosen.

The best results were achieved with surfaces roughened by coarse scrappers and clay mortar mixed with gypsum. The Figure 14 displays the tension and shear strength of the optimized brick surface and clay mortar which is compared

Figure 13: Sandy, finger-scratched and coarse scrapper roughened brick surfaces.

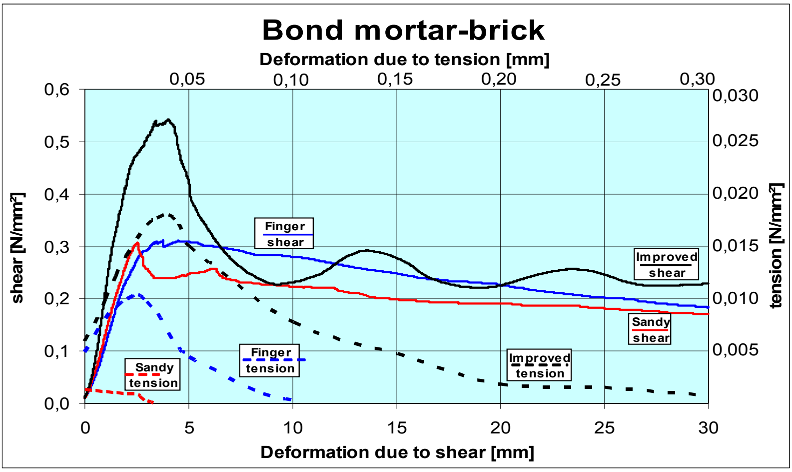

Figure 14: Stress-strain curves of different brick surfaces and clay mortar additives – tension and shear.

to the traditionally used sand and finger-scratched bricks and clay mortar without additives.

5 Shear resistance of traditional and improved adobe masonry

The shear resistance of traditional and improved adobe Masonry were determined according to the Mann/Müller theory [1], using the material properties evident in the previously described tests.

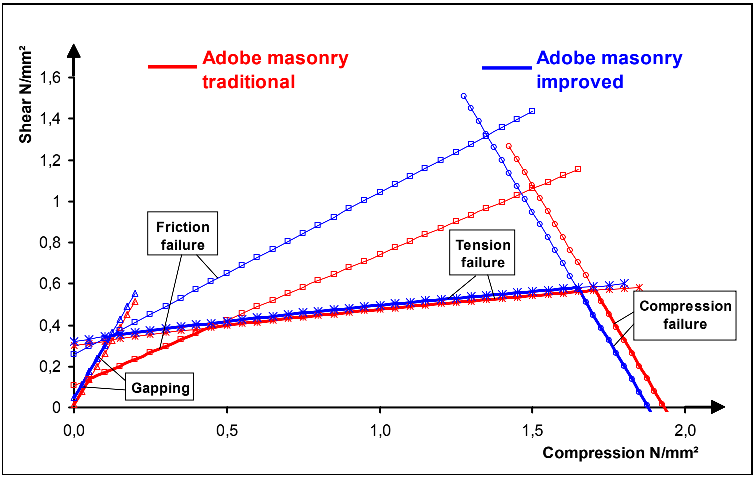

Figure 15: Shear failure criteria for traditional and improved adobe masonry.

Whilst the traditional adobe masonry features all typical criteria for shear failure, friction failure does not appear in the improved masonry material. Conversely there is a wide range of compression, where the tension failure is the decisive criteria, indicating the necessity of a further enhancement of the tensile strength by fibre reinforcement in the clay bricks.

6 Concluding remarks and future research aspects

The described static tests can provide information about material properties, energy absorption capacity and shear resistance, but they are not designed for the accurate determination of the behaviour of masonry under earthquake actions. Additional cyclic tests have been carried out on adobe masonry walls to this end, but are not covered in this paper.

References

[1] Mann, W.: *Schubtragfähigkeit und Schubnachweis von gemauerten Wänden*. In: *Mauerwerk-Kalender* (1995). Ernst & Sohn: Berlin 1995
[2] DIN 1053-1: *Mauerwerk*; Teil 1: Berechnung und Ausführung; Deutsches Institut für Normung e. V.; Beuth Verlag; Berlin 1996
[3] Minke, G.: *Building with Earth - Design and Technology of a sustainable Architecture*, Birkhäuser Verlag: Basel, Switzerland 2006
[4] Hanse; Nykänen; Gottfredsen; *Shear Behaviour of Bed Joints at different levels of Precompression*; Masonry Int., Vol. 12, 1998.

Section 8
Issues from education, research and practice
(Special session by J. Stark)

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Eco-aesthetics: nurturing nature in the education of spatial design

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Abstract

Providing opportunities to investigate new biophilic forms in architecture and interior design rather than taking a human centred approach to design redirects beginning design students' imagination towards a *nature-centred* approach with the freedom to explore creative approaches to design using natural forms. In this methodology, the focus on design aesthetics provided by nature can be examined more closely void of traditional design constraints. Additionally, nature influences and fosters new methods for academicians with the utmost goal to build a greater awareness, sensibility, appreciation and placed value upon nature as a form-giver in the built environment. A series of spatial exercises were assigned using natural forms selected by the students. Biophilic and fractal design patterns were analyzed, sketched, and modelled in prototype form. Lastly, each student generated physical models of architectural structures, interior space plans and product design, which might include furniture, lighting, and other consumer oriented products, each resulting from patterns observed using the natural forms. This theoretical approach to teaching beginning space design provides a platform for students to draw from during advanced design studios. From these exercises, students were able to generate design solutions using natural forms more efficiently and quickly; most importantly, the results were far more creative as a result of looking outside for design inspiration inside.
Keywords: biophilic design, fractal patterns, nature, interior design, pedagogy.

1 Introduction

The natural environment has been a source of wonder and inspiration for millennia. It is not uncommon to see our natural environment as a catalyst for the production and use of everyday objects to connect on a physical, emotional,

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and intellectual level. Kellert [1] suggests that interaction with nature is necessary for our well-being and physical and mental development. The human condition to connect to our natural surroundings manifests itself in the visual consumption of our environment realized in the design of products and shelter. Plato, Vitruvius, and Aristotle were all founders of design based on organic, natural forms and structures. Egyptians and Ancient Greek civilizations studied nature along with the human body to abstract these forms into harmonious geometric proportions according to Pearson [2]. Flannery [3] states that "we have become more separated from the natural world, the value of what contact we do have, and minimal though it may be and often in the form of representations, becomes more important."

Objects are artefacts of the human condition; they reflect historical changes in technology, shifts in cultural and political views, socio-economic changes, trends and fads, all working together to transcend design to become part of our history. Post World War II, advancement in techniques for creating products expanded greatly with moulded forms, single injected moulded plastic shapes, bent tubular steel and plywood. Historically, references to natural forms in design and architecture have been decorative and cosmetic applications traditionally used as ornamental motifs whereas modern design continues to focus on experimenting with natural form, shape, and fractal patterns. This new technology allows designers to express themselves in ways they previously could not. With a sense of environmental urgency, finding more ecological and sustainable design process made nature not surprisingly, a clear source to explore new bio-inspired design solutions.

Nature's influence on product design and human behaviour is evident from its vast use within architecture, landscape architecture, and the decorative arts. Design shapes behaviour, behaviour shapes culture, and culture shapes design. Our world in ever changing, and design is ever evolving. "What is true of the chair is true of all the artefacts we create…we design them; but once built, they shape us" says Cranz [4]. Nature influences design and in turn design becomes a by-product realized from natural expression whereby nature proceeds to shape human behaviour through its design. When we select a certain object for use, we have inadvertently shaped our behaviour relative to the object's design. Take the chair for instance, probably the most widely used object on a day to day basis and probably the one item most taken for granted. The shape, slope, curve, softness and hardness all play a role in how the human body performs during sitting. Whether we recline, sit with our legs crossed, fidget from lack of comfort, or rock in constant motion, these behaviours are a direct result of the object's design.

2 Design theory

Design can be considered intention, purpose, communication, reaction, beauty, meaning, and influential in shaping our lives. The process of designing suggests in itself a set of guiding laws or principles for examining the success of new concepts and ideas. Beginning design students are introduced to a core of design values referred to as the elements and principles. These two categories hold the basic concepts for communication within all design professions and are the tools for the creation and design of all things.

Pentti Routio [5] identifies specific goals that all design should acquire; Usability – utility and function; Beauty – aesthetics (principles and elements of design); Meaning – messages sent; Ecology – impact to the environment; Economy – value and price; and Safety. Design is an experience through all of our senses meeting all of our basic human needs. Our relationship to art, architecture, and interior design is a personal one based on the way we perceive our surroundings and our natural environment. Beginning design students must understand how to use the elements of design in coordination with the principles of design for the outcomes to be effective, appropriate, and creative.

3 Natural forms and design

Nature in itself is a form of non-verbal communication that transcends all cultures. Holistically, it is the purist element to derive inspiration from and to be used in the development of product for human consumption. Natural symbols are culturally specific and in-turn possesses a greater meaning and social significance. For instance, consider the use of the bald eagle in American culture or the crane in Japanese culture. The use of these and other forms are not only culturally specific, but geographical as well. A pine cone from the forest or a nautilus shell from the ocean may lack regional appeal for someone residing in an arid, desert region. As both symbol and metaphor, objects inspired from nature draw deeper personal connection to relate to the everyday in a way that creates more meaning. Objects designed from the use of nature can develop meaning beyond its intended purpose creating narrative and story of its creation thereby forming more interest and personal connection to the individual user. This has the potential for nature applied design to become an outward expression of a specific person, place, or culture.

From the jagged lines of mountain top to the simple curves of a calalily; organic, natural design is all around us. Interior designers and architects seek inspiration from many sources. Natural forms have influenced the work of architects Frank Lloyd Wright, William Morris, Antonio Gaudi and artist Leonardo De Vinci. We draw inspiration and examples from nature into the design of a simple chair to a skyscraper using recognizable forms allowing the human experience to immediately make an identifiable connection to the object or space being experienced.

The basic components of all design are simple shapes. Rectangles, circles, squares, and triangles are basic shapes utilized in design. Frank Lloyd Wright drew inspiration from the hollyhock flower for his design of the 1921 Hollyhock House in Los Angeles, California. His refinement of the natural form into basic geometric shapes illustrates the flexibility of nature in creating new forms. The iconic Egg chair designed in 1958 by Arne Jacobsen is an example of the modernistic approach to using simple forms. Jacobsen *carved* out the desired shape for his chair creating interplay of positive and negative space while maintaining the simplicity of the original form. This same concept is evident in the Ear chair, 1968, by Georges Laporte and the Tongue chair Designed by Pierre Paulin in 1967. These examples suggest the use of human forms in addition to natural forms.

Nature selected for design provides a source of symbolic connection to place and context, reflection of cultural attitudes and beliefs, and exploration of design through new technologies and materials. The Bahá'í Temple in New Delhi is a pure geometric form representing a giant lotus flower [7]. The meaning of this symbol represents the spiritual connection the lotus flower has to the Bahá'í faith. Beyond nature as metaphor, using natural forms creates a sense of justification and relevance to an object that may not have existed otherwise and making its intended purpose more visible. If a design is overly simplified or even complicated nature becomes a source of recognition drawing connection with natural qualities which in turn provides meaning that explains and reasons the design to the user. Using nature in this manner is intended to explain a design which is otherwise confusion and often times not understood. “Nature… tends to organize growth patterns into this sequence…therefore; we automatically judge something in nature as aesthetically pleasing or beautiful” Reed [8].

As technology changes, ideas change, and so do the products we buy and the behaviours resulting from their use. Objects are symbols of social status and often used for expression of current social and cultural norms. When designers communicate through the use of materials in a new way, they may be expressing new ideas, concepts and establishing future perspectives for the advancement of their personal beliefs and often of their culture. Cranz [5] states that “The implicit theory is that the design line, proportions, shapes, and decorative motifs of the time crystallize the concerns and aspirations of the day.”

4 Design interprets nature

Circular repetitive forms of a shell, the angular and rhythm of a palm frond, or the radial symmetry in the petals of a flower are examples of natural pattern forms. These patterns exist in every natural form whether human, animal, or plant. Richard Dubé [6] states that “when a designer chooses a pattern form on the basis of aesthetics, the choice will likely be driven by one or more of the following factors: emotions, scale, texture, or broad applicability.”

So powerful is design and its impact on our day to day living that comprehending a holistic perspective of what *design* is, especially as a new design student, can be all but impossible. Students learn by rules, either established classroom requirements, or a set of steps to achieve success to a project. Students, as learners of new knowledge look for advice, for direction, for a source to guide them in their educational path to this knowledge. However, rules can be stifling, offering little to the imagination for a designer or artist. Building solid foundations that allow students creative freedom to explore and experiment with new design knowledge requires a source for guiding these initial investigations. *Enter nature.*

5 Nature in the design studio

Beginning design students may find it difficult to grasp basic design theory as it applies to the creation of product and shelter. During a first year introductory course on design theory a project was developed using natural forms for design exploration. The purpose of the project was to use an active learning approach for instructional delivery to generate a greater comprehension of this new knowledge according to Bonwell and Eison [9]. This learning style when applied to a first year design course sought to strengthen the students learning from the traditional lecture method. The intent of the project was to provide process based learning using multiple techniques for design inquiry to form. Acquisition of the new knowledge included methods of observation and analysis, sketching, modelling, and writing to approach learning the principles of design defined by Kilmer and Kilmer [10] as harmony, unity & variety, scale, proportion, emphasis, rhythm, balance and the elements of design; space, line, shape, form, texture, colour and light. Through these multiple modes of inquiry students would be able to form a deeper understanding and connection to design theory at an earlier stage in their education. Approaching beginning design in this manner, using the elements and principles, helps to find the right balance of both creativity and function while in turn introducing style and aesthetic importance to the final outcomes. If we break natural forms down into the basics for analysis, then application has the potential to be much easier and understandable for the student in applying theory to solve complex interior and architectural problems simultaneously generating an awareness and appreciation for bio-inspired and eco-friendly design.

5.1 The process

The deliverables of the design project involved the application of design principles and theory through exploration of natural forms into a three dimensional object for human use. The design process consisted of three phases: (1) object selection, (2) 2-D sketch investigation, (3) 3-D model prototyping and (4) final design solution implementation.

5.1.1 Phase 1: natural object identification and selection

The selection requires students to openly consider and closely examine design in nature where complex forms, shapes, textures, and growth patterns can provide an opportunity to investigate basic design principles. Examples of these forms might include a dandelion seed, a peacock feather, a spider's web, or the human body. Students are discouraged to consider forms that are limited in visual expression. If the object is too simple, such as a smooth rock, it may be difficult to execute.

5.1.2 Phase 2: concept development and sketching

In the second phase, students were asked to explore the object through analysis of the object's markings, patterns, shapes, textures, forms, and proportions from all observational angles and sides. These observations generated a series of study sketches, or *visual biological language*, which provides source material for the development of the newly created object or space later in the process. The students must generate plan, elevation, section, perspective and enlarged and sketch close-up views of the object as necessary. Additionally, sketches should capture texture, light, shadow, and shape.

Observed patterns were combined through continued sketching executing new patterns providing an opportunity for the students to explore additional design possibilities. Through this process, students were able to dissect the original form into its basic geometric and organic shapes refining the object while maintaining a sense of the original form. Figure 1 illustrates a series of sketches of the common dandelion seed shape and peacock bird feather exploring and narrating expressions of forms and patterns from the student's chosen natural object.

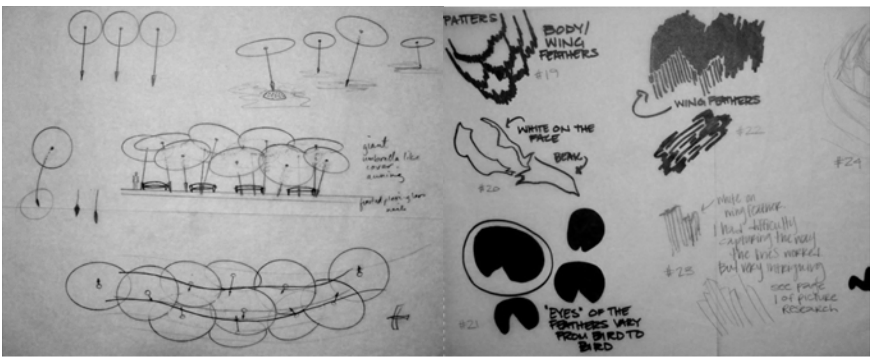

Figure 1: Initial patterns sketched to explore the various configurations of a dandelion seed shape and form (left) and the eye of a peacock bird feather (right).

5.1.3 Phase 3: 3-D modelling and prototyping

Students generate an extensive collection of visual notations and bio-inspired graphic language assembled into a conceptual document of the design process. Once a clear concept of the structure of object to be created emerges, a series of study models are developed to explore the 3rd dimension while learning to translate and apply the principles of design visually. These models were encouraged to be an "abstracted" form, not literal of the original natural object, but rather simplified while maintaining the original natural form and combined, arranged into new forms as shown in Figure 2. The students may repeat each step of phase two (sketching and prototyping) until a desired solution is found.

In Figure 2 the students concentrated on the organic qualities and curvature of each of their chosen forms in three-dimensional model prototypes. Here they use any materials (paper, plastic, and cardboard, wire) to experiment with various solutions to their intended final structure or object to study nature as spatial form-givers.

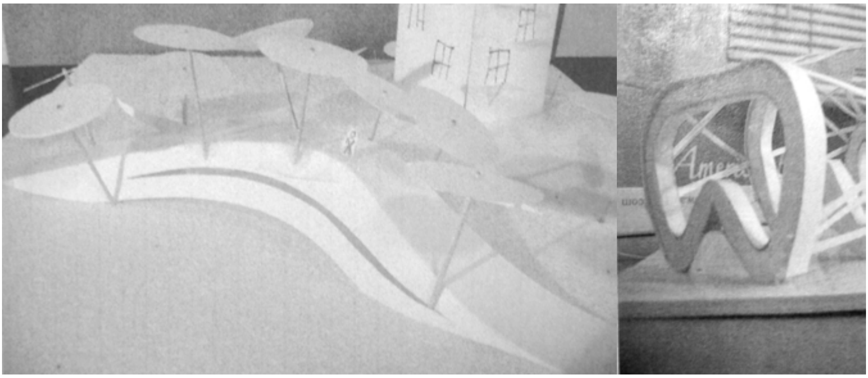

Figure 2: Prototyping initial concepts in three-dimensions as a result of visual pattern language generated in sketch studies.

5.1.4 Phase 4: final design solution implementation

After completion of the abstraction of the students' selected natural form they were asked to consider alternative purposes for the object. If this were to be manufactured for human use, what form could the object assume for practical use? Depending on the original object, student models resulted in the natural form lending itself to recognizable products such as a building, pedestrian walkway, lighting, furniture, etc.

During this phase additional study models may be generated to refine the natural form and explore additional design patterns. Once a final design has been identified and sketching near completion, a final production model representing the structure or object emerges, Figure 3.

In each solution, evidence can be seen for using nature to interpret basic design theory in beginning interior design courses. It should be noted in the initial project delivery, material selection was considered. Materials were chosen to represent the interplay of light and shadow, translucency and opacity further adding to the visual connection and recognizable cues of the design to the original organic form. The "aesthetic usability effect" so named by Lidwell *et al.* [11] suggests that the final design solution's aesthetic designs will be "perceived as easier to use than less-aesthetic designs." The results illustrate that students were able to maintain the integrity of the natural form-giver through creative use and interpretation of material and design.

6 Conclusion

In applying nature at the beginning stages of design education two factors emerge; (1) the aesthetic design opportunities nature provides for exploring basic design theory and (2) the elevated awareness and appreciation for nature earlier in the academic timeline whereby natures provides a basis for reasoning the design to the student and in doing so sets a precedence for natural forms leading

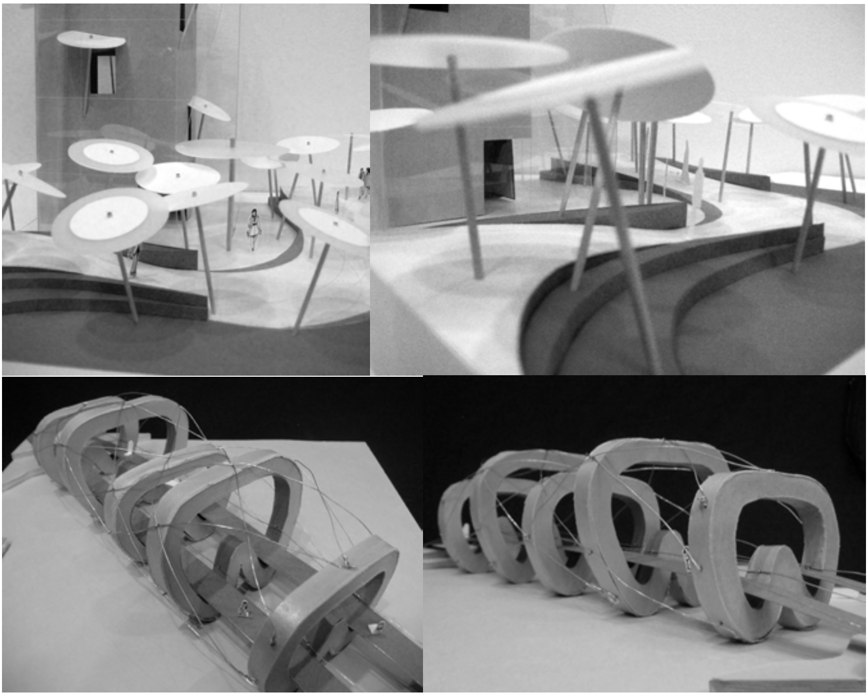

Figure 3: A series of final solutions including a pedestrian park with opaque and translucent areas of shade and cover based on the dandelion seed and a pedestrian bridge utilizing the eye of a peacock feather as the structural form.

to further advanced studies in eco and bio-inspired design. This theoretical approach to design positions itself in a less subjective manner strengthening the relevance of nature in the final solution.

Nature informs design. This work presents a point of consideration for possibilities of learning about design, *through design*, and the power to connect and generate ideas. Using nature as a source for inspiration and creativity allows for design realization to occur more fluidly. Students are exposed to alternative forms for exploring design and therefore retain a greater awareness through observation and exploration of uncommon forms tapping into the beauty of nature and its potential to influence design decisions.

In addition, the nature project creates a connection and sensitivity to nature that possibly leads students towards a deeper appreciation for green and sustainability design in later coursework. This process illustrates a method to incorporate active learning styles with source inspiration for teaching basic design theories to beginning interior design students. The nature project as pedagogical approach permitted better synthesis of knowledge and a broader base for understanding the principle of design resulting in a deeper understanding of design theory and approaches for design inquiry to occur.

6.1 Future implications

Subsequent iterations of the natural form-givers design problem will include the additional design factor of physical and actual materiality vs. modelling tools to achieve experiential results. This addition will increase the students' awareness of social responsibility in the selection and application process of finishes and materials. Materiality presents an opportunity for students to consider natural evolutionary processes in formulating hypothetical outcomes as a factor in the potential performance evaluation of both the design with the material(s).

Finally, instilling respect and appreciation for what nature offers creates a deeper level of social awareness of natural forms among our youth. This in turn generates a greater sense of social responsibility significantly impacting the future of our built environment.

References

[1] Kellert, Stephen R., *Building for Life: Designing and Understanding the Human-Nature Connection, Island Press:* Washington, pp. 1-8, 2005.
[2] Pearson, David., *New Organic Architecture: The Breaking Wave,* University of California Press: Berkley, p. 30, 2001.
[3] Flannery, Maura C., Jellyfish on the Ceiling and Deer in the Den: The Biology of Interior Decoration. *Leonardo,* 38(3), pp. 239-244, 2005.
[4] Cranz, Galen., *The Chair: Rethinking Culture, Body, and Design,* W. W. Norton & Company: New York, pp. 15 & 69, 1998.
[5] Routio, Pentti., *Theory of Design,* http://membres.lycos.fr/routio/122.htm
[6] Dubé, Richard L., *A Pattern Language: A Practical Source for Landscape Design,* Van Nostrand Reinhold: New York, p. 63, 1997.
[7] Extracts from Interviews with the Architect, www.bahaindia.org/temple/interview.html
[8] Reed, Ron., *Color + Design: Transforming Interior Space,* Fairchild: New York, p. 105, 2010.
[9] Bonwell, Charles C., & James A. Eison., *Active Learning: Creating Excitement in the Classroom,* ASHE-ERIC Higher Education Report No. 1. The George Washington University, School of Education and Human Development: Washington, D.C., 1991.
[10] Kilmer, Otie W. & Kilmer, Rosemary, *Designing Interiors,* Rinehart and Winston: Fort Worth, TX, pp. 88-121, 1992.
[11] Lidwell, William, Holden, Katrina, & Butler, Jill, *Universal Principles of Design,* Rockport: Gloucester, MA, pp. 18-19, 2003.

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Materials affecting neonatal and environmental health

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Abstract

Industrial activity provides products of service and convenience that perhaps unintentionally compromise human and environmental health. Yet these products and materials are ubiquitous, even in those environments intended to foster wellness. Persistent bioaccumulative toxins and volatile organic compounds are two categories of substances that consistently appear in interior products and materials, and are associated with temporary conditions such as eye irritation, chronic conditions such as chemical sensitivity, and terminal conditions such as cancer. Identifying and developing healthful alternative materials is facilitated by advancing technologies, including nanoscience, innovative approaches, e.g., biomimicry, and comprehensive efforts that consider environmental, equitable, and economic impacts such as the Joint Committee for Sustainable Textiles.
Keywords: sustainability, green materials, healthcare, interior environments, persistent bioaccumulative toxins, volatile organic compounds, newborn intensive care.

1 Introduction

An intention of industrial activity throughout the 20th century was the manufacture of materials and substances that seemingly made our lives better in various ways. Mass production provided a wide range of products that generally were less expensive, manufactured in large quantities, readily available, ubiquitous, continuously upgraded, and easily replaced – and they still are. Yet an unintended consequence of this activity was enormous albeit nonobvious costs to soil, air, water, and general well-being. Some of these products and materials, for example, contain substances that are harmful to human health such

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as formaldehyde. Other products and materials require exploitation of individuals who comprise the work force necessary to bring the product to bear. Development of other products and materials drives the sacrifice of one source of livelihood for another, such as tourism for mining. And most materials and substances degrade the air, soil, or water at some point in their life cycle – perhaps during the harvest of the raw materials or at the end of their useful life when the products are relegated to a landfill or an incinerator. These all are issues that preclude the use or development of materials that are "green" or sustainable. Other than products of nature that are truly cyclic across their lifespans as described in the cradle to cradle protocol [1], most products are not sustainable and many are harmful to human and environmental health. This is the current condition even in healthcare settings, despite their intention to facilitate wellness. Concern about the environmental quality of interior environments is particularly salient to patients including neonates who are unable to manage exposure to harmful environmental agents. The purpose of this paper is to recognize substances harmful to human and environmental health that are typical of healthcare settings, identity feasible substitutes, and speculate alternative approaches and technological advances that may address the current concerns.

2 Products and materials in healthcare environments

At a conference in 2007 regarding newborn intensive care, Lynne Wilson-Orr, architect, designer, and principal at Parkin Architects in Toronto, described with colleagues in healthcare a typical hospital room with its usual installation of products and materials [2, 3]. They articulated locations of materials that often treatments, and furnishings. For patients who are newborns, their typical hospital

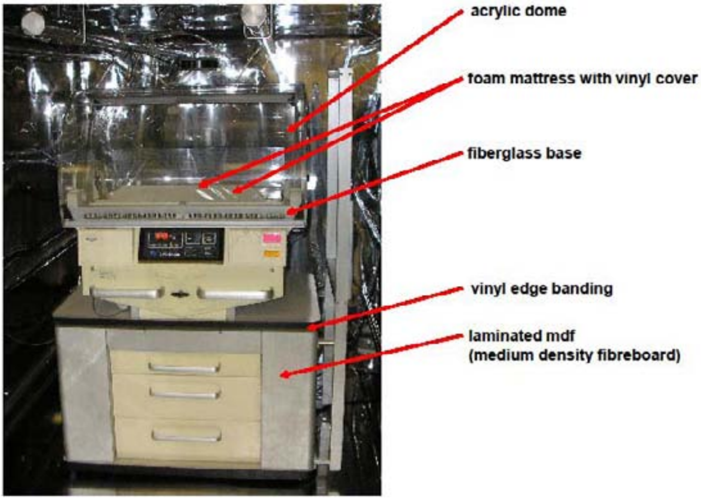

Figure 1: Materials that are typical of infant incubators, regardless of manufacturer.

"room" is an incubator which also harbours harmful substances in the infant chamber, cabinetry, and mattress, as well as in caregiving materials such as enteral bags and intravenous tubing, fig.1. Knowledge of the effects of materials such as these on patients or occupants of interior space is critical to those involved in the design of the built environment. Developing or acquiring this knowledge begins with a fundamental understanding of the substances that are prevalent in products and materials readily available for installation, application, and use in our interior environments.

3 Substances harmful to human and environmental health

Two broad categories of indoor pollutants are persistent bioaccumulative toxins (PBTs) and volatile organic compounds (VOCs). Substances classified as either or both PBTs and VOCs may cause short term health conditions such as eye irritation, chronic conditions such as asthma, chemical sensitivity, and allergies, or terminal conditions such as cancer. PBTs and VOCs that cause these conditions may be absorbed through the skin, ingested, or inhaled, and all are pervasive in interior environments.

PBTs do not break down easily in the environment – they "persist." Thus, exposure over time results in an accumulation that magnifies up the food chain. For example, PBTs accumulate in large fish not only because of their individual exposure to PBTs, but also from the amounts of PBTs stored in the tissues of the smaller fish that the larger fish ingest – and that PBT count in the smaller fish accumulates as a consequence of the PBTs they ingest by eating smaller marine animals. Through this process, PBTs "bio-accumulate," thereby providing the highest concentrations to those animals at the top of the food chain: human beings. Heavy metals such as arsenic, lead, mercury, and cadmium all are PBTs and all are known to affect negatively the nervous system, liver and kidneys, and to be associated with developmental delays, lowered IQ scores, and cancer [4].

Once ingested, PBTs reside in the fatty tissues of animals but convey easily. A nursing mother, for example, transfers PBTs to her infant through breast milk [5]. Because the detrimental effects of PBTs on human and environmental health are well-known, organizations such as the U.S. Environmental Protection Agency (USEPA) establish specific levels of exposure to toxic substances, *e.g.*, heavy metals. A consequence often is a recommendation such as that from the USEPA to limit consumption of large fish including tuna. Recent reports, however, indicate that even trace amounts of harmful substances may have significant health effects [6].

Some PBTs are also volatile organic compounds (VOCs) which are measured as organic gasses [7]. VOCs are the primary source of indoor air pollution. The USEPA reports that levels of VOCs average 2-5 times higher in indoor than outdoor environments though Greenpeace reports that these levels are 100 times higher. Health effects of VOCs are directly related to the amount of exposure, but again can range from irritation to allergies to chemical sensitivity to cancer.

Polyvinyl chloride (PVC) is perhaps the most pervasive VOC in interior environments. It is in our kitchen utensils, the paint on the walls, and the plumbing in our homes. It is in children's toys, shower curtains, and covers of 3-ring binders. It insulates wires in our computers, covers our floors, and binds the backs of our carpets and rugs. Though the dangers of PVC are seemingly invisible because they occur "upstream" in its manufacture or "downstream" in its disposal (in a landfill or incinerator), the use of PVC also is dangerous [8]. PVC is made from chlorine and ethylene. Chlorine is typically the product of a mercury cell process which is a significant source of mercury pollution. When chlorine and ethylene combine, two intermediate chemicals result: ethylene dichloride which is classified as a possible human carcinogen and vinyl chloride monomer which is a known carcinogen. The consequence of these two combined chemicals is polyvinyl chloride or PVC.

PVC is not only made from two carcinogenic substances, but also releases dioxins as a by-product of the manufacturing process. Dioxins also are classified as carcinogenic as well as reproductive and developmental toxicants which alter the immune and endocrine systems. Dioxins were considered a larger environmental and health problem when most hospital waste was incinerated and dioxins were released into the air. Although that practice has been greatly reduced, much of the presumed nonhazardous waste from hospitals such as iv bags and tubing still may be incinerated, and these supposed benign products do release dioxins into the air during incineration. Wilson-Orr and colleagues [2] report that 80 million tons of PVC are used in hospitals each year.

PVC is an example of a product of industrial activity that is inexpensive, manufactured in large quantities, readily available, ubiquitous, and thus easily replaced. It is generally irreparable and typically ends its one useful life or purpose in a landfill or incinerator. Other costly PBTs and VOCs include:

- Phthalates. PVC is brittle and hard when it is first produced. Phthalates or "plasticizers" such as di-2-ethylhexyl-phthalate (DEHP) are additives that soften PVC, making it more flexible and pliable. Catheters, IV bags and tubing, and enteral nutrition feeding bags typically are made with PVC and DEHP. Nurses in newborn intensive care first became aware of a problem with plasticizers when PVC tubing inserted into preterm infants lost its suppleness, presenting as a harder more brittle material when it was removed from the infants. This change in texture indicated that the plasticizer had leached into the infant [2]. DEHP is a VOC that impairs reproductive health, particularly in infant boys, and is reported to suppress the immune system and damage organs and the nervous system [9, 10].

- Polychlorinated biphenyls (PCBs) are chemical mixtures that are non-flammable and chemically stable with high-insulating properties [11]. These qualities make PCBs ideal for use in materials such as paint, plastics, and rubber products. But PCBs are PBTs that accumulate to levels that are carcinogenic.

- Brominated or halogenated flame retardants (BRFs) such as polybrominated diphenyl ethers (PBDEs) are used to reduce the risk of fire in furniture, textiles, and electronic equipment. BRFs are PBTS and suspected endocrine disruptors that produce dioxins and furans when heated. They typically are found on clothing and blankets such as infant sleepers and bed linens [12].

- Perfluorochemicals (PFCs) make products resistant to heat, oil, stains, grease and water [13]. PFCs are VOCs and typically used in nonstick products and stain-resistant carpets and fabrics such as window treatments and upholstery.

- Urea formaldehyde is a VOC that is toxic, allergenic, and considered a probable carcinogen by the USEPA [14]. It is used as a binder in medium density fibreboard (mdf) and in fibreglass to reduce the self-abrasive qualities of the individual filaments that foster breaking. Urea formaldehyde foam is used as an insulating material and in furnishings, including upholstery foam, pillows, and mattress pads. Formaldehyde also is used as a binder in adhesives, a preservative in paint, and can add permanent press qualities to clothing and drapery.

- Acrylic, a clear plastic, is a product of acrylic acid which is classified as a VOC. Though not considered carcinogenic by the USEPA, acrylic acid is known to be an eye, skin, and mucous membrane irritant [15]. In addition to plastics, products of acrylic acid include floor polish, coatings or finishes for upholstery, paint, and the infant chamber on the incubator.

Despite their toxic qualities, all of these substances are typical of our day to day environments as well as our healthcare environments. The materials used in healthcare such as ceiling tiles, floor and wall coverings, window treatments, millwork, and furnishings likely contain PVC, acrylics, formaldehyde, phthalates, perfluorochemicals, and brominated flame retardants. These same substances likely occur in the acrylic dome of the infant incubator, its mattress and vinyl cover, the fibreglass base, and mdf cabinet, despite an intention to provide a controlled, healthful environment for newborn infants whose health is compromised by a variety of conditions or events. When we tested the air quality of an infant incubator that was 8 years-old, for example, a series of toxic substances appeared in the analysis as shown in table 1 [3]*. Of the 20 individual chemicals emitting into the air during a 24 hour testing period, some such as cinnamaldehyde appear to be scents in cleaning agents that dissipated rapidly. Others such as formaldehyde and acetaldehyde, known carcinogens, had a constant presence during testing that may have emanated from the fibreglass base, vinyl covered foam mattress, or mdf cabinet. The levels of these two substances measured twice that recommended by the state of California. Importantly, recommended levels of exposure typically are calculated for adults, not children and certainly not developing infants whose arrival in an extrauterine

Table 1: Potential effects of volatile chemicals in the air of the infant incubator, measured as μg/m^3 (air concentrations). *This project was partially supported by a grant from the Interior Design Educators Council in 2005.

Substance	1st hour of Operation	Following 4 hours of Operation	Following 24 hours of Operation	Effect
1-Hexanol, 2-ethyl			2.5	1
2H-1-Benzopyran-2-one	2.3			3, 6s, 7s, 10s, 12s
2-Propanol, 1-(2-methoxypropoxy)	2.1			3s, 5s, 6s, 7s, 8s, 9s, 10s
Acetaldehyde	7.4	3.0	8.6	2, 3s, 4s, 5s, 6s, 7s, 8s
Benzaldehyde		3.6		5s, 6s, 7s, 8s, 9s
Benzyl Benzoate	3.1			6s
Cinnamaldehyde, (E)-	2.9			7, 8, 9
Cyclohexane, methyl	4.2			6s
Cyclohexanone	5.3	6.7	24.5	3s, 4s, 6s, 7s, 8s
Formaldehyde	26.8	31.9	36.8	2
Hexanal		2.6		1
Hexane, 3-methyl	4.5			1
Limonene (Dipentene)				7, 8, 9
1-Methyl-4-(1-methylethyl)cyclohexene			9.2	1
o-Hydroxybiphenyl ([1,1-Biphenyl]-2-ol)			6.3	3s, 5s, 6s, 7s, 8s, 9s, 10s
O-Methylhydroxylamine	2.1	2.3	2.1	1
Phenol, 2-methoxy-4-(2-propenyl)	4.4			4s, 6s, 7s, 9s
Propanal	11.4	2.3	14.4	6s
Toluene (Methylbenzene)	4.1			3, 4s, 8s, 9s, 10s
2,2,4-Trimethyl-1, 3-pentanediol diisobutyrate			5.6	5s, 7s

1	unknown effect	5(s)	suspected kidney toxicant	9(s)	suspected gastrointestinal toxicant
2	known carcinogen	6(s)	suspected neurotoxicant	10(s)	suspected cardiovascular or blood toxicant
3(s)	suspected developmental toxicant	7(s)	suspected skin or sense organ toxicant	11(s)	suspected reproductive toxicant
4(s)	suspected immunotoxicant	8(s)	suspected respiratory toxicant	12(s)	suspected blood toxicant

environment may have been premature. Thirteen other toxicants present in the incubator air were known or suspected toxicants affecting systems including respiratory, gastrointestinal, and reproductive as shown in table 1.

4 Alternative materials

In many instances, alternative materials can be used that are not – or at least may be less – harmful to human health. For example, linoleum and rubber flooring can be used in healthcare environments instead of sheet vinyl. Carpets backed with chlorine-free and PVC-free materials such as polyvinyl buteral or thermoplastic that are installed using low- or no-VOC adhesives reduce or eliminate VOCs in the indoor environment [16]. PVC- and fibreglass-free wall coverings are more difficult to find, although no-VOC paint is readily available. Formaldehyde-free composite woods and solid polymer counter tops can substitute for laminated cabinets and counters. Furnishings made of steel, polypropylene, polyethylene, and wood can be used instead of PVC, acrylics, and other plastics. Soy-based foam is an alternative to urea formaldehyde foam. Fabric backed or moulded chairs can preclude the use of upholstery foam altogether, and selecting fabrics that are inherently stain resistant such as polyester eliminates the need for finishes such as brominated flame retardants. Rubber, polyethylene, or nylon membranes can replace vinyl mattress covers.

Regarding medical equipment, polyethylene and silicone are safer alternatives for tubing and enteral feeding tubes that typically are made from PVC and DEHP. Intravenous products may be made from polypropylene or polyethylene, materials that can be reclaimed and recycled. Glass is a substitute for some acrylic applications. Yet although these alternative materials, *e.g.*, linoleum, are safer to human health than more typical products such as vinyl floor covering, not all of these products are considered ecologically safe.

5 Needed substitutes

Alternative materials such as nylon, polyester, polyethylene, and polypropylene may not contain PBTs and may be low- or no-VOC products and materials, but they still may be harmful. Each of these materials relies on petroleum. Nylon fibre used in carpets and fabrics, for example, is extruded from petroleum. It may not be a PBT or a VOC and it ultimately may be reclaimed and reused in a technical cycle described by the cradle to cradle protocol [1], but it relies on fossil fuels. This is an enduring problem regarding “green” or sustainable materials. So often there is not an alternative material that is sustainable throughout its life cycle, from harvest to process, through packaging and shipping, installation, use, and maintenance, then reclamation, reuse, or disposal. Beyond the environmental effects are economic and equitable considerations regarding the sustainable nature of a product. If the work force necessary to bring a product to market is not paid a living wage, then the product, despite its “green” qualities, is not sustainable because the work force necessary for its production is not sustainable. If the product is a consequence of an economic trade-off such as compromising eco-tourism for mountain-top removal, then the product's economic impact is not sustainable and, thus, neither is the product sustainable. These are challenges that manufacturers must address.

6 Promise of new technologies and approaches

Almost daily, new technologies and approaches surface to address critical, global needs related to development of sustainable products and practices that support human and environmental health. Although development of truly sustainable products and practices remains complicated and complex, new directions of industrial activity that include nanoscience, closer looks at nature, and comprehensive approaches offer great promise for the immediate future.

Reyad Sawafta uses nanoscience and nanoengineering to develop products that are less costly to human and environmental health [17]. For example, Sawafta developed a drywall material that holds and releases heat, thereby reducing the amounts of fossil fuels necessary to heat a space. Incorporating into drywall phase change materials that store the energy they generate when changing from a solid to a gel enables the wall or ceiling surface of a room to absorb, store, and then release heat across the course of a day. In a separate project, Sawafta is using nanoarchitecture to develop diapers and other products intended to absorb moisture that either maintain or collapse their structure when wet. The diaper absorbs and holds moisture from an infant, for example, who is in either a supine or prone position. Yet if that diaper is then placed in a toilet, the nanoarchitecture that preserved the structure of the diaper when moisture was absorbed in specific ways begins to deconstruct. Because of the onslaught of moisture from all directions, the diaper degrades to the point that it may be flushed down the toilet rather than sent to a landfill.

Janine Benyus extols scientists and industrialists to study the ways and means of nature through biomimicry [18, 19]. She reminds us, for example, that spiders spin a fibre that is proportionally stronger than steel and is the consequence of "eating dead flies." She reminds us that barnacles produce an adhesive as strong or stronger than that produced using the best synthetic substances available, and that barnacles produce this adhesive under water. She reminds us that the feathers of peacocks do not include iridescent blue pigments, but rather a physical structure which bends light rays that we then perceive as "blue." Through workshops, seminars, and lectures, Benyus encourages thinking that models the effective processes of nature. As a consequence of this approach, more and more products and materials that mimic the healthful practices of nature are being developed such as structural paint which is based on the principle of bending light rays rather than adding pigments; self-cleaning paint that "rolls" drops of water down its surface collecting dirt and debris similarly to that of rain rolling off of leaves; and "gecko tape" that mimics the small vacuum spaces that geckos create with their feet that hold surfaces together without the use of adhesives.

Unfortunately, not all these technological processes using nanoscience and biomimicry are themselves sustainable. Nanoarchitecture, for example, can produce “nano” waste. Yet many manufacturers are looking toward renewable sources for materials. Plastics, for example, can be biodegradable when they are made from corn [20]. Soy-based foam can replace urea formaldehyde foam. Sugar cane rather than petroleum is being used to produce green polyethylene. Even in these instances, however, the potential for a secondary problem exists when food crops are diverted to industrial use. This is one concern surrounding ethanol made from corn. Instead of food crops, agricultural waste is sometimes used as a renewable source that does not compromise the food supply. Wheatboard or strawboard, for example, is a material often used in cabinetry that is made from the shafts of wheat. Kirei board is made from sorghum straw and can be used in cabinetry and furniture.

One last example regarding green products and materials is development of a sustainable standard for commercial textiles. This is an on-going effort by a multi-national Joint Committee for Sustainable Textiles coordinated by the National Standards Foundation. This standard considers environmental, equitable, and economic impacts throughout the supply chain of commercial fabrics including raw materials, suppliers, manufacturers, purchasers, fabricators, and users. The intent of the sustainable standard is not only to measure existing products and practice, but to set benchmarks for continued improvement and innovation.

7 Conclusion

Altering traditional or standardized use of materials is difficult not only because of the knowledge necessary to do so, but also because appropriate substitutes may not exist. Yet becoming knowledgeable about materials and viable substitutes is critical to designers and others who select and specify materials for our indoor environments. This is particularly important to individuals in healthcare settings who not only anticipate wellness, but who also are not positioned to affect their exposure to harmful substances. Designers and others responsible for the built environment shoulder this responsibility on behalf of the occupants of the space. Fortunately, global awareness and demand for more healthful products and practices is increasing and industries are responding with advancing technologies such as nanoscience, alternative approaches such as biomimicry, and comprehensive efforts such as the work of the Joint Committee for Sustainable Textiles.

References

[1] McDonough, W. & Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things,* North Point Press: New York, 2002.

[2] Wilson-Orr, L., Archer, J., MacMillan-York, E., MacIsaac, E., & Reid, A., Greening of a nursery. *Syllabus of the 20th Annual Gravens Conference on the Physical and Developmental Environment of the High Risk Infant:* Clearwater Beach, Florida, (no page number), 2007.

[3] Marshall-Baker, A. The design of neonatal intensive care units: Information gathering and practitioners as consumers of research (Chapter 6). *Informing*

Design, eds. J. Dickinson & J.P. Marsden, Fairchild Books: New York, pp. 159-190, 2009.
[4] Zadorozhnaja, T.D., Little, R.E., Miller, R.K., Mendel, N.A., Taylor, R.J., Presley, B.J., & Gladen, B.C. Concentrations of arsenic, cadmium, copper, lead, mercury, and zinc in human placentas from two cities in Ukraine. *Journal of Toxicology and Environmental Health,* **61**, pp. 255-263, 2000.
[5] United States Environmental Protection Agency (USEPA). Pollution Prevention and Toxics Website, Washington DC, http://www.epa.gov/opptintr/index.htm
[6] Waldman, P. Common industrial chemicals in tiny doses raise health issue. *The Wall Street Journal,* A1, 25 July 2005.
[7] United States Environmental Protection Agency (USEPA). Indoor Air Quality Website, Washington DC, http://www.epa.gov/iaq/voc.html
[8] Health Care Without Harm, http://www.noharm.org/all_regions/issues/toxins/pvc_phthalates/
[9] Calafat, A.M., Needham, L.L., Silva, M.J., & Lambert, G. Exposure to di-(2-ethylhexyl) phthalate among premature neonates in a neonatal intensive care unit, *Pediatrics,* **113(5)**, pp. e429-e434, 2004.
[10] Swan, S.H., Main, K.M., Liu, F., Stewart, S.L., Kruse, R.L., Calafat, A.M., Mao, C.S., Redmon, J.B., Ternand, C.L., Sullivan, S., Teague, J.L., and the Study for Future Families research Team. Decrease in anogenital distance among male infants with prenatal phthalate exposure, *Environmental Health Perspectives,* **113(8)**, (no page number), 2005.
[11] United States Environmental Protection Agency (USEPA). Polychlorinated biphenyls Website, Washington DC, http://www.epa.gov/osw/hazard/tsd/pcbs/index.htm
[12] Darnerud, P.O. Toxic effects of brominated flame retardants in man and wildlife, *Environment International,* **29**, pp. 841-853, 2003.
[13] Minnesota Department of Health. Perfluorochemicals Website, http://www.health.state.mn.us/divs/eh/hazardous/topics/pfcshealth.html
[14] United States Environmental Protection Agency (USEPA). Indoor Air Quality Website, Washington DC, http://www.epa.gov/iaq/formalde.html
[15] United States Environmental Protection Agency (USEPA). Technology Transfer Network Air Toxics Website, Washington DC http://www.epa.gov/ttn/atw/hlthef/acrylica.html
[16] Health Care Without Harm, http://www.premierinc.com/quality-safety/tools-services/safety/topics/epp/downloads/hcwh-alternatives-pvc-dehp.pdf
[17] QuarTek, http://www.quartekcorp.com/
[18] Benyus, L. *Biomimicry: Innovation inspired by nature,* New York: HarperCollins Publishers Inc.
[19] Ask Nature, http://www.asknature.org/
[20] NatureWorks LLC, http://www.natureworksllc.com/

The human side of the triangle: using green textile standards to address social responsibility

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Abstract

Textile specification in the interior design field has evolved to include attributes in addition to aesthetics, cost, building occupant health and safety, and specialized performance criteria. Initially, "green" specifications addressed environmental impact reduction through renewable, recycled, recyclable, non-toxic and low-emitting materials. Worldwide, third-party certifications continue to expand sustainable attributes to include social equity impacts on human health, safety, training and compensation throughout the product life cycle. Comprehension of these new assessment tools is essential for designers to effectively balance economic, environmental, and social responsibility.

Although social responsibility has been discussed in the context of global sustainable development since the 1970s, third-party evaluation attempts to systematically connect the effects of product manufacture, use, and disposal to the human condition are relatively recent. Environmental and social impacts are interrelated, but not interchangeable. Social equity criteria are not addressed uniformly in textile certifications. This paper presents research on designers' perceptions of social responsibility, awareness of social issues in the textile life cycle, and prioritization of textile specification criteria. The study also considers to what extent designers take responsibility for sustainable design decisions, and if sustainable design is becoming a standard practice. The analysis focuses on responses generated by a questionnaire distributed through an online interior design publication based in Texas (USA) and distributed internationally.

Keywords: social responsibility, interior design, life cycle assessment, material selection, sustainable textile standards.

1 Introduction

Spiegel and Meadows [1] have documented the attribute-based approach for green building product specification. Broadening business bottom-line economic goals to include both social and environmental benefits has evolved from early triad models by Elkington [2] and Lovins and Lovins [3] to those more specifically aligned with design as described by Bonda and Sosnowchik [4] and Pearson [5]. Currently, The Green™ Standard is developing specification tools for the global market that acknowledge U.S. Environmental Protection Agency environmental impact categories and expand a single attribute approach to focus on life cycle assessment [6]. Pearson [7] encourages more in-depth analysis to understand the complexities of human and ecosystem health throughout the product supply chain, for example, raw material processes, manufacture, delivery, installation, maintenance, and disposal. As Wendt [8] points out, “discussion of sustainability in the green building industry often focuses on the first two legs of the stool – economy and environment – with discussion of equity occurring only in relation to occupant health and other immediate concerns.” The current understanding of social equity extends beyond end user well being and embraces labour practices supporting fair or competitive wages and human rights concerns for safe work environments and equitable living standards for all those impacted throughout the product life cycle.

Although educational and professional standards dictate that interior designers take responsibility for sustainable design decisions, the studies done on designer attitudes reveal inconsistencies in what designers say they should be doing and actual practice. In her discussion of the “state of the contemporary interior,” Beecher [9] cites a 2000 Interior Design study which reports that 83 percent of designers surveyed believed they had a moral obligation to offer environmentally responsible solutions to their clients although only 37 percent indicated they actually did so. In their study of interior design practitioners in the American Society of Interior Designers, Kang and Guerin [10] found that in a series of statements on global interior design practice, indoor environmental quality and interior materials, “every statement showed the highest mean score in the category of importance to designer and the lowest mean score in the category of frequency of application.” Steig [11] has identified this phenomenon as “the sustainability gap [which] exists between theory and practice: between what we believe to be right and what we know to be right; between how we should practice sustainable design and how we are able to practice it.” The gap is based in a deficiency of reliable data combined with an overwhelming amount of information, limited access to transparent evaluative tools and a lack of critical analysis skills to fully understand and integrate them meaningfully into the interior design process [12]. Other perceived obstacles to a sustainable approach are client unwillingness, restricted aesthetic choices, and higher cost [13].

Using textile specification as a lens can be instructive in understanding designers’ awareness of social responsibility issues and the extent to which these issues are becoming part of sustainable design practice.

2 Framework

Although many nuances exist in language and definition, there is general agreement that sustainable development practices require a balance of economic, environmental and social impacts. This “triple bottom line” [14, 15] approach provided the context for an online survey questionnaire, *Social Responsibility and Interior Design*. The instrument included quantitative and qualitative items and was structured in four sections: Social Responsibility and Textile Specification, Sustainable Design Practice, Business Profile, and Demographic Profile.

Primary investigative question:

To what extent are interior designers aware of social responsibility issues?

In general:

- How do designers define social responsibility
- To what extent are social responsibility attributes considered for project work

Specifically related to textiles:

- To what extent are social responsibility attributes considered individually and relative to other attributes
- To what extent are social responsibility life cycle issues considered individually and relative to environmental impact life cycle issues
- What is the level of awareness held by interior designers of options for sustainably designed textiles?
    - Familiarity with related agencies, standards & certifications
    - What do designers value in certification criteria
    - What are designers’ sources of information
    - What influences designers to reference sustainable certifications
    - What influences designers to specify sustainably designed textiles

Secondary investigative question:

Is sustainable design becoming a “best practice”?

- What factors influence designers’ sustainable design decisions
- To what extent are designers taking responsibility for sustainable decisions
- Is there evidence of a “sustainability gap”?

2.1 Population and sampling method

Data were obtained for this research using a convenience sample of respondents from the contacts of PLiNTH & CHiNTZ, The Online Interior Design Magazine.

This publication provides advice on industry issues for current design students, new design graduates, design educators, and professional practitioners in design or affiliated industries such as design-related sales and service. According to the magazine's internal data, P & C attracts tens of thousands of readers per month from over 25 countries (primarily from the United States, followed by the United Kingdom, Australia and The Netherlands). Readers are both male and female, have a mixed ethnic composition, and an age range of 18-65 [16]. More specific demographic data on the sample population were not available to researchers.

Invitations to participate in this online survey were distributed through an email to approximately 9,200 who have signed up to receive "special events / notices", a prominent post on plinthandchintz.com, and a follow-up reminder in the magazine's monthly email newsletter, which goes out to approximately 9,900 who have signed up to receive it. Due to logistical limitations, a randomly selected sample was not obtainable. In addition, since the total number of "invited" respondents is unknown (due to the advertising methods described above and an unknown degree of overlap) a response rate cannot be calculated. However, given the exploratory and broad sweep of this investigation, generalizability is not a primary analysis goal and thus the non-probability sample should not be a major concern. Given this however, interpretations of tests of statistical significance should be viewed with caution. Focus in this analysis will be given to substantive significance and emergent themes.

Table 1: Years of experience.

How long have you worked (full or part-time) in the interior design industry?	**Frequency**	**Valid Percent**
Still in/just out of school and not employed	15	15.5
1-2 years	12	12.4
3-5 years	10	10.3
6-10 years	13	13.4
11-20 years	14	14.4
21+ years	33	34.0
Total	**97**	**100.0**

Table 2: Work activity.

Project type work activity	**Frequency**	**Valid Percent**
100% Residential	13	13.4
75% Residential/25% Commercial	20	20.6
50% Residential/50% Commercial	11	11.3
25% Residential/75% Commercial	9	9.3
100% Residential	24	24.7
Total	**97**	**100.0**

2.2 Description of the sample

72.2% of respondents are practicing (full or part time) interior designers, with the remainder composed of students (12.4%), recent graduates not working in the industry (7.2%), educators (6.1%), and design industry affiliates (2.1%). See Table 1 for years of experience.

38.1% are self-employed and 41.2% work for a company or institution. 57.7% responded that they did not work on any international projects. See Table 2 for percentages of work activity.

Designers were questioned about what percentages of their project work involves sustainable design strategies, green product specification, green building programs, and attention to socially and environmentally responsible issues. They were also asked to characterize their approach to these practices.

Demographically, respondents were U.S. residents (96.9%), Caucasian American (87.6%), female (85.6%), married (62.9%), 45+ years of age (49.5%) with a bachelors degree (59.8%). 41.2% have 1 to 2 children and 46.4% have none.

2.3 Analysis methods

Regression analysis was performed on data gathered on the quantitative items from the 97 respondents. Variables were constructed to describe relationships between levels of social responsibility awareness and design practice behaviours. For the qualitative comments, a particular goal was to "identify themes and subthemes," in order to gain insights from this study which will become the basis for future analysis [17]. Using a cutting and sorting technique, categories were identified based on repetition of topics and comparison across responses.

3 Findings

3.1 Social responsibility awareness

The open comment answers to the initial question, "Briefly describe your understanding of 'social responsibility' as it relates to interior design," revealed several major response categories (see Table 3). "World View" responses were characterized by broad, general statements about the environment and society. "Health, safety and welfare" was a consistent theme, with more emphasis on current than future users. For design process strategies, designers were interested in balancing social responsibility with client expectations and proposing timeless solutions. Materials selection techniques ranged from a general approach favouring green specifications to detailed product attributes. Designers also discussed social responsibility as a matter of individual ethics, but acknowledged that other factors often have the last word in project decisions.

3.2 Importance of social responsibility and the gap between independent ratings and relative rankings

Overall, participants expressed that social responsibility was an important issue for them in specifying textiles with 77.3% (75 respondents) indicating social responsibility was very or extremely important. However, 41% (40 respondents) still *ranked* social and environmental impacts as the two least important criteria in specifying textiles as they work in school or on the job. In this ranking, social impacts fared worse than environmental impacts, with 66% (64 respondents) ranking social impacts dead last as the least important factor in specifying textiles as they work in school or on the job.

Table 3: Social responsibility.

Category	Subcategory	Percent*
World View	Triple bottom line; society at large; cultural sensitivities	5.9
	Do no harm to the environment	4.6
Health, Safety, & Welfare	HS&W for clients; current end users	11.2
	HS&W for the general public; current population at large	9.2
	HS&W for human beings, environment over time; "future generations"	5.3
Design Process: Strategies	Conservation; waste reduction; timeless; inclusive	5.3
	Balance client requirements and environmental resources; making money and saving the environment; best value	4.6
	Meet or exceed client requirements	4.0
Design Process: Materials Selection	Reduce, reuse, recycle; locally sourced; non-toxic	11.8
	Sustainable approach; use green specs	8.6
	LCA; how product is made	7.9
	Certifications; standards	1.9
Practice	Individual ethics; responsibility to educate others; support community	14.5
	Provisional outcomes; look to others in industry to define responsibility	3.3
	Don't know; not sure	1.9
Total	*[* - 97 participants generated 152 responses]*	**100.0**

In addition, logistic regression of the relationship between respondents' ratings of the importance of social responsibility and their likelihood of ranking social and environmental impacts anywhere above the least important factor in specifying textiles revealed no statistically significant relationship. Rating social responsibility as very or extremely important did not increase the likelihood that social impacts would be ranked above the least important factor in specifying textiles (model χ^2 = 1.699, Df = 1, p value = .192), nor did it increase the likelihood that environmental impacts would be ranked above the least important factor in specifying textiles (model χ^2 = 2.737, Df = 1, p value = .098)

3.3 Textile standards and certifications

In 2005, the Association for Contract Textiles (ACT) began work with GreenBlue, NSF International, and ANSI to develop The Sustainable Textile Standard, scheduled for introduction in 2010 [18]. When asked what they had heard about the standard, 64.9% (84 respondents) had heard "nothing," or "very little." Designers were also asked to rate their familiarity with existing third-party standards. Respondents were "somewhat familiar" with the Greenguard Environmental Institute, and "not very familiar" with ISO 9000 and 14000. The remaining standards all received their highest scores in the lowest, the "not familiar," category: ACT; Scientific Certification Systems; C2C (MBDC), ©2009; GreenBlue, ©2006; SMaRT© Sustainable Textile Standard; Global Organic Textile Standard; Eco Labels; and Environmental Product Declarations.

When asked "What is important to you about a sustainable textile standard?", designers ratings were as follows: "extremely important" - prepared by a third-party agency rather than a manufacturer, and applicable to a green building program such as LEED®; "very important" - evaluates multiple green attributes, evaluates environmental life cycle issues, accessible and easy to understand; and "somewhat important" - evaluates socially responsible issues.

Designers were given multiple options to choose from as the sources for most of their information about sustainably design textiles. The top four choices were market based: manufacturers' literature, websites; manufacturers' representatives; trade publications; and trade shows and exhibits.

Two open comment questions addressed influences for interior designers.

Table 4: Specification influences.

"What influences you to specify environmentally responsible (ER) and socially responsible (SR) textiles?"	Percent*
Client request; project criteria	28.7
Green product concept; green characteristics desirable; LCA issues	15.5
World view of environmental stewardship and social responsibility; "good for all"	13.2
Personal beliefs; ethical, moral issue; responsibility to educate client	10.8
Nothing; ER and SR textiles are not used	8.5
Company standards; use when ER/SR textiles are available and project compliant	7.8
Manufacturers' information; third party certification	5.4
LEED® points	4.7
Miscellaneous attributes; aesthetics, availability; country of origin; health	3.9
Personal beliefs are pro ER/SR and in conflict with company	1.5
*[*97 respondents generated 129 responses]*	**100.0**

Table 5: Sustainable influences.

"What influences you to use sustainable textile standards or certifications?"	Percent*
Third party unbiased approach; anti-greenwashing	36.4
Nothing; not aware of sustainable textile standards	27.3
Client request; project criteria	19.2
Personal commitment; concern for environment and social responsibility	6.0
Use if available; not enough available; can't convince management	6.0
Recommendation by magazine or peers; promotional material; product portfolio	5.1
*[*97 respondents generated 99 responses]*	**100.0**

3.4 How do these attitudes affect what designers actually do?

Several items assessed respondents' actual practices of implementing sustainable design, green specifications, and socially/environmentally responsible design practices. Respondents' ranking of the importance of social responsibility did seem to be statistically significantly linked with their standard approaches to incorporating sustainable design strategies (chi-square = 35.885, p value < .001). 23% of those ranking social responsibility as "extremely important" characterized sustainable design as a standard approach required for all projects, while only 11% of those ranking social responsibility as "somewhat important" did the same. Conversely, only 10% of those ranking social responsibility as "extremely important" characterized sustainable design as offered only by client request, while 44% of those ranking social responsibility as "somewhat important" offered sustainable design approached only on client request.

Exploring this in terms of the percentage of respondents' work that was commercial revealed an interesting contradiction when this relationship disappeared for those respondents who worked primarily (75% or more of project work) in commercial projects. For those not working primarily in commercial projects this relationship remained consistent (chi-square = 26.643, p value = .002). For those in commercial projects, while 37.5% of those ranking social responsibility as "extremely important" characterized sustainable design as a standard approach to every project, 25% of those ranking social responsibility as "somewhat important" did the same, a difference of only one respondent that was not statistically significant (chi-square = 3.743, p value = .711).

At the same time that respondents' working primarily in commercial projects seemed to be using sustainable design approaches less on the basis of their own sense of the importance of social responsibility, they were also slightly more likely overall to report that incorporating sustainable design approaches were a part of the required standard approach to every project (27.3% for respondents' working primarily in commercial projects vs. 21.9% for respondents' working in residential or mixed projects). While this difference was not statistically significant (chi-square = 4.055, p = .256), considered in light of two other items (discussed below), this difference does warrant investigation.

When asked how often their projects require attention to and actually implement social and environmental responsibility (in four separate items), respondents working primarily in commercial projects were more likely to indicate these approaches were *required* of them and ultimately employed by them in a greater percentage of projects, particularly in terms of environmental responsibility. Of respondents working primarily in commercial projects, 39.4% indicated that attention to environmental responsibility is always or usually required of their projects as compared to only 25% of those working in residential/mixed projects, a difference that is not statistically significant (chi-square = 9.217, p = .056), but is substantively large. In addition to this, working primarily in commercial projects was associated with higher percentages of projects that actually *employ* sustainable design and green products specification (chi-square = 12.804, p = .012).

Further examination of this disparity revealed a similar pattern. For all respondents higher ratings of the importance of social responsibility were associated with a higher likelihood of being required to pay attention to social responsibility issues (r = .380, p <.01) and environmental responsibility issues.

4 Discussion

Although there was some evidence of the "sustainability gap" phenomenon [19], findings differed between the contexts of textile specification and general sustainable design practice. A high rating of importance of social responsibility was not linked to assigning a higher priority to socially and environmentally responsible attributes in textile selection. Disparity between theory and practice in textile specification was also indicated in designers' lack of awareness of evaluative tools. For example, although third-party certifications are valued for their objectivity, designers rely primarily on market-based information sources. In terms of sustainable textiles, for the most part, designers are not aware of the agencies that could provide the third-party information.

Table 6: ER & SR motivators.

Motivators		**Positive Outcomes**	**Negative Outcomes**	**Provisional Outcomes**
EXTERNAL	***Client***	Client requests ER/SR product	Client rejects ER/SR product	Ambivalent client/project requirements and/or company policy allows ER/SR product use if project criteria and ER/SR attributes align and if suitable product is available
	Project	Project criteria; LEED® points	Project criteria preclude ER/SR product	
	Company	Company standard practice	Company standard of low or no ER/SR value	
	Market	Manufacturers' information; peer and publication recommendation; ease of access	Scepticism; lack of trust	
	Third-Party	Unbiased information; awareness; ease of access	Scepticism; not accessible; not aware	
INTERNAL	***World View***	Environmental stewardship and social responsibility	No value placed on ER/SR products	Designer specifies ER/SR product if project criteria and ER/SR attributes align and if suitable product is available
	Professional Ethics	Personal responsibility to educate client and use ER/SR	Designer's beliefs in conflict with company	
	Holistic Approach	Sustainable design concept; LCA, HSW issues	Designer not aware of choices, evaluative tools	

In general practice, respondents' ranking of the importance of social responsibility did seem to be significantly linked with their standard approaches of incorporating sustainable design strategies. Furthermore, there was a link between ranking of the importance of social responsibility and the extent to which sustainable design practice was a standard project approach. Designers working on commercial projects seemed to be using sustainable design because this was a required approach rather than on the basis of their own convictions. The indication that sustainable outcomes are required in commercial projects is consistent with the fact that the commercial field is more regulated than residential design, and a commercial project is more likely to be part of a green building program.

Both qualitative and quantitative responses suggest that designers and their project work environments are at various stages in the development of sustainable practice. On the one hand, designers are motivated by external factors such as client preferences, project requirements, company management and standards, market information, and third-party certifications and testing data. On the other hand, many bring internal convictions for environmental and social responsibility through a personal view of the world, an understanding of professional ethics, or a holistic design approach. Seeking a balance between these factors was a common response. Some outcome scenarios were provisional or situational and occurred in the context of ambivalence of one or more parties.

The following model is instructive in understanding these dynamics.

5 Limitations and recommendations for future study

The web-based survey yielded a low number of responses, and since a randomly selected sample was not obtainable, it is not possible to speak to the objectivity of the participants. Individuals who had an interest in social responsibility may have been more likely to respond to the questionnaire.

More study is needed to explore the possible relationships between project type, social responsibility and sustainable design practice. Also of interest is whether specification of sustainable textiles or other product types generalizes to broader sustainable design practices. Other variables that could be explored include designers' length of experience and amount of international project work. The length of the questionnaire should be shortened to focus on targeted categories for the purpose of developing an instrument for evaluating social responsibility in interior design practice.

6 Conclusions

Interior design along with other professions in the building design and construction industry is in the process of changing the paradigm of how issues of social responsibility are addressed. Traditionally, professional and ethical standards of the interior design discipline have required that practitioners take responsibility for the consequences of decisions related to the health and safety of the public, e.g., individuals using and occupying the spaces they design. Although not yet mandated in the U.S., this same requirement is being extended in the European Union to individuals involved at all levels of the supply chain [20]. Triad models are evolving to be three dimensional and even four dimensional addressing life cycle impacts over time. Based on the trends toward an increasingly global perspective, it is not unreasonable to assume an increase in policy and regulation directed more specifically at both environmentally and socially responsible impacts and practice. This study supports that standard or best practice mandates may minimize or eliminate real or perceived obstacles to environmentally responsible and socially responsible decisions.

References

[1] Spiegel, R. & Meadows, D., Green Building Materials: A Guide to Product Selection and Specification, John Wiley & Sons: New Jersey, 2006.

[2] Elkington, J., Cannibals with Forks: The Triple Bottom Line of 21st Century Business, Capstone Publishing Ltd.: Oxford, UK, 1999.

[3] Lovins, A. & Lovins, L. H., Natural Capitalism: Creating the Next Industrial Revolution, Little, Brown & Co.: New York, 1999.

[4] Bonda, P. & Sosnowchik, K., Sustainable Commercial Interiors, John Wiley & Sons: New Jersey, 2007.

[5] Pearson, J., Design & Sustainability: Opportunities for Systemic Transformation, GreenBlue: Charlottesville, VA., 2006. Online. www.greenblue.org/PDFs/PEARSON Design+Sustainability.pdf

[6] Dunning, D. & Zander, R., A vision revisited: Sustainable product design + evaluation. The Green Guide to NeoCon® 2008, developed for Interiors & Sources® by The Green™ Standard, pp. 24-28, 2008. Online. www.isdesignet.com/articles/detail

[7] Pearson, J., Design & Sustainability: Opportunities for Systemic Transformation. GreenBlue: Charlottesville, VA., 2006. Online. www.greenblue.org/PDFs/PEARSON Design+Sustainability.pdf

[8] Wendt, A. Building for people: Integrating social justice into green design. Environmental Building News, 18(10), pp. 1, 10-15, 2009.

[9] Beecher, M. A., What's new? What's now? What's next? Interiors & Sources, (January-February), 2003. Online. www.interiorsandsources.com/articles/detail.aspx?contentID=3776

[10] Kang, M. & Guerin, D., The state of environmentally sustainable interior design practice. Proceedings of the Interior Design Educators Council (IDEC) 2006 Annual Conference, pp. 43-47. Online. www.idec.org/pdf/06ConferenceProceedings.pdf

[11] Steig, C., The Sustainability Gap. Journal of Interior Design, 32(1), pp. vii-xxi, 2006.

[12] Crane, T. J., Sustainable Design as Second Nature Incorporating Sustainability into the Interior Design Curriculum. Thesis (M.F.A.)—Florida State University, 2008. Online. http://etd.lib.fsu.edu/theses/available/etd-07122008-140432.

[13] Jones, L., (ed). Environmentally Responsible Design: Green and Sustainable Design for Interior Designers, John Wiley & Sons: New Jersey, 2008.

[14] Elkington, J., Cannibals with Forks: The Triple Bottom Line of 21st Century Business, Capstone Publishing Ltd.: Oxford, UK, 1999.

[15] Bonda, P. & Sosnowchik, K., Sustainable Commercial Interiors, John Wiley & Sons: Hoboken, New Jersey, 2007.
[16] McDonald-Stewart, L. Personal communication, 20 July 2009, Founder and Editor, PLiNTH & CHiNTZ, The Online Interior Design Magazine, Dallas, Texas.
[17] Ryan, G. W. & Bernard, H. R., Techniques to Identify Themes. Field Methods, 15(1), pp. 85-109, 2003.
[18] The Sustainable Textile Standard, www.greenblue.org/activities_stm.html
[19] Steig, C., "The Sustainability Gap. Journal of Interior Design, 32(1), pp. vii-xxi, 2006.
[20] Dunning, D. & Zander, R., A vision revisited: Sustainable product design + evaluation. The Green Guide to NeoCon® 2008, developed for Interiors & Sources® by The Green™ Standard, pp. 24-28, 2008. Online. www.isdesignet.com/articles/detail

Section 9
Case studies

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Sustainable buildings in Austria – performance indicators and implications on the construction industry

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Abstract

Energy consumption in the building sector accounts for more than one-third of energy consumption in Austria. Heating energy consumption has been decreasing due to defined heating energy indicators required by subsidy schemes, and since 2009 also by the revised building codes, as required by the EPBD. However, electricity consumption has been rising due to increasing cooling needs, in non-residential buildings as well as in residential buildings. Therefore, emphasis is not only necessary to reduce heating energy use, but also on encouraging sustainable methods of ensuring summer comfort, for example through facilitating integrated design. This brings architects and energy engineers together in the early planning stage to limit overheating in summer by architectural design, passive measures, and solar cooling. To promote this development, the Austrian klima:aktiv building standard has been developed. The standard sets requirements to be met for heating and cooling needs, user comfort, ecological construction materials, and material use. Buildings meeting all the requirements are awarded the klima:aktiv label, and in addition they meet the basic requirements to achieve the even more ambitious building certificate according to TQB (the Austrian national sustainable building certification scheme). The combined step-wise model was chosen to lower the barriers for companies to become familiar with environmentally conscious construction. This contribution provides an overview of the Austrian building sector and the policy instruments applied to decrease energy consumption for heating and cooling. It points out the implications on the construction sector by describing case study buildings with excellent environmental performance.

Keywords: green building assessment, sustainable building, climate change.

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1 Introduction

Residential buildings represent the majority of the Austrian building stock: according to statistical analysis carried out by Statistics Austria, in 2001 there were 2.05 million buildings and approximately 3.86 million dwellings. Three quarters of all Austrian buildings are single family households and detached houses, and 14% are non-residential buildings. Concerning the number of flats, the distribution is more or less equal between single family houses and detached houses, and apartment buildings. 21% of residential buildings were constructed before 1919, and 47% were constructed in the period between 1945 and 1981 [1–3]. The latter portion is most important in terms of constructed buildings as well as in terms of energy consumption and thus also energy saving potential. In these buildings, annual energy use for space heating exceeds 200 kWh/m^2 in single-family houses and 145 kWh/m^2 in apartment buildings (see Figure 1).

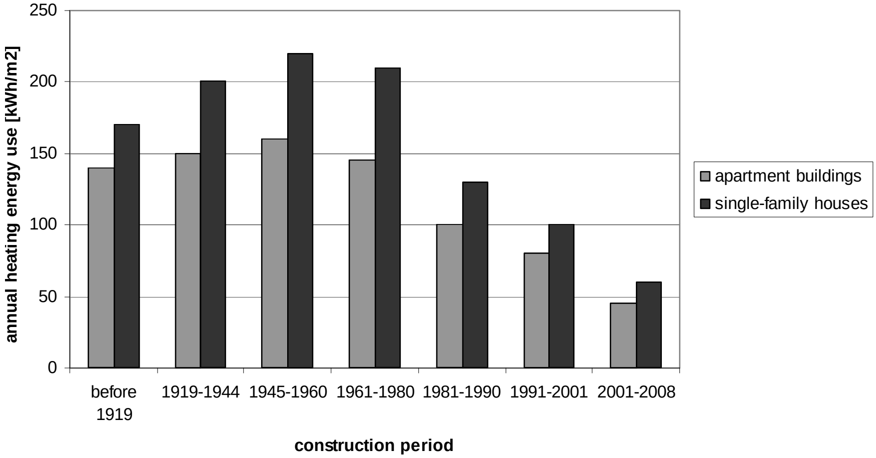

Figure 1: Heating energy use in residential buildings by construction period [3].

While energy use for space heating and energy use for domestic hot water is predominant in residential buildings, energy consumption patterns are more diverse in non-residential buildings, depending on the purpose of the building: hospitals, shops, offices, schools, etc., and there is little statistical information. However, it is evident, that electricity consumption is increasing dramatically, mainly due to cooling needs. Studies (reclip:more project) carried out to analyse the impact of climate change on Austrian regions show that the number of days with temperatures above 30°C will increase fourfold in the East of Austria [4]. As a consequence, electricity consumption is likely to skyrocket if no precautionary measures are taken.

In order to reduce heating and cooling energy consumption in the building sector, and to optimise buildings as a whole in terms of sustainability, a package of policy instruments has been applied in Austria.

These consist of measures to further develop the regulatory framework, while there are also subsidy schemes, voluntary schemes, awareness raising programmes, and research activities. This bundle of activities has caused a shift in building quality towards a building performance close to what can be called truly "sustainable", in terms of economic, environmental, and social aspects.

2 Subsidy schemes as drivers for sustainable buildings

The social housing subsidy scheme has been a driver for sustainable buildings in the residential sector. In Austria, the social housing scheme has a long tradition. Criteria are set up in way so that the majority of Austrians is eligible to apply. For many years, the social housing scheme has been extended towards including energy efficiency criteria, addressing renewable energy systems, and subsequently also to criteria targeting ecological materials. The social housing subsidy scheme provides additional money upon condition that energy and other ecological criteria are met. There are 9 provinces in Austria, and subsidy schemes as well as building codes are the responsibility of the provinces, thus resulting in 9 subsidy schemes and 9 building codes. Although this might seem not very efficient, there is a positive aspect in the competition among the provinces, resulting in a constant improvement and increasingly ambitious criteria and targets (see Figure 1 and Table 1). A treaty between all provinces and the federal government ensures that, among others, minimum requirements in terms of energy are met: heating energy use (useful energy for space heating; losses for transforming the energy in the heating system are not included; energy use for domestic hot water is not included, either) must not exceed the figures listed in Table 1. Limits are given considering the compactness of the buildings, described by the surface to volume ratio (A/V-ratio).

In this document, limits are also given for the new build construction of public non-residential buildings and for refurbishments of residential and public non-residential buildings [5]. They are more ambitious than the limits prescribed by the mandatory building code.

Table 1: Limits of heating energy use in the art. 15a agreement [5].

	Heating energy use in kWh/(m².a) for residential buildings, new build construction	
Minimum requirements	A/V-ratio $\geq$ 0,8	A/V-ratio $\leq$ 0,2
Until end of 2009	65	35
From 1.1.2010	45	25
From 1.1.2012	36	20

Regarding the social subsidy scheme, more ambitious targets are rewarded with more money. Funded measures include insulation of the building envelope, upgrade of windows, solar-thermal systems, biomass heating systems, heat pumps, district heating (traditional and based on renewable energy sources), controlled ventilation with heat recovery, and ecological materials. In addition, the municipalities are free to offer grants at the level of the community, for instance for better insulation or solar energy use. User behaviour strongly influences the actual energy consumption and is therefore also addressed by defined instruments such as energy advice programmes. For the non-residential sector, there is the environmental subsidy programme “Umweltförderung im Inland” provided at the federal level with corresponding programmes at the level of the Austrian provinces. This scheme addresses the building sector in terms of energy efficiency measures and installation of renewable energy systems [6].

3 Green building assessment

3.1 The Austrian green building assessment scheme TQB

In 1997, Austria joined the Green Building Challenge, an international platform for the development of green assessment schemes for buildings (successor organisation IISBE - International Initiative for a Sustainable Built Environment). At that time, the BRE Environmental Assessment Method (BREEAM, developed in UK) was in place and experiences delivered valuable input for establishing an international platform for green building assessment. In Austria, green building assessment schemes also offered an opportunity to address residential buildings outside the social subsidy scheme, and - even more importantly - to address the non-residential sector. There was the expectation that requirements regarding energy, materials, water, land, indoor air quality, emissions, and many others, would substantially facilitate the transition towards a sustainable building sector. However, it soon became evident that data generation, collection, and examination had to be adjusted to the Austrian planning and construction practice, in order to avoid high transaction costs. In Austria, small and medium-sized companies are predominant, and it was the objective to provide a tool for widespread application. Therefore, the Austrian TQB (Total Quality Building) assessment scheme was developed (at that time called “TQ – Total Quality assessment scheme”, which was changed after a major revision of the system in 2009) and put into operation in 2003 following a testing phase [7]. A survey conducted among developers clearly pointed out that performance criteria limited to energy efficiency measures, renewable energy technologies, and ecological materials would lack acceptance. However, developers were willing to apply a comprehensive building assessment scheme which includes aspects such as noise protection, indoor air quality, flexibility, and others besides environment-related criteria. Furthermore, the assessment scheme should be useful as a quality control tool as well as a marketing instrument. Therefore, the TQB assessment scheme was composed of a comprehensive set of criteria to be applied at the very beginning of a project and to adjust design targets according to the criteria to achieve a good assessment result. In order for buildings to pass the TQB assessment, checks are made twice, first at the end of the planning stage and then after completion of construction. The objective is to ensure that the building was constructed in compliance with the design which will be especially important if the building is designed in an integrated way. In this case, architectural aspects and energy technology aspects are intertwined and small changes during construction to reduce costs will result in substantial problems concerning comfort and energy performance during building operation. After the planning phase, drawings and calculations are checked, and after completion the compliance with the design is examined, and measurements are carried out.

Figure 2 shows the concept of the Austrian building assessment scheme.

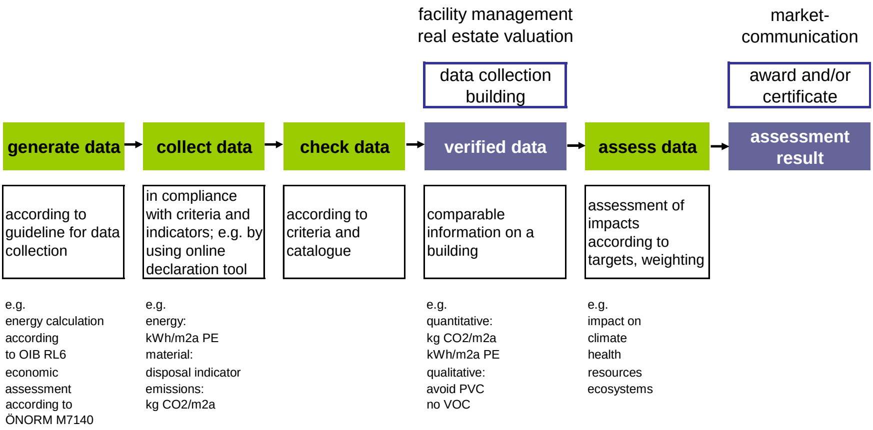

Figure 2: The concept of the Austrian TQB green building assessment scheme.

3.2 Climate protection and klima:aktiv building standard

In 2004, the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management launched the climate protection programme “klima:aktiv”, aiming at a substantial reduction of CO_2-emissions and a substantial increase in energy efficiency [8]. The programme addresses the relevant sectors, including construction, industry, households, and transport by funding comprehensive activities such as the production of information material, consulting services, network development, and the elaboration of quality control procedures. One sub-programme addresses the building sector by offering a building standard for residential and non-residential buildings, for new build constructions as well as for refurbishments. This standard consists of selected criteria of the TQB standard with a focus on outdoor and indoor environment, to communicate individual benefits along with the reduction of CO_2-emissions. Good indoor living quality through avoiding overheating in summer, ensuring thermal comfort in winter, fresh air, and avoiding indoor pollution raises demand for klima:aktiv buildings, at the same time resulting in more CO_2-savings.

The criteria system comprises the following categories:

- A Design and Construction
- B Energy and Supply
- C Materials and Structure
- D Comfort and Indoor Air Quality

All categories consist of several sub-criteria. Categories A, B, C, and D are the same for residential buildings, non-residential buildings, new build constructions, and refurbishments, but sub-criteria and allocation of points are different, taking into account differing options and priorities.

Table 2: Overview of klima:aktiv criteria for non-residential buildings [8].

New build construction	Refurbishment
A Design and construction	
Avoidance of individual motor car traffic	
Simplified calculation of life cycle cost	
Product management to avoid harmful substances in construction materials	
Minimization of thermal bridges in the design stage	
Energy efficient and natural ventilation	---
---	Inspection to detect harmful substances
---	Examination of compression opportunities
Construction of airtight building envelope	
Installation of monitoring devices for control of energy consumption during operation	
B Energy and supply	
Heating energy use (space heating)	
Cooling energy use	
Daylighting	---
Primary energy use	
Renewable energy use	
---	Energy efficient ventilation system
C Materials and structure	
Avoidance of substances harmful for the climate	
Avoidance of PVC	
---	Ecological optimisation of materials
OI3 indicator of thermal envelope	---
Disposal indicator for the building	---
Use of certified building products	---
D Comfort and indoor air quality	
Comfort in summer (avoidance of overheating)	
Controlled ventilation with heat recovery and optimisation regarding quality of air, sound protection	As per new build construction or optimised outdoor air ventilation (sound protection)
Actual air quality in compliance with guidelines for indoor air quality	

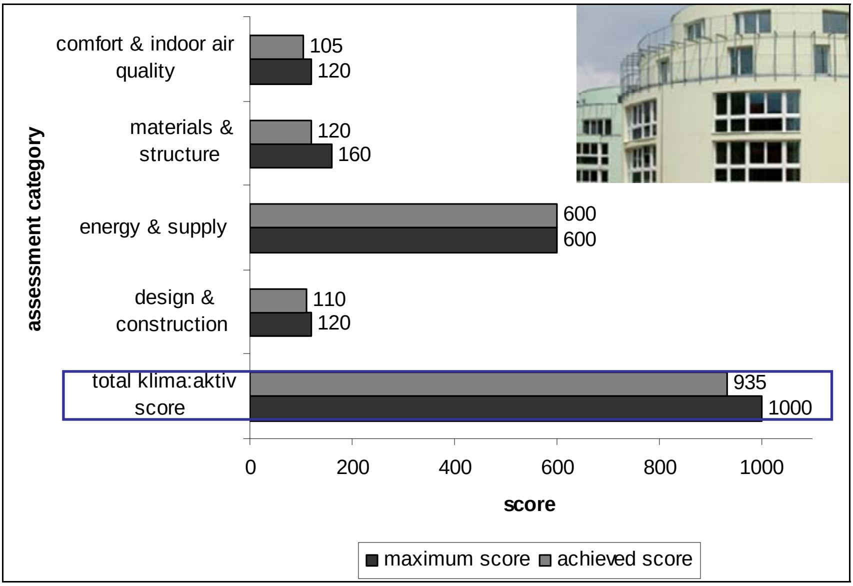

Figure 3: klima:aktiv residential building: part of documentation of passive house Dreherstraße 66, Vienna (5 storeys, 27 flats) on the database [9].

Compliance with klima:aktiv criteria is demonstrated by uploading the requested documents for a specific building to the klima:aktiv database. After having passed a plausibility check, the building owner receives the klima:aktiv award, and the description of the building is activated on the database. The description is accessible for the public and provides detailed information on the energy concept of the building, on materials used, on companies involved in the design, and more. It also displays how many points the building achieves compared with the maximum available score (example residential building, new build construction, see Figure 3).

The publication of this information and relevant data such as lectures, folders, and newsletters contribute to creating awareness to the advantage of eco-buildings.

In 2004, an awareness raising campaign on energy efficient buildings started on the European level. The GreenBuilding programme is funded by Intelligent Energy Europe and addresses specifically energy efficiency in the non-residential sector, aiming at achieving substantial reductions in energy consumption. Building owners who fulfil the requirements are awarded the GreenBuilding partner status [10]. In Austria, the GreenBuilding project has been carried out in close connection with the klima:aktiv programme. Often, carrying out energy efficiency measures to achieve the status of a GreenBuilding partner is just the first step towards broad improvements. Since 2009 the klima:aktiv building standard for non-residential buildings has been in place, offering the opportunity for GreenBuilding partners to receive the klima:aktiv award for high quality also beyond the energy sphere. The Austrian GreenBuilding project and the klima:aktiv programme are both managed by the Austrian Energy Agency.

3.3 Example: business centre: Niederoesterreich

The GreenBuilding partner status and the klima:aktiv label were awarded in November 2009. The building complex houses those institutions of the province of Lower Austria which offer information and services for entrepreneurs. There are 4 buildings which represent the four quarters of Lower Austria, also demonstrated by using different materials for the façades. Façades are highly insulated, windows meet passive house standards, and the buildings are equipped with a highly energy efficient controlled ventilation system. Primary energy consumption is low due to free cooling, and energy is provided by a heat pump, while using thermal-active building components for heating and cooling.

The indoor air quality is excellent due to the management of chemicals during procurement and construction. A process defined by the klima:aktiv building standard ensured that products containing volatile organic compounds (VOCs) were completely avoided. Energy monitoring secures energy savings during operation, and data are displayed on a screen in the lobby to raise awareness to employees and visitors [11].

Figure 4: Business centre Niederoesterreich (© Kammeter).

3.4 Step-wise system: energy certificate - klima:aktiv - TQB

Since the full implementation of the EU Directive 2002/91/EC (EPBD) in 2009, a step-wise system has been in place. The combined model was chosen to lower barriers for companies to become familiar with environmentally conscious design and construction. It was the objective to make use of the dynamism stemming from the EPBD, and to facilitate market penetration of eco-buildings by linking the voluntary, environment-related klima:aktiv building standard with the mandatory energy certificate [12, 13]. Therefore, the klima:aktiv category "B Energy and Supply" fully corresponds with the energy certificate. On the way towards a sustainable building, the first step is a good energy performance documented by the energy certificate. If the developer or building owner seeks good performance beyond the energy sphere, the klima:aktiv criteria "A Design and Construction", "C Materials and Structure", and "D Comfort and Indoor Air Quality" can be fulfilled, and after a plausibility check the klima:aktiv label will be awarded. If the building owner or developer is ready to document that the building achieves high quality also in terms of noise protection, flexibility, and other criteria, then there exists the option to build upon the klima:aktiv data and to extend the data collection in order to receive the TQB certificate. As a condition, the building must pass a detailed check of data.

klima:aktiv was developed based on a study commissioned by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, and TQB was developed based on studies commissioned by the same ministry, the Austrian Federal Ministry for Transport, Innovation and Technology, and the Austrian Federal Ministry of Economy, Family and Youth.

Since 2009, the ÖGNB - Austrian Council for Sustainable Construction has been running both building assessment schemes [14].

4 The role of research and demonstration

The Austrian research programme "Building of Tomorrow" is an integrated research programme which funds research projects, prototype development, and demonstration projects. Since 1999, numerous projects have been funded, among others the development of the TQB building assessment scheme.

Sustainability requirements resulted in development of new products and technologies, such as [15]:

- Thermal flat collectors to be used as 'facade collectors', which can be installed without any back ventilation onto facades. The new component represents a high architectural quality and style element for facades, and can be recycled after the lifetime has ended.
- Photovoltaic modules for building integration. PV-modules provide energy and at the same time take over additional functions such as building covering or shading. They can be manufactured on demand in various sizes, and due to their "break-through security" the modules are applicable for facades as well as overhead glazings.
- Single-stage adsorption chiller working with water as cooling agent and silica gel as adsorbent agent for a low range of performance (2 to 50 kW refrigerating capacity), and based on energy supply with hot water, provided by solar panels or district heating.
- Product development for the inside thermal insulation for houses designated as having special historic status, with restrictions concerning the insulation of outer walls.

Demonstration buildings were constructed using new concepts, products and technologies developed in the research programme. Demo-projects are easy to be found with the “Buildings of Tomorrow” roadmap, which is available on the programme website [16].

4.1 Demonstration building office building: Tattendorf

The objective was to encourage (1) the sustainable production of energy, (2) the use of sustainable energy efficient technologies, and (3) the use of sustainable building materials. The clay-wood-straw passive house construction is based on prefabricating large sized modular parts. The demonstration project generated valuable findings on construction details concerning the degree of prefabrication and cost reduction for future production.

The outer surface of the building consists of biofibre-clay and a section of the facade was built as a translucent thermal insulation based on reed by way of trial. The building is characterised by a very comfortable indoor climate, having avoided the creation of substantial sources (for example glue) of synthetic VOCs.

The integrated design team used simulation methods to optimise the building as a whole. After completion, the building was equipped with sensors to measure energy performance and comfort during building operation.

Evaluation results pointed out clearly that comfort targets as well as energy performance targets were fully achieved.

Figure 5: Office building Tattendorf, construction of south facade [17].

5 Conclusions

Energy efficiency is improving fast due to the mandatory requirements set by the building codes which have been revised in the course of the EPBD implementation. Awareness raising programmes such as the EU-funded GreenBuilding project have contributed to lowering the barriers for owners and developers to become familiar with energy efficiency aspects. Voluntary comprehensive building assessment schemes such as the Austrian klima:aktiv building standard address quality aspects beyond the energy sphere and contribute to constantly improving building quality not only in terms of energy efficiency but also regarding renewable energy use, indoor air quality, and other quality criteria. In Austria, the combination of mandatory and voluntary instruments, research funding and subsidies has resulted in energy savings and improved building quality. However, constant improvement never ends, because the best available standard is defined in relation to what is technically feasible and economically reasonable. Therefore targets and indicators of sustainable building assessment schemes are changing with the progress they cause, and vice versa. Thus, the next major revision of building assessment schemes is pending, also in the light of the EPBD Recast [18]. Among others, the term “nearly zero energy buildings” still poses a challenge for method development regarding the balance of energy flows in a building. However, work can build upon ongoing research activities, such as Task 40 “Towards Net Zero Energy Solar Buildings” carried out in the Solar Heating and Cooling programme of the International Energy Agency [19]. Requirements of the EPBD Recast will also activate further development of comprehensive building assessment schemes and facilitate the transition towards a sustainable building sector.

References

[1] Statistik Austria, Gebäude- und Wohnungszählung 2001.

[2] Energy Economics Group, Vienna University of Technology (2009): Energieszenarien bis 2020: Wärmebedarf der Kleinverbraucher, im Auftrag des Umweltbundesamtes.

[3] Lang, G.; Lang, M. (2009): CO_2 und Energie im Wohnbau. Wien: IG Passivhaus Österreich.

[4] reclip:more project website, http://foresight.ait.ac.at/SE/projects/reclip/

[5] Vereinbarung gemäß Art. 15a B-VG zwischen dem Bund und den Ländern über Maßnahmen im Gebäudesektor zum Zweck der Reduktion des Ausstoßes an Treibhausgasen. http://www.wien.gv.at/recht/landes recht-wien/landesgesetz blatt/jahrgang/2009/pdf/lg2009045.pdf

[6] Kommunal Kredit Public Consulting, http://www.public-consulting.at/en/portal/

[7] Geissler, S.; Bruck, M.; Lechner, R. (2004): Total Quality (TQ) Planung und Bewertung von Gebäuden. Wien: Berichte aus Energie- & Umweltforschung 08/2004, Bundesministerium für Verkehr, Innovation und Technologie.

[8] Austrian climate protection programme, http://www.klimaaktiv.at/article/archive/11911/
[9] Building documentation, http://www.baubook.at/kahg/index.php
[10] Green Building project website, http://www.eu-greenbuilding.org/
[11] Business Center Niederoesterreich: data for klima:aktiv assessment
[12] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (EPBD). Official Journal of the European Communities, 4.1.2003.
[13] OIB Richtlinie 6 Energieeinsparung und Wärmeschutz, Ausgabe: April 2007. Wien: Österreichisches Institut für Bautechnik.
[14] TQ and TQB certified buildings, http://www.oegnb.net
[15] Description of the research programme and reports for download, http://www.hausderzukunft.at/english.htm
[16] Map for download, http://download.nachhaltigwirtschaften.at/hdz_pdf/oesterreich_demonstrationsgebaeude.pdf
[17] Meingast, R. (2005): Lehm- Passiv Bürohaus Tattendorf. Wien: Berichte aus Energie- und Umweltforschung 29/2005, Bundesministerium für Verkehr, Innovation und Technologie.
[18] Agreement on EPBD Recast 18. November 2009, http://www.eceee.org/buildings/EPBD_Recast/
[19] IEA Task 40 “Towards Net Zero Energy Solar Buildings”, http://www.iea-shc.org/task40/

Advanced technologies for sustainable building in the protected areas: two case studies in Italy

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Abstract

For some years now the General Directorate for the Protection of Nature of the Italian Ministry for the Environment, Land and Sea, and the Department of “Fisica Tecnica” of the “Sapienza” University of Rome have been collaborating on issues such as sustainable development in protected areas and new technologies concerning innovative low-impact materials to be used in areas of particularly high environmental sensitivity.

The first case study presented for the Protected Areas deals with a pilot project in a suburban green area jointly individuated with the “Assessorato all’Ambiente” of the Municipality of Rome designed to evaluate low-impact building in contexts of environmental “Excellency”, such as parkland in urban areas, city outskirts, green areas and national parks. In line with the Strategic Environmental Evaluation, the reversibility of such buildings has been evaluated with particular care, although other considerations, such as aspects related to the education towards sustainability in architecture, were also looked into.

Research has been oriented towards pinpointing ‘new’ envelope technologies in which to assembly components and technical solutions already known as “sustainable” and/or “energy efficient” (such as coat insulation, roof garden, ecologically compatible materials such as wood, etc.), but whose combined application has not yet been tested as a whole complex system.

During the realization of this 500mq eco-sustainable structures the following technologies have been included: wooden structures and sheathing for a low energy consumption and naturally recyclable material; green roof coverings; systems for water cycle management; solar collectors for hot water production and photovoltaic systems; high performance glass in terms of light transmission, solar control and thermal insulation.

The second case study, coming from the experience of the pilot project, is the realization of a 15 mq infopoint that is energetically self sufficient in the

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protected area of the Asinara island (Ardito S., Parks of Italy – the protected areas system, Italian Environmental Ministry – Carsa Edizioni, 2004, 226-230 – abstract).

This structure is made of a light architecture supporting a controlled and didactical use and fruition of a critical environment; this bungalow is made of a wooden modular shape with low technological equipments, based on the principals of prefabrication and low energy consumption, fed only by 1,5 kWp photovoltaic system integrated into the roof.

In this paper are summarized the first preliminary results of the monitoring campaign actually performed in both structures.

Keywords: sustainable, integrated, green energy, solar energy, energy efficiency, sustainable technologies, natural elements, climatic resource, saving CO2.

1 Technology for sustainable buildings

According to a general protocol regarding the Best Available Technique for building construction in the protected areas pointed out by the Department of Fisica Tecnica and the for the Italian Environmental Ministry, the application of the following technologies has been evaluated for the two pilot projects [2].

1.1 Wooden structures and sheathing for a low energy consumption and naturally recyclable material

Much used in building, wood is prized on account of its resistance and because its structural performance has qualities that are akin to steel. As a low energy material, its production cycle optimises the use of a material that is poor in itself but which offers elements that are not otherwise used because of their size (dimension and transport).

As well as being aesthetically pleasing, wood for structure is also innovative and reliable: Reliable because its entire production process is ruled and continuously monitored. The end result is a product with definite and certifiable performance. Innovative because planning, working, assemblage and joining techniques are in continuous evolution and offer increasingly broad prospects in terms of feasibility and cost containment.

The overall pleasing effect of timber in architecture derives from the fact that the material is selected also with this in mind and is presented in all its naturalness, compact and without defects. Among the many advantages of timber are its excellent thermal, electric and acoustic insulating properties; it is a hygroscopic material that is therefore able to reduce humidity fluctuations from the surrounding environment; an organic material made up of roughly 50% carbon, 42% oxygen, 6% hydrogen, 1% nitrogen and 1% other elements.

Timber in buildings has a substantially higher resistance to fire than most other traditional construction materials such as brick or steel. When exposed to fire, the supporting wood elements guarantee a good level of static security for a building and offer a visual warning of fire, not considering chemical fireproofing treatments that can be toxic in the event of combustion.

1.2 The application of green roof coverings

The chronic lack of green in built up areas is an issue with far greater implications than the enjoyment of the inhabitants of a town. The overwhelming presence of asphalt and cement in the reflecting surfaces of buildings in cities concerns both the health of the buildings themselves and the quality of life of town dwellers. Although little can be done to mitigate the over-heating of road surfaces, with the exception of areas used for parking, it is nonetheless both useful and possible work on the asphalt and cement rooftops of buildings.

On a summer day the horizontal surfaces of buildings exposed to the sun can reach temperatures of up to 80°C, with temperatures dropping to as low as 20°C at night. This means that there is a temperature difference of around 60°C. In wintertime the temperature of building surfaces in northern Italy can drop to around -20°C, which means that in a year the surface temperature of a building can vary by 100°C or more.

Besides the structural stress such temperature variations subject buildings to, the phenomenon of general heating in urban areas entails rising costs through the use of conditioners and consequently further overheating from the emissions of convectors. This generates the phenomenon known as "urban heat islands", which the Department "Fisica Tecnica" has been looking into also with studies aimed at pinpointing ways in which it can be mitigated. The green covering of flat-roofed buildings provides a number of key services for urban contexts. As well as contributing to the production of oxygen in built up areas, such coverings act as filters for fine dust particulate produced by traffic and reduce noise pollution. They also act as a natural attenuator for the variations in temperature described above: up to 25°C between night and day in the summer and a minimum of -10°C during winter. One must also consider the recreational value such coverings offer to citizens, both in terms of direct and indirect fruition, through access to pleasant and ventilated green areas in areas where the presence of high rise buildings necessarily means that green areas at street level would not enjoy the same advantages.

1.3 Overall water cycle

Despite being the third country in the world in terms of water consumption after Canada and the United States, for four months a year (June to September) in Italy roughly 15% of the population – which corresponds to eight million people – receives less than the accepted minimum daily water supply of 50 litres a day per person. Italy's water resources are absorbed 60% by the country's agricultural sector, followed by 25% for energy and industry and 15% for civilian use. The most indicative figure, however, is that the country's entire water needs are covered by the drinkable mains water system, which entails vast costs both in social and financial terms. Most of the consumption is taken up by non-drinkable uses such as WC flushing, watering and household appliances such as dishwashers and washing machines. Up to 50% of water consumption in this sector could be replaced by stored rainwater or recycled water.

Systems for storing rainwater provide water for a number of uses and permit considerable saving of drinkable water in private homes, public buildings and in industry. Trapping rainwater also reduces the risk of damage from heavy rain, which otherwise ends up in water purifying through the sewers, considerably reducing their purifying capacity. Rainwater trapping systems are essentially made up of three parts: cistern, a filter and a pump. Rainwater runs off the roof and is channelled by a system of drainpipes into a collecting tank. From here the water runs through a filter into cisterns with a float that stops more water pouring in when the full mark has been reached and that are protected against small animals entering.

A submerged pump carries the water into a decanting tank, whereupon the water can be used for the household's nondrinking needs. Spacer permitting, human sewage can also be channelled into constructed wetland systems, which are relatively easy to install in tanks placed in holes dug into the soil and equipped with filter grills that can be inspected. These are then filled with gravel and planted with plant species with known filtering properties. These simple systems provide water that can be used for watering or reintroduced into the water cycle of the sustainable household as a means for the water closet.

A sustainable integrated water cycle clearly implies separate plumbing systems for drinkable and non-drinkable water, which entails adaptation costs for existing buildings. Such costs can be considerably reduced if separate plumbing systems are incorporated into the initial design of new buildings.

1.4 Solar collectors for the hot water production and photovoltaic systems

Within the framework of a generalised reduction in energy consumption, a number of local administrations in Italy have approved incentives for the energy sector in civilian urban developments. The City of Rome in particular has deliberated that all new constructions must be provided with renewable energy sources. All newly constructed buildings for private use must be reliant on renewable energy for 30% of total consumption and at least 50% for the production of hot water. The deliberation pays particular attention to the aesthetic aspects of solar panels. Each installation must be evaluated with a view to striking a balance between the best possible exposure to the sun and the need to preserve Rome's historic and artistic heritage.

Thermal panels heat water for domestic use without consuming either gas or electricity.

A first comparison marker of the different technologies available can be obtained by measuring the average quantity of carbon dioxide released into the atmosphere, in comparable conditions, for the production of hot water for domestic use. The energy analysis revealed that the power consumption of a family of four for the production of hot water, using an electric boiler, amounts to 7.74 KWh (electric)/per day. In order to produce one KWh of power, stations in Italy release an average of 0.58 kg of carbon dioxide (CO_2), one of the chief gases responsible for the greenhouse effect4. This means that only for its household hot water needs an average family that uses an electrically powered boiler releases roughly 4.5 kg of CO_2 a day into the atmosphere (1.125 kg per person a day). Methane powered boilers release 0.25 kg of CO2 for every thermal kwh produced, which means that a family of four produces 1.74 kg of CO2 per day (0.435 kg of CO2 per person a day).

Solar panels providing an integrated source of energy to combine with gas powered boilers offer an interesting alternative today. These combined solar/gas systems ensure the same level of comfort throughout the year, and on latitudes such as Rome's offer a saving of roughly 60% on the annual consumption of gas. This means that the same family of four can reduce its daily CO2 emissions to 0.69 kg, for a daily average of 0.174 kg/CO2 per person. The production of hot water for domestic use from an electric current passed through the resistance of a boiler is costly in energetic, to gas powered boilers. Where possible, substituting electric boilers with an integrated solar/gas system could therefore be of interest to a high number of domestic and a small number of public consumers.

Photovoltaic systems reduce the energy demand from traditional sources and contribute to the reduction of atmospheric pollution (carbon dioxide emissions that would otherwise be produced by power stations).

Power produced with photovoltaic costs nothing in terms of fuel: for every kWh produced with this system there is a saving of 250 grams on oil consumption and a reduction of 700 grams of CO2 emissions, not to mention other gases that contribute to the greenhouse effect. This necessarily translates into an overall environmental and financial advantage. Given that a system of this sort lasts about 30 years and that a small 1.5 kWp system can cover two thirds of the electricity needs of an average Italian family (2,400 kwh), during its lifespan one can estimate that it will produce 60,000 kWh. This would save roughly 14 tonnes of fossil fuels and avoid the emission of roughly 40 tonnes of CO2. In private dwellings and condominiums small solar panels can power appliances that are positioned in areas not served by electricity, such as gardens and the lighting of public spaces.

1.5 High performance glass in terms of light transmission, solar control and thermal insulation

A number of technologies including sun radiation control, aeration, passive heat absorption, anti-dazzling, privacy safeguarding, the increase of natural light and so on have been studied for glass in an effort to control and modify the quantity or quality of light. The aim of these new technologies is to optimise and make the most of natural light in indoor spaces by carefully controlling and optimising sunlight.

Special kinds of glass (coloured, reflecting, low-emission, antisolar) can be obtained by using sophisticated technologies and the spreading of oxides or metals over the surface. Together with evolved technology this has enabled an ever greater solar control, thermal insulation and a reduction in energy costs and consumption.

High performance glass is able to control solar radiation, maximising the ratio between light transmission and heat conductibility. Low emission glass keep heat indoors during winter thanks to a very low transmission coefficient and ensures cool during summer thanks to its low solar factor and low energy transmission.

The study of the performance of transparent building shells is therefore considered essential for containing energy consumption and improving energy efficiency in building.

2 The pilot project for the municipality of Rome

This pilot project, located in a 7000mq area of a Polyvalent Green Point of the Rome Municipality, works with all the described different passive and active technologies, located in the same area, in order to permit the realization of a didactical path where the end users and the scholars could appreciate the renewable energy production and CO_2 saved in real time through electronic screens.

Figure 1: Masterplan and render of Spinaceto building.

The ‘active’ elements are as follows.

• *Solar thermal panels*
This system is of a natural circulation kind, with the boiler visible. The panels are flat and the surface corresponds to a minimum module of 2 m2 of exposed surface and a boiler of roughly 300 litres;

• *Solar photovoltaic panels*
The available surface for setting up a photovoltaic system is 12 m2. Considering the installation of polycrystalline modules and a production of roughly 1 kW per 8 m2 of panel the production of electric power will be roughly 1.5 kW, which is enough to cover the energy requirements of communal areas.

• *Water cycle (active part)*
Conceived for providing collected rainwater for sanitary use, this system is composed of an underground tank that collects the water that is then pumped into the sanitation system (WC flushing); this system is integrated with the traditional plumbing system that covers the remaining water needs.

Figure 2: Photovoltaic lighting system.

Figure 3: Details of wood vertical closure structures.

The ‘passive’ elements are as follows.

• *Elevation and vertical closure structures*
These are made of external cladding: larch staves; air gap; conduction layer: wooden panel; thermal insulation; vapour barrier; vertical structure: laminated panels; internal cladding: wooden panel (spruce pine) [3].

The selected technology consists of a natural material (wooden panels) able to guarantee good seismic resistance coupled with thermal-hygrometric performances according to the D. Lgs. 192/05 and 311/06 (high energy performances in buildings).

• *Upper closure with roof garden*
These are made of the following layers: external cladding: grass, bushes and plants; cultivation soil; no woven polyester filtering separation layer; drainage; aeration layer; bituminous primer; insulation layer; vapour barrier; sloping layer; wooden structure.

2.1 The foundations

Wooden structures usually need continuous concrete slab foundation. Because of the structural building system, made with wooden continuous panels, plinths cannot be used. We need to find a continuous foundation system using less concrete than in a regular slab foundation and that requires a minimum excavation of the ground. In order to reduce the landscape impact, the foundations are designed as a concrete riddle along the perimeter of the building. This riddle is not deeply set in the ground thanks to the breadth of the one-storey wooden structure, preserving as much as possible the natural ground surface, thereby reducing the excavation and limiting the use of artificial materials such as concrete. This kind of solution permit an easy removal of the building envelope avoiding substantial changes at the natural landscape so that the same solution can be even applied in high natural value areas such as environmental protected ones.

2.1.1 The functional elements of the water cycle

A subsurface flow constructed wetland system has been devised for the building of wastewater treatments; it is composed of two subsequent and contiguous basins localised in the south side of the building. This kind of solution permits to avoid connection with the sewage system, without a long transversal excavation. In fact, the purifying effect is based on microbiological, physical, chemical and aquatic plant processes in the plant – gravel system. The first basin (Subsurface-flow), roughly 70 cm deep, should be waterproofed with a layer of clay and filled with different sized gravel without an open water surface. The waste-waters flow under the gravel surface, in order to avoid foetid aerosol. Macrophyte species will be planted in the gravel, with filtering and nutrients interceptive functions. The second basin (surface-flow), has a more educational function, and presents a central open stretch of water surrounded by a border of aquatic plants. Small inspection wells as well as grillage systems permit the monitoring of the water quality and remove non-degradable litter.

3 The project of the Asinara Island

The natural park of Asinara Island is one of the most important and interesting environmental protected areas of Italy which hosts some historical buildings used in the past years as hospitals and prisons; consequently the access to the island in the past 200 years has been strongly restricted and the absence of a wide human presence has preserved the biodiversity of this unique Mediterranean location. The difficulties of the described project were in the respect of the strong environmental and building requirements in both the construction and the management phase for the realization of a tourist restoration desk and infopoint in the location of Stretti.

The main goal of the design was the realization of a structure totally removable (no foundation or soil contamination is admitted in the conservation guidelines of the Park) made up of totally natural materials (such as wood) and

Figure 4: Landscape view of the infopoint in Asinara Island.

Figure 5: Details of the wood structure and the ventilated roof.

completely energetically self supported, due to the lack of electric and water supply in the area [4].

The final result of the design consists in a light structure realized with a wide use of prefabricated wood elements supporting a photovoltaic plant on the roof able to supply all the technological equipments and the lighting devices.

In detail the 16 mq bungalow (medium height of 3 meters) hosts an infopoint with two PC and an information screen and, in the opposite site, a restoration desk and a toilette for small groups of tourists.

The structure has no foundation - the Sardinia islands is the only Italian region with no seismic requirements - but is able to stand against 120 km/h strong winds due to its wide base platform, 30 cm high, filled with local heavy stones as shown in the picture taken during the construction phase. The roof, open to ventilation, is able to guarantee good performances for air recirculation and spring and summer free cooling and the photovoltaic plant of about 1,3 kWp (24V) supplies power for all the lightning equipments, 2 personal computers, a wide screen and 2 refrigerators for food and beverage.

The project has been realized with the financial contribution of the Ente Parco dell'Asinara.

4 Conclusion

The final aim of the two pilot projects is the evaluation of the effectiveness of the combination of the installed technologies, following the global approach of the sustainable design, in a Mediterranean climate, measuring the reduction of CO2 emissions and of land resource consumption during the first year of life of the structures. In order to evaluate a global result a monitoring campaign based on four seasonal measurements is being performed by the Department of Fisica Tecnica together with Italian Environmental Ministry and the Ente Parco of Asinara Island. Final consideration will be available in October 2010.

References

[1] Ardito S., Parks of Italy – the protected areas system, Italian Environmental Ministry - Carsa Edizioni, 2004, 226-230 - abstract

[2] Cinquepalmi F., Gugliermetti, F, Cumo, F., Technologies for sustainable building the pilot project of the municipality of Rome, Palombi and partner 2008 - 1

[3] Berta L., Bovati M., *Progettare con legno* – Maggioli editore 2007 - 2

[4] De Santoli L., Moncada G., fondamenti di sostenibilità energetico-ambientale, 2008 - 3

The mechanism of the *rawāshīn*: the case study of Makkah

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Abstract

This paper highlights one of the traditional architectural features in Makkah, the holy city of Islam that is located in the Hijaz region of Saudi Arabia. This element, which is called locally "*roshan / roshān*, pl. *rawasheen* / *rawāshīn*", is a type of projected wooden screen. It covers the façade of the building and protects it as a garment. Most, if not all, of these buildings have been demolished, due to the need for the enlargement of the area surrounding the Holy mosque to accommodate the increased number of pilgrims. Therefore, understanding the mechanism of the *rawāshīn* could help to: emphasis its importance, reinvent a similar element and/or to preserve such an element through documentation.

This wooden garment that wraps the skin of the building has unique parts and is constructed in a way that mimics the features of the human face. That is, the upper part could be seen as the forehead, the middle part mimics the eye and the nose and the lower part as a chin. Each part, with its ornamentation, fulfils a specific function from within the house and keeps it cold and airy. The *rawāshīn* do not just work as functional architectural elements, they also provide aesthetic benefits from inside and outside the house. This paper reflects also cultural aspects related to the architecture and inhabitation of the region and the impact of Islamic architecture in Makkah. More importantly, it echoes the harmonisation between architecture and the nature of the environment. That is to say, traditional architecture and its elements, as a source of knowledge, can give lessons in many aspects to the coming generation, including eco-architecture.
Keywords: rawasheen or rawāshīn, projected window, wooden window, traditional houses, Makkah, Saudi Arabia, Islamic architecture, dry environment, mechanism.

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1 Introduction

Roshān or *roshan* (pl. *rawāshīn*) is an old term used for a wooden projected window found in Makkah and in some cities of the Islamic world. It was documented as "*roshān*" in planning and building regulation documents of the Islamic cities during the Mamlūk era (1248-1516), as Amin and Ibrahim [1] assert. In fact, the *roshān* is not a local term excluded to the Arabian Peninsula; it is still in use in Sawakin in Sudan and Rashid and Qusir in Egypt. The linguistic origin of the term *roshān* is Farsi, and it means a source of light. The historical origin is based upon the word *roshān* from the very distant past. The presence of the Persian in the Hijaz region and Makkah in particular was even earlier than Islam, as some studies argue [2–4]. Traditional houses in Makkah are interwoven with this wooden architectural fabric where the term is still actively used. Structurally, the *roshān* is usually completed with three parts (the lower part, the middle part where the openings are located and the upper part); each part has its local name. It could be seen as one separate unit to cover an opening or a side of a room, or a continuous one that envelopes the whole façade of the house, fig. 1.

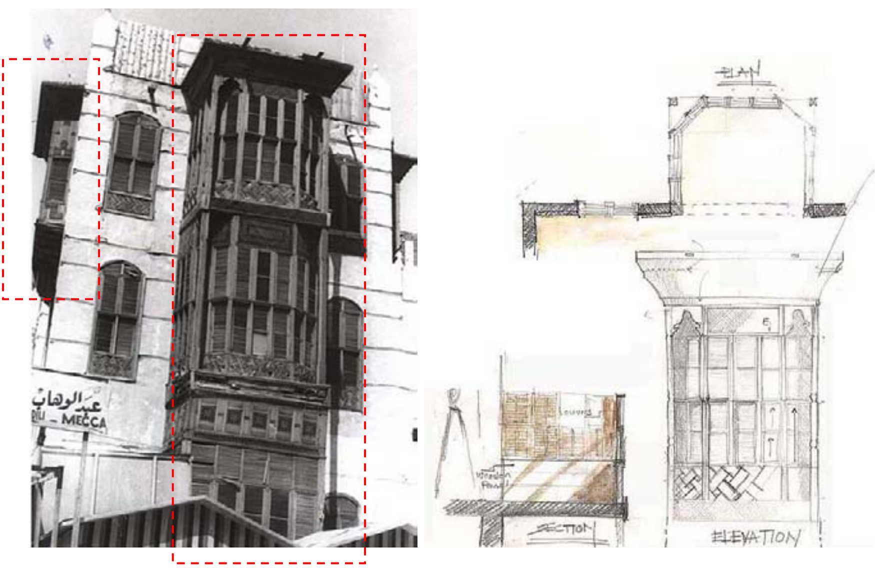

Figure 1: The *roshān*–separate and continuous unit.

2 The construction of the *roshān*

The traditional *roshān* is assembled from identical parts and units sourced locally, so that the side panels of the *roshān* have one standard height, which also applies to the front panel with slight variations, not in the construction but in small details, fig. 1. The variation may occur as a result of the joints between one panel and another, and in order to achieve a satisfactory general appearance of the *roshān* as a whole. This could be with the proviso that generally the width of the side panel should be equal to the distance between the uprights that divide the panels of the *roshān* as claimed by Hariri [5]. However, Taha [6] argues that the interior division of the upright panel has to be appropriate and coordinated, he also states that: the *roshān* is divided into a number of upright sections so that the horizontal aspect of the *roshān* should be symmetrical (in most cases) while its vertical aspect need not be symmetrical because of the variations in the component parts and their use. Thus if the *roshān* were made up of a vertical unit 'X' which is repeated, the unit 'X' would be a unit of, say 50–70 cm and the *roshān* would then be made up of several units.

Since the present study does not deal with the precise dimensions of the *roshān*, the above measurements may be taken as approximations of the example in question, i.e. 50–70 cm for each of the standard repeated units as a module. The internal divisions of the standard unit can be considered as horizontal units connected in sequence from bottom to top. If the standard upright unit is 'X', on the inside it would be bottom X, upper X and middle X considered as separate parts. Consequently, the inside of the standard upright unit would be a unit with a horizontal measurement repeated for each of the (X) sections, fig. 2. There are also additional trimmings and extras to join the parts of the traditional *roshān* as a whole into one fixture. Then the various decorative and imaginative items appear inside each unit and its parts, in the plain and empty areas and the hollowed-out and projecting parts, as in fig. 2, fig. 3.

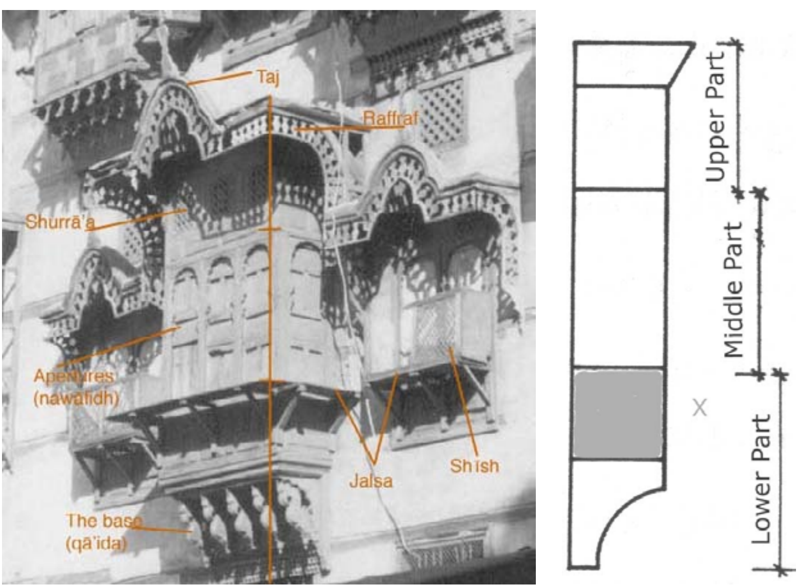

Figure 2: The *roshān* construction parts.

Figure 3: The lower and the upper treatment [11].

2.1 The lower part

The lower part of the *roshān* is made up of two sections: the support (*da'āma*) and the base (*qā'ida*). This part may be decorated on the outside and plain on the inside to form a harmonious part of the interior surroundings. From inside the room it looks like a cover resting on a frame to be used for sitting. The area between the floor of the *roshān* and the lower panels may be covered with horizontal panels varying in height between 40 and 50 cm. This part forms a suitable height for supporting the back of who is seated in the *roshān*, and gives a clear outside view as stated by Hariri [5]. In fact, the lower part is the fixed part of the *roshān* and its measurement varies between approximately 30 and 70 cm.

As for the support or *da'āma,* the *rawāshīn* of Makkah rely on wooden supports (beams) between the floor and ceiling of the room, which extends by the same distance as the *roshān* protrudes. They are usually made of strong, squared lengths of wood, set close together, or the supports may be on both sides of the lower part of the *roshān*, forming an approximate triangle, fig. 2, fig. 3. These are called locally *karādī* (sing. *kurdi*). The *kurdi* bears the weight of the *roshān* on strong wooden beams projecting from the surface of the wall at an angle of about 90 degrees. The beams are left exposed without any covering, or they are hidden behind shorings and decorated planks. These shorings may be carved or decorated. However, the *rawāshīn* on the ground floor are set on projecting stone supports or on a projecting base wall that is built up from the ground to the level of the *roshān* base.

In the Hijaz region of Saudi Arabia the *rawāshīn* of the houses are supported on projecting supports that called locally *kawābīl*, (sing. *kabuli*). These *kawābīl* are made of wood, and their design and size varies according to the resources and taste of the householder. According to Khan [7] these wooden supports that are set inside the walls of the building to bear the weight of the *rawāshīn* and the *kawābīl* are also used as decorative architectural features, some being carved in the form of peacocks, which are common features in Persia and India.

2.2 The middle part

The middle part is the section that has the apertures, which are made up either of one moving section or of two sections, one of them fixed and the other moving. The essential aspect of this part is that it should be movable, because it is the part that controls how much air and light is admitted to the room. If it is made up of one section, it consists of panels that open sideways or slide upwards, and they may be either plain or perforated or have small sliding panels. If it is made up of two sections, they are usually sliding shutters, fig. 3. Louvres are also used in these sliding shutters to control air and light. In fact, if the openings were of sliding panels with louvres, the flow and amount of air is more controlled. These louvres govern the direction of the air in which it flows downwards into the room or upwards, as the householder wishes. That is, the appropriate number of louvres in the sliding shutter can be considered as a separate unit that can be controlled independently.

This part plays a great role in controlling most of the *roshān*'s functions; including the view and penetrating air and light into the interiors. Sometimes, an extra lattice screen is used to conceal these apertures for more privacy. This extra screen, which called locally *shish*, is an indication of the family or women's presence. It could be added to the *rawāshīn*, as well as ordinary windows, to give the sense of another hanging, screened, projected box that could be seen as 'mini *roshān*', fig. 2, fig. 4. The *shish* is mainly designed to permit the occupants to see without being seen. It is a well-known element in the Hijaz region, as well as Sawakin and Egypt. Islamic architecture has maintained the use of these extra wooden screens when it is essential to open windows and balconies overlooking the street, as well as the inner courtyards in order to protect whoever is behind

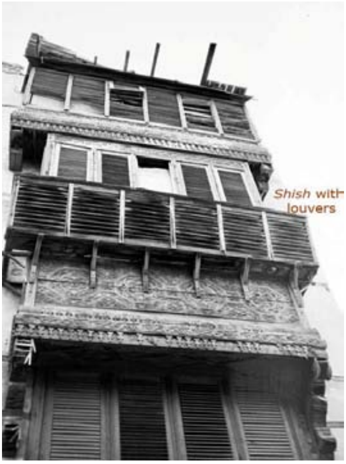

Figure 4: The *shish* and the louvers.

them from the eyes of visitors and passers-by. This extra lattice screen, regardless of its local name, is used to cover apertures in the middle part of the windows and *rawāshīn* alike. It is an extra screen layer which attaches to the openings to secure privacy.

2.3 The upper part

The upper part is made up of two sections, the upper window (*shurrā'a*) and the top treatment. The *shurrā'a* is the upper part of the *roshān* connected to the apertures, or the middle part. It may be plain or partly perforated, (i.e. plain parts and perforated parts with holes arranged in a particular pattern) as in fig. 1, fig. 2. A plain *shurrā'a* is a horizontal surface, patterned or decorated with plant or geometrical designs which extend from the top of the apertures to the top of the whole *roshān*. A partly perforated *shurrā'a* consists of geometrical designs incorporating perforations which are a permanent source of light. The more perforations there are, the more light is admitted to the room, and usually clear or coloured glass is fixed from the inside to prevent dust from entering. It is sometimes possible to move the glass upwards or downwards to allow air to flow into the room. The top of the *roshān* is the last part above the *shurrā'a* and takes various decorative forms from plain geometrical treatment to floral decorative crowns, fig. 2, fig. 3.

These additional parts are extensions and trimmings used to decorate the top end, which act as a protective shield for the *rawāshīn*. This top treatment could be a *raffraf* or a kind of umbrella for protection with a crown which is sometimes called *burneita*, fig. 3. In spite of the great quantity of woodwork in the *roshān* that extends outside, the three parts of its construction work as a whole to help the *roshān's* mechanism. These parts are designed to benefit the interiors of the house. The *rawāshīn* act not only as air filters but also as light filters, since they regulate the entry of light and air alike. However, it is worth noting that the *roshān* may constitute the whole outer wall of the interior space, and this large area helps to combat inadequate lighting, but it also catches the breeze.

3 The mechanism of the *roshān*

The traditional *roshān* has fulfilled various desirable aims and purposes from ancient times because of its strength (of construction) and its continuity over many centuries with its wooden tracery so much in harmony with traditional Makkan houses. Each of its parts has a function and a purpose to achieve. Even the trimmings and additions complete the function and enrich it with beauty and decoration. From a practical point of view, the *roshān* is a window that looks out on the outside world and a screen veiling the light of the strongly blazing sun. It is a basic part of the building's air conditioning and part of the furnishing of the home. In some cases it is even an extension to some of the rooms above the street below. It acts as the centre of the family where most domestic activities take place. Such mechanism can fulfil the following benefits:

3.1 Achieving Islamic rules and social norms

These are expressed in terms of privacy and the protection from outside intrusion of all that happens in the home apart from the *roshān* being an expression of relation between the inner and outer spheres. This privacy for the people living in the house protects them from the gaze of passers-by in the street while giving them the opportunity to follow what is happening outside. It provides the inhabitant with the possibility of looking out without allowing passers-by to see inside the house, either via small openings between the pieces of turned wood and other openings in the *rawāshīn*, or through the narrow gaps and the openings in the geometrical designs in the *roshān* and the grill *shish*. The fact that it is darker inside than outside also helps to achieve this aim.

In this way, a woman in her private apartment inside the house can see life going on in the street outside without being seen by anyone, so that the *rawāshīn* are considered an advantage to her. If she wants to look outside through the panels, she can see without being seen because the field of vision through the louvres when the screens are closed is about 90 degrees. This can be achieved by moving the louvres up or down, which gives great flexibility to the field of vision. The louvres at the same time break the line of vision and prevent whoever is inside from being seen.

Women are the significant factor between the *roshān* and the *hijab* (veil). Likewise the *hijab* as a concept governs the daily-life of women in Islam whereas the *roshān*, as an enclosure, is a screen masking the openings of the house. These screened windows are like the eyes of the house; having the windows screened will protect the interiors and will respect the householders' privacy. The *hijab* as a concept is the main character in Muslim daily life. Nevertheless, the veiling of women is just one form of a broader range of understanding of its implications. The word *hijab*, as a noun, comes from the Arabic verb *hajaba*, which means 'to hide from view or conceal'. It can mean to screen or draw a curtain or a barrier of any kind.

It is essential to have the windows open during the daytime in such a hot climate, but it is also essential not to jeopardize the privacy of the inhabitants. Consequently, the *shish* is added to the middle part of the *roshān* to keep this part open all the day for climatic reasons. These screens are attached to family rooms and wherever women occupy the rooms, fig. 4. The middle part works as the eye and the nose of this cladding fabric; however, screens provide privacy and catch the breeze perfectly. These screens not just fulfil the demands of the *hijab* concept wholly, but they give other benefits such as observation and cross-ventilation.

This vision mechanism behind the *roshān* could be seen in this way: the inhabitant inside the house can observe the street by standing by the *roshān*, which has a *shish* attached to it. Being closer to the *shish*, from inside, allows the observer to see outside views clearly, but it is difficult to identify who or what is behind it, fig. 2, fig. 4. This distance and the treatment of this part increases the angle of vision from inside, where the *shish* holds the middle part of the *roshān* creates a zone to control this mechanism, fig. 4. Considering the play of light and shadow on both sides, it plays a significant role in enhancing the view and creates a spectacular effect to the observer from both sides. The character of this analysis is based on the notion of more protection for women, where these extra lattice screens play a role in the visual analysis and work as barriers. This feature is attached to the *roshān* to give more protection and prevent vision intrusions to the interiors.

The *rawāshīn* with their alcoves, grids and openings also act as a means of interaction between the inner and the outer sphere, for it is possible for the residents of the house to make contact with the outside world without there being the least invasion of their domestic privacy. Therefore they can be psychologically relaxed while maintaining natural and correct relations between the people of the house and the outside society and environment around their residence. The *roshān* allows the resident of the house to use one's senses (hearing, sight and smell) to find out what activities and interactions and local events are taking place around the house simply and easily and without impediment. Thus the individual in his house is involved and connected with the society and the surrounding environment.

3.2 Flexibility in a flow of air outward and inward

The *rawāshīn* are spread out as box-like units projecting into spaces outside, staggered both horizontally and vertically so that they cast their shadows on the façade of the building. They also help to reduce the amount of heat absorbed from the rays of the sun reflected from surfaces facing the building. The result of these variations in the amount and length of the projection to the outside from below to above with the depth of the *rawāshīn* increasing with the height of the building, attracts the maximum amount of breeze to the higher levels above the street and the maximum amount of shade in the lower levels for most hours of the day.

Whether they extend to the outside at one level or several, these extensions increase with height, so they act as shades for the spaces outside and the lanes around the building, thereby shielding the passers-by from the rays of the sun in the lanes and between the buildings and also decreasing the amount of hot air entering the lower spaces during the day. The covered area then becomes like a trap for the air, allowing the minimum amount of hot air to enter while trapping breezes at the lower levels of the lanes and so cooling them. The walls try to absorb the air trapped in the area during the day to cool the interior space and the temperature of the walls falls, and the area becomes cooler as a consequence. It is as if the walls and the wood breathe during the night with a gentle breeze to cool the space.

The flow of air in the interior spaces is governed by the openings and apertures in the various kinds of *rawāshīn*, as well as the *shish* -where it exists- in such a way that these parts act as layers of filters for both the air and the dust. The openings in the *roshān* also admit the air to enter and be sucked to the interior, thereby reaching the various parts of the house. This could be either as a result of a drop in pressure in the vertical air passages, or by the house being built facing a direction which causes it to attract a breeze and create a flow of air in between that will penetrate the building. In addition, the broad exposed area of the *roshān*, with the shade in the upper end, makes the air move very slowly as it enters so that it carries only very little dust, as Khan [7] argues. Whereas if the openings are of sliding panels with louvres, the flow and amount of air is controlled because the variations in the way the louvres can be moved makes it easy to govern the direction in which the air flows downwards into the room or upwards, as the householder wishes. Similarly, the amount of air can be controlled by opening the appropriate number of louvres in the shutter/sliding panel; and each shutter can be considered a separate unit that can be controlled independently.

When the air flows and enters the inner space, the alcove of the *roshān* is the result of its extension outwards which creates an area where air can be transferred or distributed. That is, taking air in from the outside to distribute it inside across the adjacent seating area (called locally, *dakka* or a *jalsa*) in which one sits. Therefore the air, after being purified and filtered through the previous layers, reaches this area, which is the coolest area in the inner space because it is hollowed out in the wall and because of the thickness of the surrounding walls and because the breeze comes in through the openings in the *roshān*.

This constant entry of the outside air currents and their speed forces a quantity of air inwards and into the inner space as a whole. The direction of the flow makes it easy for the air to enter but difficult for it to get out, which keeps the inner space cool. This is a special benefit because the currents of air circle round in it and may collide if there are internal currents caused by a door or some such thing which helps cool the area further. The force of the current of air coming from outside is not matched by any internal current, and so the airflow is concentrated within.

3.3 Maintenance of desirable temperature

This is possible in the internal spaces as a result of the houses being isolated from the outside as far as temperature is concerned, where wood as a natural insulator prevents the burning rays of the sun reaching the building, except via the walls or through the openings and apertures. In addition, the staggered or regular projection of the *rawāshīn* throws shadow onto the façade of the building and so limits the penetration of direct sunlight and the rays of the sun reflected from the surfaces facing it. Thus it helps the building to withstand heat from the outside, especially if the surfaces of the buildings facing each other are similar so that the two façades absorb the heat and insulate the area from the heat.

The bases of the *rawāshīn* are designed to attract shade onto the building and the street to keep the temperature down while allowing in the shaded air so that it bounces off their angles and the walls become cooler, which helps the cooling of the interior of the building. The other parts of the *roshān* and the decorative extensions and trimmings also contribute to creating shadows and breaking the concentration of the direct rays of the sun, which are dispersed by striking these angles and cavities and irregular surfaces.

At night, because of the thickness of the walls in traditional houses and the attempts of the morning sun to penetrate being prevented by the *rawāshīn*, the temperature remains comfortable. This will be the case in the lower areas of the buildings that manage to retain their coolness through their proximity to the lower empty spaces which are comparatively cool because they are so little exposed to the sun's rays relative to the spaces on the upper floors. Although the *rawāshīn* are large, the openings in them are appropriate to their size as if the projection of the *roshān* fishes for air in the sea outside, but remains in firm control.

3.4 Control of the desired amount of light

The *rawāshīn* act not only as air filters but also as light filters since they regulate the entry of light and brightness into the interior spaces and solve the problem of glare. This is even more controlled within the interior space if there are supplementary lattice screens and *shish*. In spite of the great quantity of woodwork in the *rawāshīn* extending to the outside, the amount of light that penetrates to the interior may be considered to be under control because the various parts and assemblages of the *rawāshīn* are sufficient to limit the strong natural light penetrating to the interior and so protect the residents from the problem of glare. If the shutters have louvres: it is obvious that the strong summer sun creates glare when the *roshān* is fully open. Therefore, the louvres are used to limit the glare so that the contrast between light and shade is acceptable and not a strain on the naked eye, fig. 5.

Figure 5: Louvres of the roshān from within [11].

On the other hand, if the *shish* is used, it helps to limit the amount of glare from the sunshine that enters into the rooms through these openings. That is, just as the rays and light of the sun are weakened many times over on the movable surfaces around the units, which allows a comfortable amount of light to enter the building without exposure to strong glare, especially in those desert areas where temperatures are very high. Furthermore, if the *rawāshīn* have both louvres and *shish*, glare is limited by a system of louvres and lattice grid so that the light passes through the lattice grid and casts wonderful interwoven patterns on the interior decorated surfaces, camouflaging the outlines between their solid and open parts. Therefore, no sharp edges appear nor any violent contrasts between the dark colour of the walls and the brilliance of the light, so that the eye is not dazzled.

The amount and proportion of light can be controlled by closing and opening the shutters of the openings, regardless their various kinds. If the shutters are plain, it is the grill *shish* that performs the task of filtering the light and limiting the amount of interior illumination. According to Hariri [5] if the shutters have movable louvres, the light passes through these louvres in each wooden panel independently with a possible opening of up to about 40% of the surface of that panel. If more intense light is wanted, the shutter can be raised so that light can enter through the whole area of the shutter. Taking into consideration the fact that each *roshān* has at least twelve shutters, and each of them can be controlled separately, it is clear how much flexibility there is in the complete control over the intensity of the lighting. The *roshān* may constitute the whole outer wall of the interior space and this large area helps to combat inadequate lighting.

3.5 Benefiting from the outward projection of the *roshān*

It seems that the purpose in building *rawāshīn* and similar extensions is to increase the floor area of the upper storeys and to make the building more beautiful. It is likely that they should be made of wood or of materials that can resist natural conditions. The outward extension of the *roshān* casts more shadow and coolness on the areas around the external spaces. As for the inside, the large size of the *roshān* results in the expansion of the size of the room, thus affecting the general form of the interior space. The extension outwards may be of balanced proportions, or it may be more one side than the other and this has its effect, both inside and outside. The variations in the amount of overhang have particular advantages in terms of vision and give a better opportunity to break the line of vision from one building to another and one storey to another in the same building, as well as giving a real opportunity to see outside, taking advantage of a bend in the street.

From inside, this extra area has a liberating effect inside for it makes it possible to accommodate many domestic activities, such as eating, sitting and even sleeping. The *roshān* also guarantees the family's privacy as well as the opportunity for direct communication and interaction with the outside, while the lower shutters of the *roshān* starts from the eye level of someone sitting, easily achieving the aims set out above. Thus the effect of the *roshān* on the interior space is evident, and hence the inevitability of its effect on the interior design patterns, considering influence of its size, through its constituent materials, its form and decoration, on the interior areas of the traditional house, as well as its control of light, air and visibility.

3.6 The aesthetic value of the general exterior appearance

The general exterior appearance of the *roshān* has a number of qualities: Firstly, the general exterior appearance is like a unifying character that gives an aesthetic touch and a particular beauty to traditional houses in particular and to the lanes of the area in general. Although the design of the *rawāshīn* differs for each building, they all keep the same spirit and concept giving to the urban environment its unity and identical character. This touch is the product of the various patterns with their contrasting and extremely precise forms. Similarly the general lines of the *roshān* and its design dominate the vertical plane in harmony with the vertical façades of the buildings.

The shutters have been designed in such a way that they do not lose their beauty whether they are open or closed to perform their various functions. Because these shutters slide vertically within channels (metal rings and loops) that specially carved out in them instead of opening inwards or outwards, thus not spoiling the general exterior appearance of the *roshān*, and the façade of traditional houses remains elegant at all times. The distribution of the *rawāshīn* as either connected or separated units along vertical and horizontal axes, has a further aesthetic aspect. That is, it structures the general façade of the house, and the combination of the same kind of *rawāshīn*, in either even or uneven arrangements on the houses of the area, or in the same lane. Such a pattern gives a different character, in spite of the variations in decoration, number and arrangement.

Secondly, the material used in making these *rawāshīn* aids the creation of this particular kind of beauty. The strength and durability of wood and its adaptability to decoration plays a decisive part in the external character of the *roshān*, for the use of wood as the basic material over large surfaces creates a unity and harmony between buildings despite wide variations in measurements and details and decorations. According to Hariri [5] wood is a rich, warm material and teak (Javanese wood) is used to be dried in the sun before use for about three months to get rid of all moisture so that it would not swell or warp or split after being assembled.

Thirdly, the general distribution of the *rawāshīn* and the artistry of their component parts naturally vary in kind and extent according to the means and taste of the householder. It generally indicates and mirrors the kind of residents occupying the houses. Therefore, the number of *rawāshīn*, the amount of decoration on them, their size, the kind of carving and embellishment used - the general appearance of the house, including doors, windows and façades - reflect the economic and social class of the owners. The richness of patterns and decoration, together with the exotic style of the *rawāshīn* and the way they are arranged, depends on the use of foreign labour employed by a limited number of wealthy families, while the widespread simple and more common type found in the lanes of Makkah are the work of local carpenters, as Fadan [8] claims.

4 Conclusion

The study of the *roshān* is not a call to return to the past; it is rather an open door to learn from the past and apply what is suitable, or what could be adopted, according to the new pace of life. The need is to comprehend the concept of the *roshān* in order to apply it or adapt it to a modern version. This is an attempt to rescue the notion of the *roshān,* because it proves its quality in such a hot and dry environment. It also fulfils Muslims' inhabitation requirements as Islamic rules dominate the essence of Islamic architecture.

The *roshān* has fulfilled various desirable aims and purposes from ancient times. Each part of the *roshān's* construction has a function and a purpose to achieve, including the trimmings and additions that enrich its beauty. The *roshān* is a window that looks out on the outside world and is a screen veiling the light of the strongly blazing sun. It is a basic part of the building's air conditioning and part of the furnishing of the home. In some cases it is even an extension to some of the rooms above the street. More importantly, the *roshān* is not merely an environmental feature; it is an absolute Islamic requirement for the sake of the household's privacy.

References

[1] Amin, Mohammed M. and. Ibrahim, Laila A. *al-Mustalahat al-Mimariyya fi al-watha'iq al-mamlukiyya*, al-Jam'ia al-Amrikiya: al-Qāhira, 1990.

[2] Al-Murahhem, Faredah, *Behind the Roshān: Visualising the Roshān as an Architectural Experience in Traditional Domestic Interiors*, Unpublished PhD thesis. Brighton University: Brighton - UK, 2008.

[3] Al-Harithi, Nasir Ali, "A'mal al-Khashab al-Mi'mariyah Fi al-Hijaz Fi al-Asar al-Uthmani: Dirasa Faniya Hadariya." Unpublished master thesis, Umm al-Qura University, 1986.

[4] Greenlaw, Jean-Pierre. *The Coral Buildings of Suaken*. Oriel Press Ltd.: London-UK, 1976.

[5] Hariri, Majdi M. "Tasamim Al-Rowshan wa Ahamiyatahu Li Almaskan". *Majallat Umm Al-Qura*. 5.3, 1991, Pp 175-237.

[6] Taha, Hatim Umar, *Taiyba wa Fanaha Al-Rafīy*., Nadī al-Madina al-Adabī: Al-Madina, 1984.

[7] Khan, Sultan M., *Manazil Jiddah Al-Qadīma*, King Abdul Aziz Centre for Science and Technology: Riyadh - Saudi Arabia, 1986.

[8] Fadan, Yousef, Traditional Houses of Mekkah, the Influence of Socio-Cultural Themes upon Arab Muslim Dwelling", *Islamic Architecture & Urbanism*, 1983.

[9] Al-Salih, Naser A., *al-Mua'therat wal al-Anmat al-Geoghrafiya Lil 'Amarah al-Taqlidiya bil Mamlakah al-Arabiya al-Su'diya*. Makkah: Umm al-Qura University, 1984.

[10] Miandji, Anooshirvan M., *Farsi-English/English-Farsi Concise Dictionary,* Hippocrene: New York, 2003.

[11] Hajj Research Centre, slides collection. Umm al-Qura University, Makkah.

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The climatic, constructional, and cultural primacy of the envelope: UR22, a case study

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Abstract

More than any other singular aspect, a building's envelope has the capacity to integrate many of the primary concerns of any new building design into a unified, harmonious artifact. UR22 (a residence built in 2008 in suburban Dallas) is presented as a case study that demonstrates how direct and synthetic responses registered by a building's envelope can successfully operate within multiple contexts – *climatic, constructional, and cultural.* Regionally, UR22 represents a shift from the excessive land and energy consumption and social alienation of typical contemporary American residential developments. UR22 is demonstrative of the client's intention for a greater sense of community and respect for the environment and energy at the scale of the development, site, and the home itself. Quantitatively, UR22 has achieved LEED-H GOLD and Energy Star HERS 50 (50% energy reduction) ratings. Qualitatively, UR22 remediates and exploits a potential conflict between comfort and some very direct expressions of natural forces/energies both resisted and gathered within the harsh climate of the North Texas. This paper presents how UR22 is consistently organized and designed to produce an integrated form with respect to site orientation, protective enclosure, control of the elements and structure.
Keywords: climate, construction envelope, culture, integrated form, solar orientation, enclosure, collected elements, structure.

1 Introduction

All architectural projects must address multiple concerns and most often a singular factor becomes the dominant "driver" from which other decisions must attempt to locate their relevancy. Certainly, within the context of a volatile climate such as in North Texas, the potential solar impact for any project could

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indeed be the most influential concern, as is the case presented here as an expansion of an earlier paper by this author [1]. However, there are many other factors which must be integrated. Moreover, the term *integration* has many meanings even if the definition is constrained within a more narrowed scope located within the field of building technologies. *Integration* here simply refers to what many consider to be the primary task of an architect. Architects have been educated and trained to assimilate vast amounts of largely unrelated information into a building artifact that fuses both quantitative data and qualitative characteristics. UR22 is presented here as a case study which: 1- seeks to extend a recurring notion that architecture is a medium whereby the complexities inherent in any contemporary construction project can be synthesized into a unified, coherent, and harmonious artifact recounting such observations similar to Wittkower's [2] and, 2- from Evans [3] as an art form, architecture is capable through resemblance to be in a special position to resolve disparate and often contradictory concepts attached to those complexities.

In addition to the general design of the building which also includes the selection and placement of numerous products and components, architects would also prefer the opportunity to be part of a project team involved in the actual design and development of much of the products and material configurations. This is not a desire out of conceit or a merely visual issue but a concern that as many parts as possible should have a resonating dialog with each other. To that, historical regional precedents – that demonstrate the intersections between these various demands particular to a given project – were closely examined. A search to unearth shared architectural expressions between the *climatic*, *constructional*, and *cultural* contexts is the real impetus towards positing an innovative architectural design solution within this region. The design of the residence UR22 was undertaken to explore such possibilities.

1.1 General site

UR22 is a residence located in the Urban Reserve; an ecologically sensitive, zero-lot line single-family housing development in northeast suburban Dallas (50 lots in 13 acres) 15 minutes from the city's center. Commissioned by the developer, this project is one of the first homes built within the new community. Most importantly, it is demonstrative of the client's intention for a greater suburban density, sense of community and respect for the environment at the scale of the development, building site, and the home itself. Storm water recycling and filtration with rain gardens & retention ponds along with native, non-invasive, low-water use plantings were used throughout the community.

1.2 Program

Briefly, the program for UR22 is targeted for those whose children are grown but return to visit periodically. The program also reflects a high degree of spatial connectivity, internally and externally. Contrary to this, family or overnight guests are provided with a strong sense of privacy, despite the overall open spatial quality. Another priority is a variety of entertainment spaces that can accommodate both small gatherings and large groups. Lastly, given the intended identity of the development and following the qualities of the master-plan, low maintenance materials and energy conservation are essential mandates.

1.3 Climate

Climate in the Dallas area is characterized as a humid-temperate region but repeatedly winds with cooler, drier air come from the north and west to reduce or remove humidity. The typical temperature extremes are from about 105ºF (41ºC) to 20ºF (-7ºC) with average temperature highs ranging from mid-to-upper 90s in July to the mid-50s in January. A 20ºF (11ºC) diurnal drop at night is common throughout the year. Annual precipitation is in the mid-to-upper 30s (inches) with usually at least some snow fall, although it may only amount to a few inches. Generally, the potential for cooling breezes in the summer may come either from the Gulf of Mexico in the south or from the plains to the north. Often during the fall and winter, strong cold fronts known as “Blue Northers” that originate from Canada, roll down the Great Plains region of the central US reaching Dallas and drastically reduce the temperature within a couple hours – a 30ºF (17ºC) shift is not unusual. Frequently, warm Gulf and cold Canadian fronts collide in a larger region referred to as “Tornado Alley” within which Dallas is also located. In other words, North Texas is a region with great temperature swings and weather unpredictability. Obviously, the building must be agile to adapt to these extremes.

1.4 Construction

Construction methods and materials within the development mirror typical American residential assemblies which generally prioritize speed and economy over durability and craft. Rapid wood frame construction with gypsum board interiors and exposed concrete floors are common to the majority of projects within this new community. To address and potentially exploit this reality, the project naturally aims to conjoin the design logic with the constructional techniques regularly used in the area.

1.5 Culture

Culturally, the region is predictably complex despite the presuppositions about Texan culture in general and Dallas specifically. Rather, the cultural aspects concerned here are those embedded within the historical architectural contexts of climate response cited in this paper as well as the contemporary expectations of the client and prospective buyer with regard to typical home construction in the area.

2 Precedents

The awareness of the significance of site orientation by those constructing buildings is clearly visible in many of the 19th century and early 20th century historical precedents taken from several areas of Texas and the other regions of

Figure 1: 19c, Sunday house, Fredericksburg, TX.

Figure 2: 19c, Officers' quarters, Fort Davis, TX.

the United States (Figs. 1,2). These examples demonstrate the empirical understanding of earlier immigrants and inhabitants as to the efficacy of buildings elongated along the east-west axis to optimize solar behavior. This fact has also long since has been proven by quantitative models starting with Olygay [4], but unfortunately has been largely ignored by post-WWII housing developments in the US where typically replicated designs are produced without regard to site orientation.

Returning to the precedents, we can compare the shapes of the building envelopes. While elongation of simple volumes is consistent, we also notice that the major elements of entry, fenestration, heating element, roof and wall harmonize into powerful, candid overall forms. While much of the configurations and materiality are program and climate dependent, all of the examples provide tangible existential and emotional protection as well. For example, the porches continue the pre-air conditioning tradition of a gathering space for social interaction due to their protection from the elements of weather. They also meditate between the public realm and the private realm of one's own home. The building's materiality, mostly related to issues of durability, also contribute to the concept of protection.

2.1 Materials

Readily abundant limestone was found by early settlers in the Texas Hill Country located in the central part of the state. Due to its soft nature, new immigrants fashioned thick walls for stability and durability. Often this material choice is advantageous because of its mass to regulate diurnal swings (Figs. 1, 2). However, Central Texas (as with North Texas) also experiences periods of high humidity where a lighter construction assembly is also acceptable and at times preferable to a heavier construction. Stamped metal cladding also provided a lightweight, stable surface in early construction and other thin gauge metal applications were used for roofing. In fact, because of custom and resilience, standing seam metal roofs are still the preferred choice today in much of Texas. Adobe brick and sandstone are also used traditionally in West Texas.

In this arid climate, a more massive material choice can take full advantage of the diurnal swing.

2.2 Protective enclosure

The protective aspect of a building would seem to be quite obvious but its fundamental ability to provide a sense of well being is frequently undermined in contemporary buildings, particularly those that privilege technology as an aesthetic for progressive design. In contrast, Picasso's painting, *Françoise, Claude and Paloma, 1954* (Fig. 3) illustrates the emotional and existential simplicity of a larger protective form as represented by the over-arching mother who provides the watchful space for the play and embrace of her children. All of the figures are in concord.

Figure 3: Picasso, Françoise, Claude and Paloma, 1954.

2.3 Controlling elements

Despite their regional differences, the 19th century buildings shown also exhibit the potential for a directness and synthesis in building by which sun, wind, and precipitation are controlled, to be either gathered or repelled depending upon seasonal requirements. Here the importance of the roof configuration is quite apparent. The materials used on a roof or wall usually vary and so one may see them as quite separate entities. The choice of different materials was usually done for reasons of cost and material availability but a change in materials also acknowledges the variation of material and assembly effectiveness due to a horizontal versus a vertical application. Technical and detailing developments have changed this whereby many contemporary buildings exhibit the use of similar materials for both roof and wall applications that can be achieved without monetary penalty. Although this practice of using the same material for the wall and roof began its use in more contemporary times as an aesthetic rather than strictly functional practice, this approach often reduces costs related detailing and trade coordination.

Regardless of material continuity, the roof configurations shown in the precedents result in multi-functional elements such as the porch which demonstrates a simultaneous protection from sun and rain combined with a purposeful collection of water and breezes. Again, we are attracted to the honesty and economy of effort in these examples which operate successfully on multiple levels concurrently.

2.4 Structure

Besides the briefly aforementioned topics of solar orientation, protective enclosure, and the collection of weather elements, the constructional assemblies of these early structures are also noteworthy. Organizationally, repetition of shape and detail was necessitated by limited supplies of materials, gaps in the knowledge of construction, and an immediate desire for safety and protection which therefore required that the newly arrived settlers expedite construction assembly and reconsider expectations of quality. This produced a condition that closely resembles the state of construction today with regard to the issue of speed. Intellectually, a repetition of structure left exposed provides a conceptual and physical datum that registers the human body within the building. Emotionally, the dynamic forces of gravity and wind resisted are physically articulated and therefore lend themselves to a kind of natural or unintended decoration through fascination and replication (Fig. 4).

Figure 4: Eclipse windmill 1900, gantry, TX.

3 UR22, a case study

After searching for an appropriate response to the many circumstances required for a design of a residence in Dallas that is reflective of its time, a methodology emerges from the recurring categories of solar orientation, protective enclosure, collected weather elements, and structure as found latent in the 19^{th} and early 20^{th} century historical structures alluded to here. Through resemblance, formal and systemic strategies are deployed to produce an interconnected construction that ties the past to the present beyond simple duplication.

3.1 Site orientation of UR22

As an intentional refutation of the indifference to site orientation common in most American developments, the master-plan of the Urban Reserve development situates most of the property lots along the east-west axis with an approximate elongation ratio of about 3:1 – a length of about 50’ (15m) and a width of 150’ (45m). In an effort to increase density, tract widths are narrowed relative to typical tracts found in suburban Dallas. Building-to-lot relationships are controlled by a zero-lot line policy where homes must be located on the northern property lines. This placement, combined with the solar orientation of the site, results in restrictions that impact the design in several ways: 1) Direct views into the adjacent property to the north are forbidden for matters of privacy, 2) Overhangs along the north property line are not possible due to their location, 3) A 20’ (6m) wide minimum south yard is required, 4) The building’s west edge must directly adjoin the community retention pond, and 5) Building heights are limited by code to 28’ (9m) above grade. These last two create the potential problem where solar access to a building’s interior in the winter months, when most desired, may be blocked by the neighboring home.

Figure 5: View from NW, UR22, Dallas, TX.

Due to the restricted site conditions cited, UR22 (Fig. 5) results in an overall building volume that is narrow and elongated along the east-west axis, a north wall with limited fenestrations which are inset and placed high, substantial overhangs on the east-south-west sides and a predominant roof slope that is inclined to the south. The much narrower east and west facades are also generally opaque and when coupled with the programmatic solid volumes (such as bathrooms and garages) they provide additional solar blockage to prevent unwanted heat gain on those typically problematic sides. These protective elements allow for a large expanse of south facing glass. This enhances the interior/exterior connection to the narrow south yard while supplying the interior with generous amounts of indirect lighting throughout the day (Fig. 6).

Figure 6: South elevation, UR22, Dallas, TX.

3.2 Protective enclosure of UR22

As recognized from the precedents, the envelope may possess both volumetric and surface protective qualities. UR22's durable slate envelope does exactly this. The cladding assembly simultaneously creates a temperature differential for enhanced ventilation and the overall building envelope is precisely configured (with deep overhangs, proper orientation between the vertical and horizontal planes) to control the environmental elements and thereby provide an embracing sense of enclosure that mediates between the inside and outside. The solid volumes and stair elements screen the interior from the public entry and alley approaches while reinforcing the notion of these objects as protected entities that are in a harmonious dialog.

While cladding an entire building in slate has been a common practice in Europe for centuries, the application of slate on both the roof and walls of a single project it is largely unused in the United States. The primary envelope of UR22 is clad with a light-colored slate for several environmental reasons (although slate attributes have yet to be recognized by LEED): 1- Durability; when properly installed Grade S1 slate will last well over 100 years. 2- No toxic waste; with no chemicals released into the environment and no landfill waste with regard to life cycle issues (since it is natural rock), slate can be reused for both building and landscape applications. 3- Breathable wall and roof surfaces; temperature differential created by the solar gain of the slate induces vertical air movement when an air space is provided directly behind the slate. This results in cooler interior surfaces and will also evaporate any moisture that may inadvertently penetrate the surface of the assembly. Double lapping (head-lap) results in good water resistance as well as produces a very breathable surface in the slate assembly when mounted on vertical furring; a necessity in the hot North Texas climate. 4- Elimination of all roof penetrations; aside from being visually clean, this provides for an obstacle-free roof surface for future easy installation of photovoltaic or solar panels. This area for future placement resulted from a desire to provide a specific location that is screened from the primary entry directions of either the front visitor's entry from the main street or from the alley access. The east and west triangular prismatic volumes and the upturned "gutter" delineate the placement area by serving as a frame for the panels (Fig. 7).

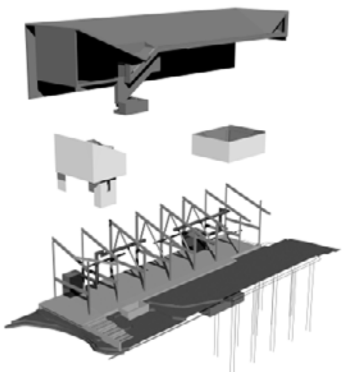

Figure 7: Organization, UR22, Dallas, TX.

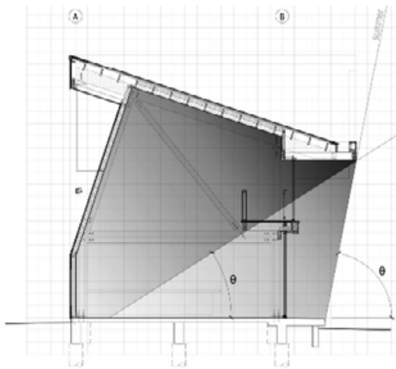

Figure 8: Solar angles, UR22, Dallas, TX.

3.3 Collected weather elements of UR22

The elements of rain, sun, and wind are controlled primarily through the envelope configuration. Formal overlaps resulting from the exigencies of collection or diversion needed to control the weather elements were aggressively pursued and determined through both graphic geometrical and digital means. Through envelope shaping and volume placement, sunlight is either blocked or enters the building dependent upon seasonal requirements. The independent, extended nature of the slated envelope not only creates a range of shaded spatial enclosures but also draws together breezes for enhanced natural ventilation. Door and window placement is crucial. Primary natural ventilation is achieved though multiple openings in the expansive glazed facade to capture prominent breezes from the south. Exit openings are located in the "slots" of the slate clad envelope on west and east facades to produce cross-ventilation instead of direct passage which would result in many areas with little or no air flow as illustrated from Boutet [5].

Digital solar studies were used to determine sizing, location, and effectiveness of specific variations in the envelope (e.g. the design of the "flaps" and "boxes" on the SE and SW corners) to mitigate heat gain in the long summers of North Texas while permitting solar gain in the relatively shorter winter months. In fact, the sun remains largely outside of the building interior between April and September (Fig. 8). In the winter, thermal lag from sunlight directed onto the exposed concrete floor on the ground level is used advantageously. Additionally, the extensive, reflected daylight that enters the building through the expanse of the window wall on the south creates bright, lofty interior spaces thereby reducing artificial lighting loads. Although the digital modeling had a direct effect on the formal subtleties of the envelope shaping on the east-west ends, most heat gain is controlled by the design of the south overhang since the transverse section represents a large portion of the house. As cited earlier, the proximity of the homes to one another may greatly affect their ability to acquire sunlight into the home during the winter months when the additional heat is welcome. UR22 attempts to reduce this impact by using the window wall and placing the glazing as high as possible. Therefore, this also results in a substantial overhang to combat the summer sun. Not only is this condition expressed honestly but it is used in conjunction with the rainwater collection system.

As with many current sustainable activities, rainwater collection is a return to previous practices that reflect a simplicity and straightforwardness. Rainwater is collected from the entire roof area and this dynamic is expressed as a "moment of collection" to a single fountain at the base of the enclosed stair with any overflow stored in a cistern. The shape of the envelope expresses this collection in conjunction with the slope of the stair and represents a visual stability of the dominant envelope, thereby representing one example of the notion of integrated systems that go beyond the functional.

3.4 Structure of UR22

As with the other categories, the deployment and configuration of UR22's structure is consistent with the historical precedents. The organization and modulation of the house is clearly visible as articulated by the exposed glu-lam frame structure. An all-wood, fast growth, southern pine structure (exc. foundation and connectors) is the primary and secondary construction material selected by both the architect and the client for its workability, availability, and speed of assembly (Fig. 9). Southern pine was also used for all exterior soffit and interior upper level flooring to strengthen the notion of using a limited palette of materials as shown in the precedents.

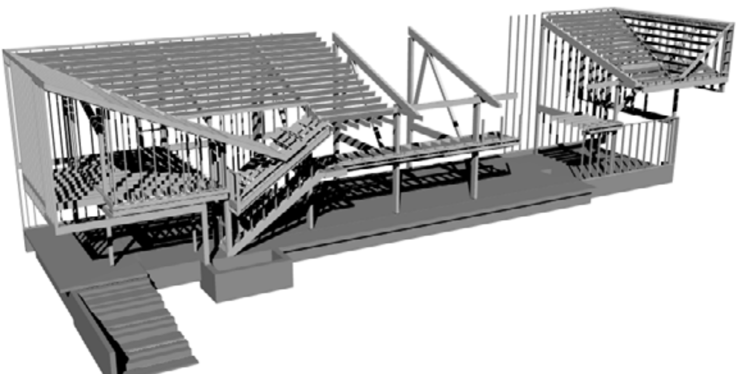

Figure 9: Architect's digital structural model, UR22, Dallas, TX.

For conceptual clarity and organization, the entire glu-lam and framing layout was also digitally modeled and initially configured by the architect (Fig. 9) to communicate more effectively with the contractor and structural engineer (the party responsible for verifying each component and systemic correctness). This 3-dimensional modeling allows for greater manageability of the structural logic-to-architectural design relationship and for enhanced quality control given the modestly priced framing and construction practices of the Dallas market. Furthermore, the repetitive spacing of the major frames at 16' on center aids in quality control by assuring that reference lines for construction are never more than 8' away.

Figure 10: Glu-lam Frames, UR22, Dallas, TX.

Additionally, OVE (optimum value engineering) framing techniques were used to reduce wood consumption. The digital modeling also assists in visualizing this cost and material savings approach since OVE largely relies on a more precise alignment of the vertical to horizontal components than used in traditional light framing.

The heavier, cadenced glu-lam frame construction also employs recurring diagonal bracing to provide exceptional lateral strength and directly express the powerful forces of wind and gravity resisted (Fig. 10). As noted earlier, exposed wood structures tend to impart a natural ornamentation through their repetition and material warmth.

4 Conclusions

Conceptually a building's envelope has the capacity to integrate many of the primary concerns of any new building design into a unified, harmonious artifact. Quantitatively, UR22 has achieved LEED-H Gold and Energy Star HERS 50 (50% energy reduction) ratings – independently verified. Qualitatively, UR22 represents a planar roof/wall system, made of a durable, ventilation-inducing envelope that is manipulated to remediate and exploit a potential conflict between comfort and the harsh climate, constructional challenges, and complex cultural contexts in North Texas (Fig. 11).

Figure 11: View from SW at entry, UR22, Dallas, TX.

References

[1] Snyder, V., Integrated Form in North Texas, *Solar Architecture & Urban Planning Conference Proceedings*, Munich, pp.115-119, 2009.
[2] Wittkower, R., *Architectural Principles in the Age of Humanism*, W. W. Norton & Company, New York and London, 1971, 1962.
[3] Evans, R., *The Projective Cast*, MIT Press, Cambridge, MA, pp. 25-27, 1995.
[4] Olygay, V., *Design With Climate*, Princeton University Press, Princeton, pp. 87-90, 1967
[5] Boutet, T., *Controlling Air Movement: A Manual for Architects and Builders*, McGraw-Hill, New York, p. 87, 154, 1987

REIs: Renewable Energy Infrastructures v1.0

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Abstract

If we recognize that architects have historically played a role as technological innovators, then we must also recognize that architects, like scientists, are engaged in a form of applied research. Our university-based team has applied design thinking skills to a problem that involves energy production, energy transmission, and urban living. We believe a Renewable Energy Infrastructure (REI) will solve this problem.

A REI generates renewable energy megawatts (MW) at an industrial scale through the simultaneous harnessing of wind, solar, and geothermal resources, but within an integrated, holistic, and free-standing facility positioned in an urban environment. A REI is *not* a retrofit of a pre-existing architectural condition, but rather is conceived as a new typology to be owned and operated by an electrical utility. While current renewable energy technologies of industrial scale are typically located in rural areas, their greatest possible service to urban areas is limited due to measurable degradation rates along transmission lines and loss during step-downs at transformers.

The anticipated impact of this REI effort is the strategic formation of a cross disciplinary, design-led research team that delivers a technically-plausible, cost-effective option for reducing greenhouse gas emissions from public power districts. Through the agency of a REI in our urban fabric, we improve the efficiencies of existing electrical technologies, improve urban land use policy, and provide an ecologically-responsible alternative that can dovetail with, or ultimately succeed, prevailing methods of electrical production at industrial scales. We are finding our preliminary REI design (v1.0) from March 2009 to have the technological potential of generating 124 MW of renewable energy.

Keywords: renewable energy, infrastructure, industrial-scale electrical energy production, urban land use policy, carbon emissions reduction, architect as technological innovator.

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1 The architect as Technological Innovator

Despite recent scholarship and interest in interdisciplinary operations, much of our intellectual world still champions knowledge bases and fields of expertise that clearly originate from, and reside within, the centres of distinct disciplinary realms. While this tendency necessarily protects a discipline's true operational boundaries (for instance, in both the licensure and governance of professionals engaged in issues of life-safety), it also fosters an intellectual environment in which its knowledge base is characterized by re-productive thinking. In turn, these boundaries adversely discriminate against new creative discoveries from being made by outside individuals who exhibit productive thinking in the conceptualization of unprecedented solutions. For instance, consider the wide ranging differences between art, design and science while also recalling the types of individuals who have contributed to two or more of these realms.

Artists are primarily dependent upon creative thinking in order to solve aesthetic problems of their own making. Because both the conception and execution of an artist's work remains subjective, the artistic problem framed is as negotiable as the solution(s) itself. Furthermore, because the artist concerns himself with solutions that shall exist in the aesthetic realm, the work yielded is required to neither have a level of use nor utility.

Scientists are primarily dependent upon analytical thinking in order to solve scientific problems that exist outside of themselves. Because the conception of scientific problems are largely in response to observed needs, the execution of a scientist's work demands solutions of sustained performance. Furthermore, because the scientist concerns himself with solutions for highly specific scientific problems, the work yielded must be tested and proven.

If artists and scientists anchor two ends of a figurative spectrum, then designers would occupy the conceptual midpoint between the two, in terms of both disciplinary interest and operation -- Designers are equally dependent upon both creative and analytical thinking, and their thinking oscillates between both as they yield creative solutions for problems framed outside of themselves. Furthermore, because the designer concerns himself with solutions that are conceived in the fulfilment of an articulated need, then the creative work yielded possesses a certain level of use and utility. Like artists, designers use creative thinking to narrow their search for acceptable solutions. Like scientists, designers address problems outside of themselves and are therefore engaged in a form of applied research.

This running description of the differences between artists, designers and scientists is necessarily oversimplified in order to quickly appreciate the major differences between them. And while most artists are unlikely to make key contributions to the knowledge base of science, the history of design provides us with architects who have extended themselves outside of their own disciplinary expertise to make new productive contributions within others. More appropriately, architects have historically played a role as technological innovators. Among them are:

- Filippo Brunelleschi and his inventive structural solution for the Florence Cathedral dome.
- Frank Lloyd Wright and the structural performance of pre-cast concrete columns in the Johnson Wax building in Racine Wisconsin.
- Norman Foster and the various inventive systems coordinated together in the HongKong Bank headquarters.
- Jean Nouvel and the operable south façade design for the Arab World Institute (IMA) in Paris France.

Of all architects who have also established themselves as technological innovators, then Eero Saarinen is arguably the greatest of these. Throughout Saarinen's distinctive portfolio of modern architecture, we find unprecedented architectural types that not only require new technological solutions, but are conceptually dependent upon the success of these innovations. For instance, the Jefferson Memorial (Gateway Arch) in St Louis, neverminding its structural design, required an inventive design for a new vertical conveyance system that would respond to a varying arc of incline as well as accommodate a high volume of visiting patrons. The General Motors Technical Center in Warren Michigan was a design vehicle for inventing several new architectural products that would eventually become industry-standard. These include the use of neoprene gaskets for sealing glass units in metal frames, the creation of insulated metal panels with porcelain enamel finish, and the glazed brick [1]. Dulles Airport outside of Washington DC required an inventive solution to transport airline passengers to larger jetliners that were necessarily parked away from the terminal proper due to the feared effects of jetwash on architectural surfaces. (This was later circumvented with tug taxis which are now industry-standard in airports worldwide. Nonetheless, some of Dulles' mobile lounges remain in operation.) When these examples are considered together, it becomes clear the Saarinen office embraced a very high-risk, high-reward design strategy that we rarely find in the United States today, likely due to legal liability, the prevalence of re-productive thinking at our discipline's centre, and a general lack of personal bravery.

If the architectural discipline is to reclaim its influence and command of the built environment, then they must conceive of research-led and performance-based solutions that address architectural issues beyond a self-serving interest in photogenic aesthetics and the market-serving provision of habitable space. For it is out of this desire for a *performative* architecture that our university-based design / research team has identified and focused on a problem that involves renewable energy production, electrical transmission, and urban land use policy. We believe a Renewable Energy Infrastructure (REI) will solve this problem.

2 Premise: five axiomatic truths

At this preliminary point, our REI problem is informed by both a variety of observable phenomena in the larger world and also a variety of internal expectations for conceptual and developmental strategies in forthcoming designs. While we observe an increasing demonstrated need for alternative modes of electrical production and transmission, our position within the disciplinary boundary of Architecture does not afford convenient opportunities for credible investigations into Infrastructure design. Instead, they have to be claimed, and in so doing, challenge the historical role that engineers have played in the conception and execution of new infrastructure types.

Figure 1: A composite ideogram identifying issues related to a *REI: Renewable Energy Infrastructure*.

Our design-led research REI effort seeks to gain credibility in the ultimate postulation of technically-plausible design solutions using existing and emerging renewable energy technologies that can be found on the market in the year 2010. In the face of very real demonstrated needs, our forthcoming solutions seek to address and fulfil these needs with viable solutions that are both “design ready” and “shovel ready.” We would be disappointed if the only venue for disseminating our resulting REI solutions were alongside these speculative designs. To this end, the REI research / design investigation is premised upon five axiomatic truths.

Axiomatic Truth Number One: “Due to the Greenhouse Effect caused by carbon dioxide emissions from fossil fuels, there is a need to invent and deploy more environmentally-responsible modes of electrical production to meet an increased demand by modern society.” If you are not already privy to the data that supports this statement, then you are likely not attending a conference titled ECO-Architecture, and you are also not likely to be reading a paper containing the words “Renewable” and “Energy” in its title.

Axiomatic Truth Number Two: “On a per square mile basis, urban areas have significantly more demand for electrical energy than rural areas.”

Axiomatic Truth Number Three: “Modes of renewable energy production are typically located in rural areas due largely to social and political forces. Furthermore, these modes are technologically proprietary and so far only capitalize on one exclusive resource.”

Axiomatic Truth Number Four: “Due to the physical properties of our current electrical grid system, there are measurable falloff rates of megawatts (approximately 10 to 15%) from their originating power source (in rural areas) along the transfer length to the end user (in urban areas).” Current renewable energy technologies of industrial scale, such as wind farms and solar arrays, are typically located in rural areas and therefore the efficiency with which they serve energy-thirsty urban areas is compromised. For every single megawatt lost during transmission, .4 is due to "evaporation" along transmission lines and .6 occurs during step-downs at sub-stations and transformers.

Axiomatic Truth Number Five: Transfer efficiency can be increased by collapsing the physical distance between the original renewable energy powersource (in an urban area) to the end user (in an urban area).

Considering these axiomatic truths, is it possible then to design a free-standing infrastructure for an urban environment that holistically considers renewable energy-producing agents such as wind, solar, geotechnical, and if applicable, hydrological resources into one holistically-designed entity?

3 The REI as a new infrastructure typology

Our team wanted to first pre-emptively understand the historic emergence of new infrastructure types and their level of acceptance achieved with the population that it serves. Society has psychologically accepted the presence of large-scale infrastructure types due to their *performance* – it is implicitly understood that the level of performative benefit of infrastructure shall exceed any adverse impact that said infrastructure has in the collective viewshed. While both urban and suburban dwellers alike have visual access to multiple infrastructure types in a given day, these populations have developed a psychological comfort with the presence of infrastructure through familiarity, and their physical presence does not adversely impact us since it is already incorporated into one's realm of experience.

Specifically, we investigated the emergence of water towers, cell phone towers, and grain elevators. Surprisingly, we are finding very little opposition during the proliferation of water towers, but only praise – The public at large seemed to understand the performative benefits of this emerging type and were immediate beneficiaries of their widespread proliferation and successful operation. However, with the emergence of cell phone towers in the late 1980s, there was widespread vocal opposition to this new infrastructure type and its impact on viewsheds. Unlike water towers which were immediately understood as a public amenity, cell phone service was an endeavour of private commerce and did not serve the needs of the general public. Furthermore, the price point for early cell phone service and equipment was relatively high for most potential end-users and their budgets, and this worked against any rapid psychological assimilation of cell phone towers in our cultural consciousness. However, as cellular service costs decreased, an increasingly larger portion of society became users of this private service, and we have since conditionally accepted the visual presence of these towers in our viewsheds as long as they continue to provide cellular service and enhanced cellular signal strength. Within the State of Nebraska, the most regionally-appropriate example of psychological adoption stems from sentry-like grain elevators distributed throughout urban, suburban and rural environments in the American Midwest. While their sublime presence is startling to visitors from non-agricultural regions, they have been completely psychologically assimilated by the local population and are rarely read as foreground objects. Their performative benefit as objects of infrastructure is understood, and their importance to the region as local economic engines is also understood. Despite their sentry-like stature, these grain elevators dot our viewsheds, but with little to no public opposition.

When forecasting upon the physical scale a REI would require to generate electrical energy at industrial levels, we presumed that a REI would be of such a physical scale and construction type that it could read as a mid-rise or high-rise building. In light of this, it becomes clear that a REI needs to first establish credibility through its quantified performance in order to then effectively challenge restrictive urban zoning policies, provoke NIMBY attitudes and induce market transformation.

A REI seeks to generate renewable energy megawatts (MW) at an industrial scale through the simultaneous harnessing of wind, solar, and geothermal resources, but within an integrated, holistic, and free-standing facility positioned in an urban environment. A REI is *not* a retrofit of a pre-existing architectural condition, but rather is conceived as a new infrastructure typology to be owned and operated by an electrical utility for purposes of servicing users in high-population areas.

4 The framing of an unprecedented design problem

According to the 2008 US Census, the State of Nebraska ranks 38th in population (out of fifty states) with 1,783,432 residents. This ranking places Nebraska in the lowest 25th percentile of the United States. In contrast to its lower population however, the State of Nebraska ranks very high in access to wind, solar and geothermal resources capable of producing renewable energy. Climatic resource availability has been thoroughly documented by the National Renewable Energy Laboratory (NREL), and on a technical level, we recognize that an optimized REI design would be custom tailored to its specific solar, wind, and geotechnical (and if applicable, hydrological) resources. Therefore, the design of a REI in Tucson AZ would look and operate very differently from one designed for Fargo ND. The specific design parameters for either would include the highest level of specificity for angles of solar incline, direction of solar arc, wind speeds achieved at higher elevations, and overall percentages of wind and solar energy technologies. All of these parameters require review in order to optimize electrical yields produced by the REI. The project deliverables that we are looking to yield shall require working with the State of Nebraska's various public power districts in the design of (3) site-specific, technically-plausible REI solutions of escalating scale in Columbus NE (population 21,595), Lincoln NE (population 251,624) and Omaha NE (population 438,646). These forthcoming options shall be site-specific to maximize urban site conditions although they already share very similar climatic conditions.

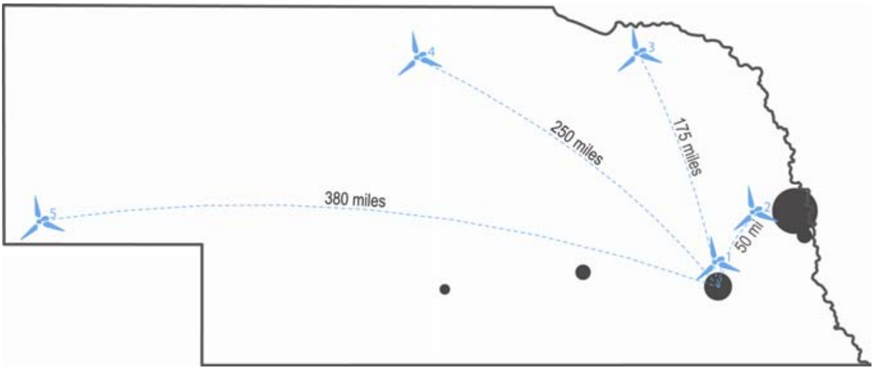

Figure 2: A map of the State of Nebraska locating each of its five operational wind farms, each of the five largest cities, and the linear travel distances between the rurally-located wind farms to those urban areas with the maximum number of end users. If all wind-generated renewable energy MWs were diverted to Lincoln NE, they would travel a total of 906 miles.

In terms of wind, the US Department of Energy ranks the State of Nebraska as 6th in wind energy potential. Despite this strength in climatological circumstances, Nebraska in 2009 surprisingly ranks only 24th in actual wind energy production with a current rate of 153.2 MW. In terms of solar, the US Department of Energy ranks the State of Nebraska as 19th in solar energy potential with a Sun Index of .89, but there are no industrial-scale photovoltaic arrays currently operating.

Of the 153.2 MW of renewable energy produced in the State, 10%-15% of this amount is believed to be lost during transfer due to degradation along transmission lines and processing through transformers. This amount totals 15.3 - 23.0 MW lost over 906 miles of long span transmission lines from five different wind farm locations, all of which are located in rural areas. We believe that we can significantly reduce this amount of loss by collapsing the distance between where renewable energy is produced, and where it is consumed.

There are several constraints when determining an appropriate site for a REI. Due to the highest need for performance, a site should be chosen that eases the distribution of electrical energy generated, but does not compromise its generation potential by positioning itself amongst urban obstacles, such as other buildings. Depending upon their respective size, proportion and solar position relative to the REI, these obstacles could foil the operation of the REI by either creating wind turbulence or shade the REI from valuable solar exposure. Another constraint in play is the economic feasibility of a REI given real estate property values. A REI developed on a site with commercial value would likely not be a cost-effective solution when compared to other energy generation facility types. Furthermore, this private land would then require re-zoning for industrial use, and would likely be denied by any municipality with reasonable

Figure 3: Location map of Lincoln NE showing the selected REI site at 8th Street and N Street. This site is owned by the City of Lincoln and leased to the Lincoln Electric System for an electrical transformer site.

concerns about open high-voltage lines in an otherwise vibrant downtown. The best sites for a REI are likely to be on the periphery of our downtown areas.

In an optimum scenario, if all other site requirements allow, REIs would be ideally positioned on sites already operated by electrical utilities and with existing transformer equipment. If the presence of this new REI construction would not itself precipitate a significant upgrade or overhaul of pre-existing transformer equipment, then the REI could feasibly occupy the airspace of this site, thereby tapping into an existing network without increasing project costs and yet improving urban land use policy. Although a REI would have a physical presence similar to that of a building, the REI would not have appropriated square footage per se, and would only be occupied by utility persons for inspection, service and repair.

The site selected for our REI v1.0 study is located in downtown Lincoln NE, immediately south of the historic Haymarket District. The site is owned by the City of Lincoln, but is leased to the Lincoln Electric System utility as an electrical transformer site. Our REI site is the airspace above this existing electrical infrastructure and in so doing, affords us the ability to tap into a previously existing electrical distribution network without increasing project costs. Furthermore, it allows a REI to occupy an urban context without acquiring privately-held land and / or demolishing existing real property.

Due to the danger presented by large-scale mechanical components in movement, we recognize the very real life-safety concerns that are associated with a REI in an urban environment. Whereas photovoltaic panels present a very low hazard level of operation, the failure of large horizontal-axis wind turbines is oftentimes both spectacular and irreparable. In the event that a bearing generates too much heat during rotation, the turbine house may catch fire due to overheating by friction. However, since these turbine types are typically located in rural areas, the horizontal-axis turbines are often allowed to burn out in place. Firefighting teams will set up a secure perimeter around the problem turbine, and protect against falling debris, including the turbine itself. Proper maintenance can prevent such fatal problems for wind turbines, but high wind speeds present another set of life-safety issues. In the event that wind speeds push blade revolutions beyond their recommended operating limits, there is a safety braking mechanism that shuts down the rotation of the turbine blades. However, these braking systems can sometimes fail. Under increasing wind speeds, turbine blades that continue to spin beyond their operational specifications can put considerable structural stress upon its respective support mast as well as the profile of the blades themselves. Under such stress, the structural profile of the mast can deflect enough to topple the spinning turbine to the ground or the blades themselves can deflect enough that they collide with the mast as they are spinning. In either case, the power exerted and quickness demonstrated in such destructive acts are marginalized in rural settings, but would certainly cause considerable collateral damage to both life and property if similar technological failure occurred in an urban setting.

5 Preliminary designs

With the design problem reasonably formed, we then sought out any design precedents that may have stemmed from a similar set of site, program and user circumstances. We were pleased to find the smaller-scale *Oasis* by Laurie Chetwood and the larger-scale *Solar Net* winning entry for the 2001 US Department of Energy Sunwall Design Competition [2]. Upon familiarizing ourselves with the design intent behind this latter Solomon Cordwell Buenz / Arup proposal, we appreciated the innovative form of the sloped concave photovoltaic wall which allowed itself to be intelligently-shaped according to the winter and summer solstice positions. Furthermore, as with all of the competition entries, we appreciated its willingness to engage non-rural, densely populated sites for generating renewable energy.

We believe the innovative value of our REI proposal lies in the bringing together of multiple renewable energy technologies on a single urban site in a deliberate, hybridized, and technologically unbiased way. While the REI is looking to establish credibility through generating quantifiable electrical yields at industrial scales, it also addresses other multiple aspects of our nation’s energy problem (the political, economic, carbon emissions, and technical) while having some collateral benefit to non-energy areas (in commerce, design, and engineering).

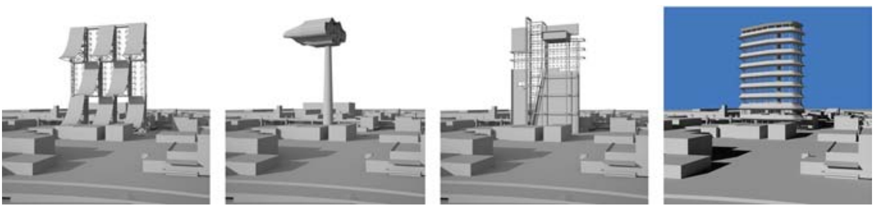

Figure 4: Preliminary designs for a REI sited in Lincoln NE. The design chosen for further development is shown at the far right.

Our preliminary designs were the result of a three day charette exercise. Our design strategy was to first use creative thinking to generate multiple options for consideration, and only then use analytical thinking to identify those traits and qualities that we wanted to ultimately carry forward into the developed REI design.

The first scheme sought to feature sloped concave profiles to optimize yearly solar angles for the 41st latitude. However, these profiles were also arranged to deflect prevailing southern winds upwards to double the air velocity moving through the vertical axis turbines located immediately above. However, due to the staggered patterning of the solution, we recognized that shadows cast upon the photovoltaics below were self-defeating. In this scheme, overall power generation would likely be; Wind = 34%, Solar = 33%, Geothermal = 33%.

The second scheme explores the possibility of (6) small diameter horizontal axis turbines covered with a photovoltaic fuselage skin. Supported by a single mast, the face of the turbine blades would always rotate to front applicable winds, and the photovoltaic fuselage would further assist the proper wind orientation with fin profiles. In order to best capture wind resources, REI schemes incorporating wind technology would need to occupy the highest elevations that municipal zoning regulation will allow. In this scheme, overall power generation would likely be; Wind = 50%, Solar = 25%, Geothermal = 25%.

Whereas the first and second schemes sought an aesthetic informed by scientific determinism, the third scheme explored a composition of vertical axis turbines and photovoltaic surfaces for its own aesthetic sake. Furthermore, we brainstormed on possible architectural programs that may also benefit from being incorporated into this scheme. We would soon conclude that whatever interest was gained in composition, it lost credibility in energy performance. This scheme was immediately rejected since it was not congruent our criteria for beneficial infrastructure design – Infrastructure design should not sacrifice physical performance for the sake of compositional aesthetics. In this scheme, overall power generation would likely be; Wind = 25%, Solar = 25%, Geothermal = 50%.

The fourth and final scheme is informed by attributes of each of the first three schemes. It is not self-conscious about its own aesthetic, but rather seeks maximum electrical production through wind, solar and geothermal resources. Scheme “D” has been selected for further investigation.

6 REI v1.0: Lincoln NE

We are finding our preliminary REI design from March 2009 to have the technological potential of generating 124 MW of renewable energy.

This scheme for Lincoln NE assumes a maximum allowable REI zoning height at 400’-0” which is equal in height to the Nebraska State Capitol building by Bertram Goodhue (1932). To maximize this likely height restriction, this REI provides (8) stacked tiers of integrated wind / solar modules each set every 40’-0” in infrastructure height.

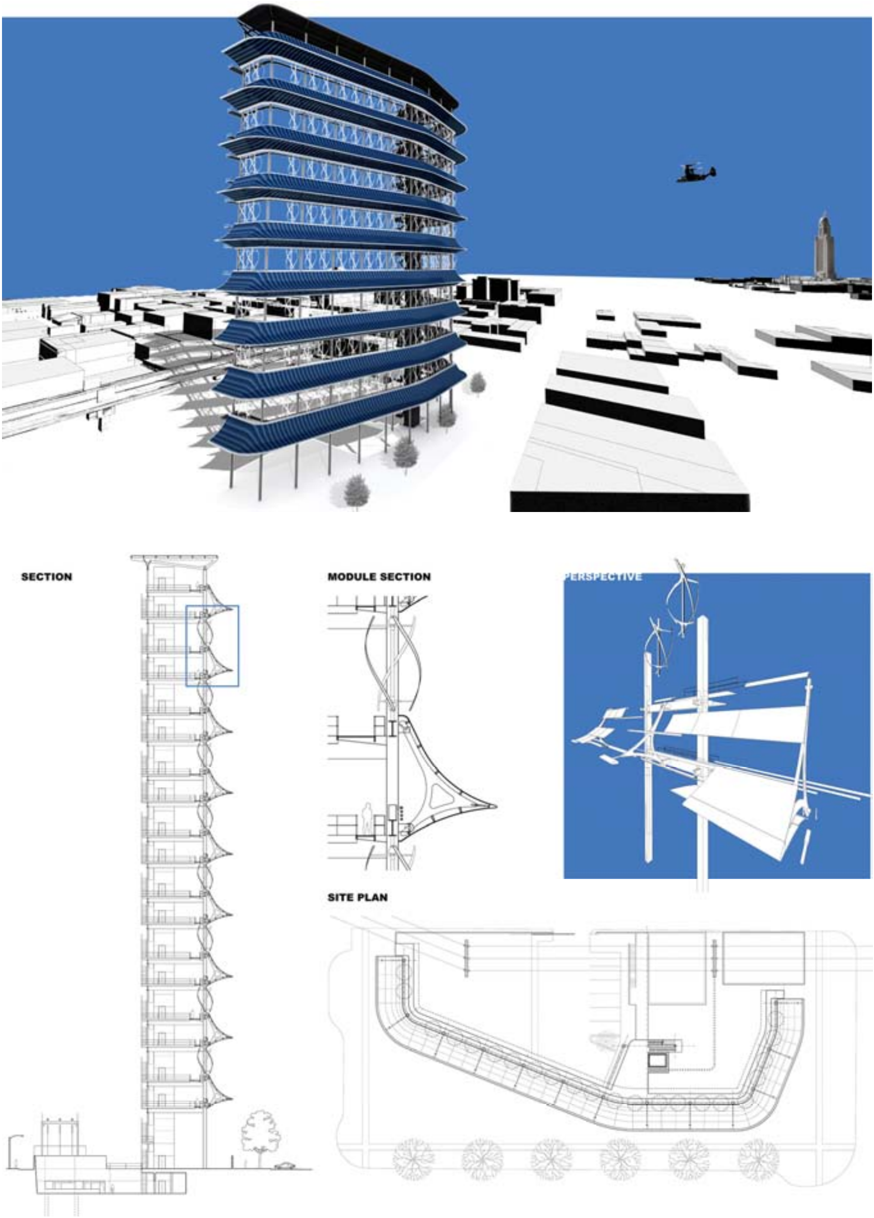

Figure 5: Design materials used to represent our REI v1.0 include perspectives, site plan, transverse section, enlarged component section, and exploded view of vertical-axis turbines, photovoltaic panels, and structural system.

Energy Production – *Wind*: Equipped with quietRevolution qr5 v1.3 Vertical Axis Wind Turbines. (22) turbines per floor with (8) floors = 176 qr5 turbines. 1 qr5 turbine = 2.74 kW @ 12 m/s. Seasonal wind data for Lincoln NE suggests that these turbines can likely generate: Jan thru Mar = 563 kW, Apr thru Jun = 1.056 MW, Jul thru Sept = 1.144 MW, Oct thru Dec = 528 kW.

Energy Production – *Solar*: Equipped with custom-shaped Schott ASE-250-DGF photovoltaic panels. 187,220 sq. ft. of PV panel per floor with (9) floors = 1,684,980 sq. ft. PV panel area. 1 sq. ft. of Schott PV produces .012kW x 1,684,980 sq. ft. = 20.22 MW generated.

Energy Production – *Geothermal*: The NREL has published that the State of Nebraska has access to internal core temperatures of 100 to 200 degrees Celsius.

This REI design assumes its construction would be phased as a scalable system where smaller portions of a REI can become operational prior to a complete build-out of the overall design. This economic model for implementation would benefit from streams of funding over time and would only then yield the highest amounts of MW once completed. It is our expectation that a REI would have upgradeable, hot-swappable technological components to both maximize life expectancy and design against expiration due to technological obsolescence. The cast aluminium frames can be attached and detached with relative ease in order to maximize access to the REI's structural frame, its electrical conduits, and for upgrading the components on the frames themselves. Furthermore, its hybridized technology strategy effectively diverges from the current trend of proprietary system design by companies that exclude other renewable energy types not in their business model / expertise. By combining vertical axis wind turbines and photovoltaic arrays on the same site, we harness multiple climatic conditions simultaneously.

Through the agency of a REI in our urban fabric, we improve the efficiencies of existing electrical technologies, improve urban land use policy, and provide an ecologically-responsible alternative that can dovetail with, or ultimately succeed, prevailing methods of electrical production at industrial scales. More appropriately, as new REIs of industrial capability are constructed, existing greenhouse gas emitting modes of electrical production (such as coal-fired electrical plants) can be decommissioned. This suggests that REIs could be impact players in future energy policy where carbon-emitting emissions can be significantly reduced without having to adversely impact electrical consumption.

7 Expected outcomes and estimated impact

The greatest impact of this REI effort shall be the delivery of a plausible, cost-effective option for reducing greenhouse gas emissions from Nebraska's public power districts. Because a REI conceptually emerges from the intersection of energy production, global warming, and urban living, it suggests that energy solutions can originate outside of traditional disciplinary boundaries and speaks to the validity of cross-disciplinary, design-led research.

This project is well-positioned to address attributes of our nation's energy problem such as our demonstrated dependency upon importing energy from foreign nations and alleviate some of the political and economic pressure associated with a dependency upon this supply line. Without the natural resources to satisfy our own national demand, embracing renewable energy would help us transform our energy market from its current fossil-based forms to domestic wind, solar and geothermal resources that can already be found in abundance stateside.

The execution of a REI would be transformational in its ability to combine, in a deliberate and intentional way, multiple renewable energy technologies in the same physical location and without proprietary technological exclusion. This would effectively diverge from the current trend of proprietary system design by companies that exclude other renewable energy types due to the specificity of their business model / expertise. A REI incorporates renewable energy technologies because it looks to establish credibility through generating quantifiable electrical yields at industrial scales, and does not concern itself those aesthetic issues determined by critics-at-large.

The pursuit of a REI would be a friendly counterpoint to other research efforts in “Smart Grid” transmission technologies by simply collapsing the distance between where electrical energy is produced and where it is consumed. This reduced travel distance for MW will translate into a sharply reduced amount of renewable energy MWs lost.

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In October 2009, this preliminary REI design received a 2009 “Monster of Design” award from the AIA Kansas City Young Architects Forum.

References

[1] Serraino, Pierluigi. *Saarinen*, Taschen: Köln, pp. 35, 2005.
[2] National Renewable Energy Laboratory. *Sunwall Design Competition; United States Department of Energy, National Solar Design Competition*, Publication Number DOE/GO-102001-1339, NREL: Golden CO, 2001.

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