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Editors of the current issue: Aikaterini Chatzivasileiadi and Maria Voyatzaki

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Editorial

Aikaterini Chatzivasileiadi and Maria Voyatzaki

Already in the third successful year of the journal, it is with great pleasure that we present the sixth issue of archiDOCT. As with the previous issues, what is presented across these pages is a result of the fruitful collaboration among a number of contributors: the editors-in-chief Maria Voyatzaki and Constantin Spiridonidis, the scientific committee, the guest editor of this issue Aikaterini Chatzivasileiadi, currently PhD candidate at the Welsh School of Architecture, and above all, the enthusiastic and aspiring doctoral students around the world.

With growing concerns around climate change, as well as the economic and cultural instability of our times, sustainability has become the centre of many discussions around the Globe addressing the environment, economy and society in one way or another. This sixth issue addresses a variety of eco topics including Welsh policies on low impact development, sustainability from a mathematical perspective, building energy demand in China, vertical greening systems in Nigeria and building integrated photovoltaics. The variety of the topics highlights the diversity of the field of Architecture - even under a common theme. It therefore aims to initiate a conversation around sustainability-related approaches, research methods and research impact in architectural research and also to highlight its multi-disciplinarity.

The good practice example by Maria Voyatzaki draws on the convictions of ancient Greek philosophers on the solid or changeable state of the world around us. It is argued that an ethical basis exists in this particular relationship between the solid and the liquid; it is not hierarchical. It can therefore occasionally acquire different hues by different priorities, associations, gravities and magnitudes. The paper concludes proposing a sustainable way in environmental design education and invites us to contemplate the future together while critically considering the past.

The first doctoral essay of this issue by Mark Waghorn is a critique on the One Planet Development. This is a Welsh Assembly Government planning policy (2010) introduced to take forward Low Impact Development principles in Wales. The author analyses several real life examples in order to review the opportunities and barriers of the program. The focus is on the cultural differences between those responsible for enacting and enforcing regulatory systems and practitioners. Waghorn concludes with ways to bridge the identified gap.

The second contribution is made by Anthie Verykiou from the National Technical University of Athens. The essay analyses the concept of sustainability through a mathematic perspective; the model of the "Fold". The "Fold" model, introduced by R. Thom, indicates the emergence of a reality in continuous variable state, which is considered as the central ontological progress of our time. The author aims to contribute to an understanding of the concept of sustainability and its impact on the general contemporary cultural context. Moreover, the study highlights the interconnections among different scientific and artistic fields that ultimately converge to the notion of landscape through the contemporary ecological sense that points to energetic, metabolic approaches.

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Xi Deng's research article explores the impact of microclimate change on the energy demand of buildings in Chengdu, China. The study has mainly touched upon air temperature change, compared against other neighbourhood morphology parameters. This is the only study of this issue where simulation tools have been used; namely tools that were developed in the Welsh School of Architecture, such as HTB2 and Virvil Plugin. Five different models were assumed considering the following four parameters on top of the standard model: building density, building compactness, building vertical layout and air temperature change. The results from the simulations, as Deng concludes, indicate a quantitative correlation between microclimate change and the energy performance of buildings at a neighbourhood scale. The study therefore provides several perspectives for architects and similar practitioners in the field to reduce the energy demand at an early planning stage.

The next doctoral essay is the third one in this issue presenting research undertaken in the Welsh School of Architecture of Cardiff University. There, Oluwafeyikemi Akinwolemiwa presents the development of a sustainable idea to combat the issue of global warming in Lagos, Nigeria, which has resulted into extreme temperature rise within the country. More specifically the effect of vertical greening systems on the occupants' thermal comfort was evaluated in a field study. The study also addressed the economic aspect of sustainability, as low-income residences characterized by overcrowding and overheating of interior spaces were investigated. A financially affordable, easy-to-erect-and-maintain vertical greening system was therefore set up and monitored for four months. The results revealed a significant reduction in the ambient temperature of the immediate surroundings of the vertical greening system setup as well as a reduction in indoor temperatures.

The last of the five doctoral essays, provided by Stefanos Gazeas from the Aristotle University of Thessaloniki, focuses on the architectural integration of photovoltaics in the buildings' envelope. As the PV integration encompasses both performance and design characteristics, the study presents the architectural criteria upon which an efficient PV integration is achieved. The main contribution of this paper is four architectural detail drawings in the form of typical construction sections, offering a clearer view of the building envelope which functions as a solar energy generator, by replacing conventional construction materials.

We do hope that the aforementioned papers will not only elevate your understanding about sustainability in architectural research, but also make you reflect on current situations or new concepts, stimulate productive conversations and inspire other doctoral students to participate. Enjoy!

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The solid and the liquid in environmental design education

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Note: *The paper was first published in "Architectural Education and the Reality of the Ideal: Environmental Design for the innovation in the post-crisis world", by the European Association for Architectural Education, Transactions on Architectural Education No 61 (2013). It can be found at http://www.enhsa.net/Publications/AR2013.pdf.*

Solid and Liquid

Between Parmenides'[1] conviction that nothing in our world is changeable, and that of Heraclitos'[2] that everything is in a permanent state of change, there is Aristotle's in-between doctrine that even though the natural world is permanently changeable, there is always something solid and constant, which nevertheless differs after changes occur. Ever since, our appreciation of the natural world has sometimes been based upon the priority given to the solid components of reality and other times driven by those in the process of changing. At least in recent history, the first approach led us towards the adoption and adherence to models, standards, archetypes, modulors, ergonomics, but also, more broadly speaking, to rationalisation, internationalisation, mass production, control and prediction. The latter approach opened us up to typologies, selected historic references, memories and cultural spatial identities, as well as differentiated social meanings and symbolisms. In the last fifteen years, we have been experiencing a new reconciliation of these two different logics. Both solid and changeable components of our world are no longer ranked on the basis of their degree of stability or transformability, but they can be occasionally prioritized as always depending upon the overall dynamics emerging by the broader and unstable conditions in which the overall system exists. Aristotle' s aspirations are now glorified.

Environment

In this new mindset and contemplation the debate on environmental issues appears to be radically transformed. It started with the adamant conviction that environmental issues are questions of physics based upon the solid and classic laws of nature and as such they should be treated as technical. After the 70s this debate progressively shifted its basic hypothesis conceiving, this time, the environmental issues not as primarily technical, dependent upon natural laws, but mostly as social and political and for this reason changeable, transformable and liquid. The terms sustainability and ambience, which has dominated this debate in the last 30 years, perfectly expresses this shift from the priority of the solid and unchangeable, in the understanding of environmental problems, to the predominance of the changeable and transformable. Nowadays, we are experiencing a shift according to which, both solid and liquid factors of the environmental

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problems are described by the term ‘parameter’, which is rather neutral. All parameters affect the complexity of the system and their temporary hierarchies emerge from the specific dynamics of the broader system. Physics and humanities are now invited to be in a condition and in a relation of ‘sympathy’. Parmenides and Heraclitos are no longer rivals; they are now allies.

Architecture

Architecture as a manifestation of our cultural values and perceptions is profoundly affected by these changes. Changes in the ways we appreciate the world transform the way our thinking is framed. Strong, new concepts emerge from the new constraints this framework imposes. This is something that both thinkers and architects support. A few years back Jean Baudrillard and Jean Nouvel had agreed that strong concepts emerge as the outcome of a creative way of encountering constraints[3]; the higher the perplexity of the constraints the stronger the concept. New constraints lead to new concepts and new concepts to new statements, practices and creations. This explains why architects are not only familiar with dealing with constraints, but they find this task challenging and intriguing.

In the second part of the last century we experienced significant changes in the fundamental concepts driving architectural creation. The persistence in the common and solid characteristics of architecture and of the humans inhabiting it led to concepts such as the ‘man of the modulor’, an expression of the common and timeless constitutive of the ‘user’, who in the name of democracy had to inhabit identical spaces accommodated in the same form, be it in France, Morocco or India. Later on, the persistence in the different and changeable, that is to say, the liquid characteristics of architecture and the human led to the concept of the human as a social being, who in the name of democracy, had to inhabit spaces reflecting his particular social, cultural and individual differences. Nowadays, due to the changes in our global understanding mentioned above, architecture is no longer considered as the act of creating an artefact that stands alone, tangible, perceived or presented to the senses. From the constraints imposed by this new mental framework, strong, new concepts emerge. Architectural creations are now defined, not as complete entities exposed objectively and factually to our experience in order to function, to serve, to represent, to note or connote, and to stimulate memories and feelings. However, they are increasingly conceived as parts of a broader assemblage of other entities and conditions, an alterity[4]. We are moving from a concept of architectural creation as a finished hierarchised total, to its conception as a part establishing multiple, not solid, unpredictable and emergent relations with the other entities of this complex and dynamic assemblage of solid and changeable elements. As part of this assemblage, the building is conceived as an interface in a dynamic system of relationships dependent upon and defined by a flux of information and data; a point in a point cloud. Between its proper substance and its alterity there is a continuum. The solid and the liquid are amalgamated in the form of information and data.

Architecture and Environment

Environmental issues have taken up a major part of contemporary architectural thinking and creating. Architecture for centuries conceived dwelling and the city either as shelters for the human beings to be protected from the natural elements, or as powerful weapons and efficient representations of their dominance over the natural forces, laws and phenomena. Even though nature, as

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generator of the alive, has always been the architects' source of inspiration, it has also always been the competitive 'other' to be conquered, mastered and dominated. This architectural production of our civilization is usually defined as the built environment, which distinctly and implicitly is opposed to the natural environment, where the former undergoes a process of naturalization and the latter a process of domestication.

The answer architecture has given to the question 'which environment for the human being?' has been structured either through the dominance of the technical perception of the environmental issues or through the above-mentioned dominance of their socio-political understanding. However, buildings continue to be major causes of harming nature. Pollution from heating and cooling buildings still exceeds that of cars. The building industry, which is the second largest industry in the world, still manufactures building materials that consume enormous energy and exhaustible resources. Buildings and their construction still account for more than half of the entire greenhouse gas emissions. Environmental sensitivity, sustainability, ecology, pollution, global warming, climatic change and the greenhouse effect, are simply terms emerging from the uncontrolled and aggressive invasion of the built into the natural environment or of human intervention in nature. Moreover, our homes, which are the highest lifetime purchase and investment, are built, to a greater or lesser extent, in the same way they were built, at least, fifty years ago. The home that will virtually define our lives for twenty, thirty or forty years in the future is designed only for today, based upon an implicit (and obsolete) conception that the future is just a repetition of the present.

The articulation of the new approaches to environmental issues with the new conceptions about architectural creation remains an open issue not only for the architectural community but also for the academic community that educates architects. What we need to redefine now is how from the new conceptions about architecture and the environment, new concepts can creatively emerge that will, in turn, drive architectural design towards interesting, efficient and innovative proposals. How the amalgamation of the solid and the liquid can open up new creative avenues to architectural design. This is an extremely important challenge to be explored and capitalised.

Information Technology

Information technology can play a very significant role in the creative amalgamation of the contemporary considerations of architecture with new views on the environment. The conception of the dwelling as an active part of a broader assemblage on the one hand, and the environment as a decisive dimension of this assemblage that permanently affects its parts and is constantly affected by their nature and action on the other, bring architecture and the environment into the same relational and associative system of information flow and data through which computer simulations investigate and manage complexity. Information technology has already provided architecture with high-end powerful computer software and hardware able to generate and fabricate intriguing architectural forms –although this achievement should not be seen as an end in itself[5]. In parallel, Computer Numerically Controlled (CNC) machines allow for testing, simulation

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and mass customization at all scales and of any volumetric or construction complexity. The contribution of digital fabrication to the environment has been underplayed, but it would be interesting to note that it can merit in less material wastage due to the ability of cutting patterns in an optimised way. Material can also be economised as with rapid prototyping the structural efficiency and performance can be tested and verified towards the marginally small sizing of components. File-to-factory techniques[6] of communication between the designers' desktop and the construction site can save shipping material to the site as it can be locally processed as well as save human power of expertise transport by operating remotely from the site while at times it can also involve robots for non-standard operations while or after the building is constructed. At the same time the same technology advances software to offer accuracy in modelling and simulation of the environmental performance of buildings and their components; advances always accompanied by the thorny subject of scaling up results and of transforming data from models to real life situations.

A body of knowledge on interactivity, adaptivity and responsiveness (actuators, transformation in real time with arduinos and intelligent environments) as well as on computation that generates new materials (encoded materiality) with specific properties that augment the environmental impact are progressively developed. Technology appears to be an affective catalyst of this expected articulation. It is promising that there are significant improvements on the interoperability between the two approaches; form generation and environmental simulations.

Environmental Design Education

How can the new conceptions about architecture and the environment be accommodated in our educational environments? Given that Building industry is responsible for more than 40% of resource consumption and environmental impact, it is in this sector that some of the largest contributions to ecological and economic sustainability may be made through better design and management. The question arising is how a school of architecture prepares its students to be part of the solution and not part of the problem?

The usual clashes on the scientific versus the humanistic bias mentioned, is not only central and fierce in many contemporary architectural curricula, but is also even tougher given the rich body of knowledge that sciences have generated in the domain of the environment. The scientific feature of this particular knowledge is what has often been the source and cause of the indifference of architects who believe that design, as a creative act, can dismiss science. By focusing on the social, political and cultural dimension of architecture (mainly in the 80s and 90s) architectural curricula kept environmental issues out of the design studio treating them in autonomous modules with a purely technical agenda.

Taking into account the experience of the previous ENHSA publication on "Teaching a New Environmental Culture; The environment as a question of Architectural Education"[7] in 2011, there is an extended urge to blend environmental education into the design studio. The pedagogy, teaching methods and techniques have been central in this discussion among educators on how to teach environmental design to architecture students. This request appears to be absolutely justified with the contemporary views and conceptions of the environment and of architecture as discussed. How

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about seeing this new mental framework as yet another constraint towards a stronger concept? What if a design perseveres the environmental obligation as a social responsibility, as a way towards a stronger and more ethical concept? These two subject areas of the spectrum have to be revisited and be complementary to the pedagogic aspects of formal education. In the same amalgamation strategy, we need to reconsider the two poles of the environmental debate. The one is the role of technology in environmental thinking as a way towards global and sustainable architecture, and the other pole is the ethical dimension of the appreciation of the broader ecosystem and the systemic role of the architect, the occupant and architecture in it.

The environment can and must be appreciated as an innovation catalyst of architectural design; as a framework from which new ideas, forms and materialities can emerge offering innovative advancements in architectural contemplation and creation. This requested innovative ideal has to enhance and preserve its links with the contemporary conceptions of reality and the human as they are shaped in our contemporary world. In other words, it is high time we redefined the environmental design ideals as objectives of our educational practices, after all the significant changes and shifts that have occurred in the last twenty years.

Epilogue

Aristotle taught us that movement and change, genesis and decay -which are particular forms of change- occur in the natural world all the time. Things actually change, and this change is registered, but at the same time, things do not always change entirely. In every change there can be something solid, something maintained or preserved, while at the same time it is different from what it was. 'We do not design from scratch' Bruno Latour[8] reminds us. There is always something known, used, experienced and tested. Something solid used as a framework of constraints, to safely build on. But at the same time through the act of creation we are introducing invention, change, transformation, alteration towards the liquid, the unknown, the risky, the mistaken, the 'intentionally uncontrolled', as Jean Nouvel states. After that the new building is never entirely new, as it is part or should be a sympathetic[9] part of what already exists in its conceptual and physical context. It has to be in a sympathetic relationship with its broader system, if it is to be amalgamated with it, to blend into it.

There is an ethical basis in this particular relationship between the solid and the liquid: it is not hierarchical. It can occasionally acquire different hues by different priorities, associations, gravities and magnitudes. As a consequence, this attitude can either lead to an extremity of the absolute dominance of the liquid in the form of inventive experimentation towards radical innovation. Contemporary technologies can become enabling technologies by introducing virtuality immaterially, as opposed to artefacts with physical presence and impact that most likely harm than enable. The same attitude can lead to the other extremity of the absolute dominance of the solid leading to non-design when building is not necessary. It is an expectation of contemporary discourses on a new environmental culture to encompass ethics as one of their cornerstones.

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This sympathetic relationship between the liquid and the solid also affects the way we look back or the way we look forward; the ways in which we invent, predict, imagine and manage the future and the ways in which we think, analyse, memorise and investigate the past. Nowadays the ethical attitude emerging from the framework we have elaborated in this essay is to avoid looking only ahead (like in modernism) or looking only back (like post-modernism). The invitation is now to contemplate the future together while critically considering the past. To creatively imagine the myth of the future, but also to critically analyse the myths we created in the past: to invite and accommodate in this contemplation both Prom(y)theus and Epim(y)theus[10].

Notes

[1] On Nature, which has survived only in fragmentary form. In this poem, Parmenides describes two views of reality. In "the way of truth" (a part of the poem), he explains how reality (coined as "what-is") is one, change is impossible, and existence is timeless, uniform, necessary, and unchanging. http://en.wikipedia.org/wiki/Parmenides

[2] Heraclitus is famous for his insistence on ever-present change in the universe, as stated in the famous saying, "No man ever steps in the same river twice" (known as 'ta panta rhei'). http://en.wikipedia.org/wiki/Heraclitus

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Essays

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One Planet Development: opportunities and barriers

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Abstract

In recent years in Wales, Low Impact Development (LID) has been recognised as providing a valuable contribution to the search for more sustainable models of development, and in 2010, the One Planet Development (OPD) planning policy was introduced to 'take forward Low Impact Development principles in the Welsh context' (Welsh Assembly Government, 2010). The limited amount of OPD applications approved to date demonstrates a continued cultural resistance to LID, whilst the ad hoc self-build approach and use of local and unprocessed materials has resulted in further tensions with other regulatory frameworks. With the help of several real life examples, this paper asks what opportunities the OPD planning policy presents to those wishing to live sustainably and needing to make do with limited resources. A number of barriers to LID are identified, with reference to these examples. The study finds that cultural differences between those responsible for enacting and enforcing regulatory systems and LID practitioners are the root of many of the barriers to LID. The paper concludes with some suggestions for how this gulf can be bridged.

Keywords

Sustainability; environment; Low Impact Development; LID; One Planet Development; OPD; making do; planning; resilience.

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Introduction

LID and permaculture, which are closely related, both rely on a close connection between people and resources, many of which are derived from the land. This requirement for land, combined with historic cultural differences between the LID community and mainstream consumer culture have resulted in the location of many Low Impact Developments in a deep rural setting. This has inevitably meant that LIDs have been at odds with the model of sustainable development sanctioned by planning orthodoxy. Permaculture principles call for a rich and adaptable interplay between difference activities and land use, which is incompatible with the rigid zoning imposed by planning law. Meanwhile, the ad hoc self-build approach and use of local and unprocessed materials has resulted in further tensions with other regulatory frameworks.

In recent years in Wales, LID has been recognised as providing a valuable contribution to the search for more sustainable models of development (University of the West of England & Land Use Consultants, 2002; Baker Associates, 2004), and in 2010, the 'One Planet Development' planning policy was introduced to 'take forward Low Impact Development (LID) principles in the Welsh context' (Welsh Assembly Government, 2010).

Despite the Welsh Government's recognition of the opportunities for OPD to provide models of affordable, sustainable development, the limited amount of OPD applications approved to date demonstrates that there continue to be significant barriers preventing One Planet Developments from being realised. In order to find ways to overcome these barriers one needs to address the reasons for continuing cultural resistance to LID. To understand how to achieve this, we need first to make a study of the history of LID and permaculture.

Low impact development

Low Impact Development (LID) is the term commonly used to describe an approach to building and living that seeks to use natural and local resources wherever possible, and minimise reliance on outside providers. As a movement, it has a clearly identifiable heritage that extends back to the counter-culture of the late sixties and early seventies. It has historically attracted people who see consumer capitalism as one of the main causes of the social and environmental problems faced by society and, as a response, place great value on a combination of self-reliance and local cooperation as ways of reducing dependency and

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building resilience in communities. Low impact development can also be seen as part of the back-to-the-land movement, which has manifested itself in different ways across the developed world. Pickerill and Maxey identify LID as 'a radical approach to housing, livelihoods and everyday living' that offers valuable insights into how societies can adjust to more sustainable models in the future (Pickerill & Maxey, 2009). Halfacree countenances against overstating the associations between counterculture and back-to-the-land movements, which, he argues is 'a very diffusive concept, whose borders blur into both more 'traditional' forms of agriculture and more 'bourgeois' forms of counter-urbanisation' (Halfacree, 2007). He also points out that gaining a livelihood from the land is challenging, and so ideological commitment to reruralisation has to be accompanied by hard work and skills. John Seymour was instrumental in both inspiring back-to-the-landers and providing them with practical knowledge (Seymour, 1976), and his legacy continues in west Wales, where he lived for many years. In recent years, the principles of permaculture have gained in popularity, often supplementing the traditional skills of smallholding.

One of the key figures of the Low Impact movement, Simon Fairlie, has campaigned for many years for changes to the planning system to allow those with genuine interests in contributing to the rural economy to live near to where they gain their livelihoods. In fact, he is credited by many for coining the term Low Impact Development when he published his book of the same name in 1996. In this book, he defined a Low Impact Development as 'one that, through its low negative environmental impact, either enhances or does not significantly diminish environmental quality' (Fairlie, 1996). Fairlie is an editor of The Land Magazine and a founding member of Chapter 7, which provides planning advice to those in rural areas struggling with unsympathetic planning regimes. Chapter 7 is named after the synonymous chapter from the Agenda 21 report from the UN Rio Conference of 1992, which argued for more equitable and sustainable methods of land-use and settlement planning and management (United Nations, 1992).

Although LID has often been viewed with suspicion by mainstream society, a number of factors are causing the movement to grow in popularity. LID is becoming relevant to more people due to changes both within the movement and in wider society. The economic turbulence since the crash in 2008, combined with an increasing awareness of the urgency of the environmental crisis, have caused many to question the value that they had previously placed on consumerism and to look for alternative ways of meeting their needs and aspirations. At the same time, many significant players in the LID movement have made efforts to engage local communities and others and to promote the benefits of low impact living. In particular, Tao Paul Wimbush has been instrumental in raising the profile of LID by envisioning the Lammas project, and in particular the Tir y Gafel ecovillage near Glandwr in Pembrokeshire. His

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book, 'The Birth of an Ecovillage' recounts the effort and time it took to counteract a resistant planning culture before it was approved in 2009 (Wimbush, 2012).

The design approach of permaculture

A permaculture approach is often adopted on land-based LIDs, as it provides useful design tools for food production and resource management on a small scale. Permaculture is a term that was invented by Bill Mollison and David Holmgren in the 1970s to describe an approach to sustainable design, land management and food production that aims to work with natural process to maximise the benefits to people without the need for continual inputs (Mollison & Holmgren, 1978; Mollison, 1979). Bill Mollison defined the term in his book, 'Permaculture, a Designers Manual':

> Permaculture (permanent agriculture) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability and resilience of natural ecosystems.
>
> (Mollison, 1988)

From the outset, Mollison and Holmgren chose to maintain permaculture as a structured design methodology. Individual national Associations regulate the teaching of permaculture and ensure that courses follow a prescribed structure. One of the main aims of these courses is to encourage an organic, iterative approach to designing and adapting one's environment. In order to facilitate clear communication of the methodology, twelve key Permaculture Principles are taught on all the courses. Three of the twelve demonstrate the importance placed on an iterative approach to design. They are as follows: 'Observe and interact'; 'Apply self-regulation and accept feedback'; and 'Creatively use and respond to change'. Therefore it is evident that adaptation to changing conditions is at the core of the permaculture approach. The reasoning is that by mimicking the cyclical processes in nature, the permaculture designer intends to benefit from the inherent efficiency of the organic world. Aside from the design courses, there are a wealth of books that give advice to those wishing to follow permaculture principles in different settings. Some focus on food production and land management (e.g. Whitefield, 1993; Law, 2001; Crawford, 2010), whilst others aim to encompass a wider context of sustainable living (e.g. Bell, 1992).

Pickerill and Maxey argue that the flexibility inherent in LID and permaculture 'teaches us not only that we can survive changes in the environment, but that it is a process of constantly evolving and adopting to our changing needs and climatic uncertainty' (Pickerill & Maxey, 2009). There has however been criticism that many of the claims of

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permaculture are not backed up by empirical evidence. Peter Harper, Research Director at CAT challenges the claims of some permaculture advocates of its ability to create abundant productivity, arguing that it has 'entirely oversold the idea, claiming to have found the Holy Grail of a low-input/high-output system' (Harper, 2013). He also questions the relevance of permaculture methods when applied outside of the field of food production: 'for some people 'permaculture' is a generic term for sustainable living, giving another whole set of shifting, fuzzy meanings' (Ibid.). Harper does however recognise the importance of permaculture when viewed as a set of pragmatic rules of thumb, and suggests that since the conception of permaculture, Holmgren has followed a rigorous, evidence based methodology (e.g. Holmgren, 2011), while Mollison has not provided adequate evidence to back up his claims.

Despite some of the criticisms levelled at permaculture, as a methodology it does itself advocate that the practitioner gather evidence and respond appropriately. Any system that is based on low inputs of energy or other resources needs a deep understanding of the processes involved. The principles of observing, reflecting on what one sees and responding appropriately engender the type of long term thinking lacking in much of today's industrialised agricultural system (United Nations Conference on Trade and Development, 2013).

One Planet Development: a planning policy unique to Wales

Since the introduction of formal development control in 1947, the planning system has needed to act as a buffer to uncontrolled and unsustainable development in the countryside. It has had some success in this goal, but has been far less successful in allowing development that would support the economy and resilience of rural areas.

In 2002, the University of the West of England and Land Use Consultants carried out research into LID in Wales, and produced a report 'Low Impact Development - Planning Policy and Practice' (University of the West of England & Land Use Consultants, 2002). The research was funded by the Countryside Council for Wales, the Welsh Assembly Government, and Pembrokeshire Coast National Park Authority. This was followed in 2004 by a report by Baker Associates, which built on this research, but was focused specifically on 'issues raised by the possibility of developing a LID policy' (Baker Associates, 2004). The Baker report identifies the reason for a fundamental tension between the goals of LID and planning orthodoxy:

> At the heart of the difficulty posed by the consideration of LID and planning is this. The planning system has a fundamental role in the promotion of sustainable development and

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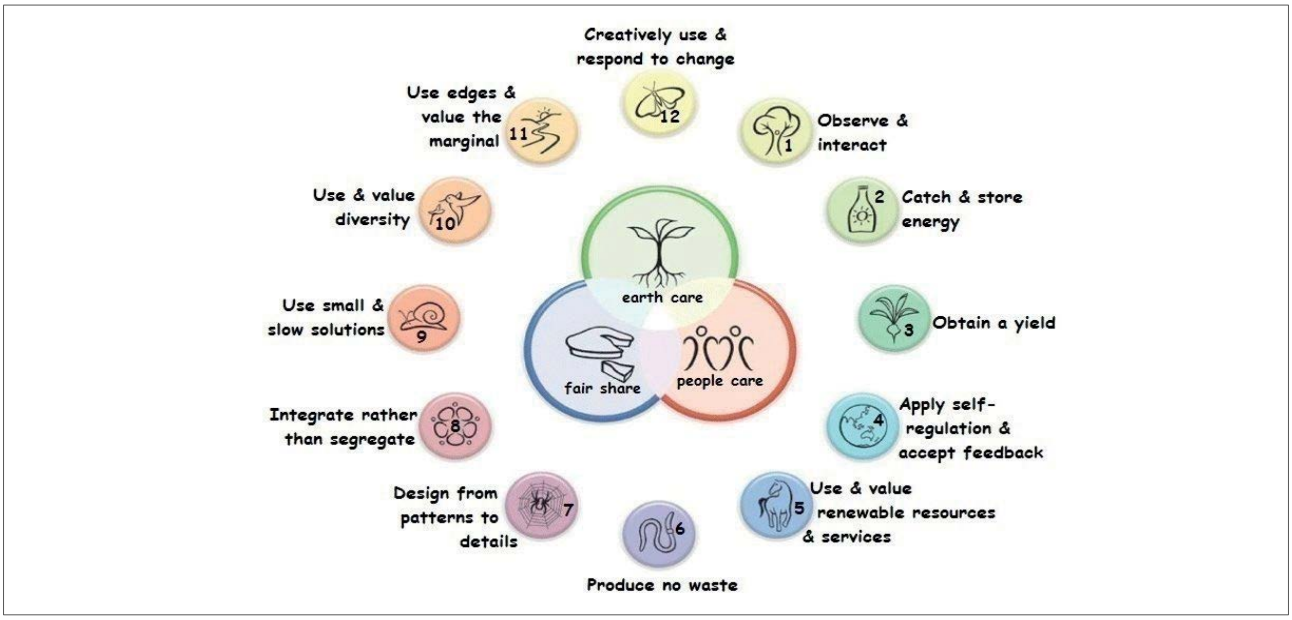

Figure 1.
The twelve permaculture principles
Source: https://nurturegreen.wordpress.com/2013/09/11/permaculture-principles/

Figure 2.
Photos from Nant-y-Cwm farm, a smallholding in Caerphilly — the first One Planet Development to be granted full permanent planning permission in April 2014.
Source: http://www.oneplanetcouncil.org.uk/resources-images/

Figure 3.
Simon Dale and Jasmine Saville's earth-sheltered home at Tir y Gafel, which was the subject of extensive disputes with local authority building control department. Photos: Simon Dale
Source: http://lammas.org.uk/gallery

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> LID is presented as a form of sustainable development, yet LID encompasses elements, notably housing, that are most fiercely resisted in the open countryside by use of the plan ning system, and with a concern for sustainable development cited amongst the justification for doing so. The task set for this project by the client and Brief is to find a practical way to resolve this paradox.
>
> (Baker Associates, 2004)

The report concluded that a policy framework for allowing LIDs in the open countryside could be developed, as long as rigorous tests were met. In response to the recommendations in this report, Pembrokeshire County Council introduced Policy 52, which related specifically to LID, in their Unitary Development Plan (UDP). It was under this policy that Tir y Gafel, also known as Lammas, was approved on appeal in 2009.
Low Impact Development has now been recognised by Welsh planning law in the form of the One Planet Development policy in TAN6 Planning Policy document, which came into force in 2010. TAN 6 states:

> One Planet Developments take forward Low Impact Development (LID) principles in the Welsh context. One Planet Development is development that through its low impact either enhances or does not significantly diminish environ mental quality.
>
> (Welsh Assembly Government, 2010)

The policy owes much to Fairlie's development of the LID model. In fact this definition of a One Planet Development (OPD) is almost identical to Fairlie's of a low impact development.

In planning terms, the OPD policy is highly significant, as it is the first national policy for LID, allowing development, including the building of new homes, in the open countryside. However, the policy sets stringent demands on those wishing to submit planning applications for One Planet Developments. Initially, very few applications were approved under this policy, partly because there was no technical help on how an applicant should go about compiling an application, or how a planning officer should assess one. In 2012, the release of the Practice Guidance addressed this weakness, and the number of applications and approvals has been increasing steadily. In early 2014, the One Planet Council was formed, as an independent voluntary body with the aim of promoting and supporting One Planet Developments, and soon after this the first full planning permission for and OPD was granted to Nant-y-Cwm, a smallholding in Caerphilly.

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Living within one's means: theory and practice

> Around ten years ago we became aware of the significant numbers of people in our country, who were opting to live very simple and sustainable lives. People who were living within their means, both financially and ecologically.
>
> (Dale & Saville, 2011)

The concept of living within one's means can be understood in both individual and collective terms. A wealthy person can live within their financial means but if their lifestyle is based on a high level of consumption and resource use it would be beyond the environment's means to support this way of living if it were replicated across society. Just as individuals need to behave in a way that recognises the constraints of their personal finances, society as a whole needs to work within the constraints imposed by the resource base of the planet in order to sustain itself.

On a day to day level, where a stable income is deemed likely for the foreseeable future, living within one's means is a simple balancing of income against outgoings. However, for those feeling the impact of turbulent economic conditions, the calculation is far more difficult to make as it requires a degree of speculation about the future. Favourable conditions need to be recognised and capitalised on, to improve survival chances during harsher times. Investments in the future may be financially quantifiable or their value may be more difficult to measure, and dependent on a particular set of conditions arising at some point in the future.

One Planet thinking, from which the OPD planning policy draws, is an attempt to apply a global perspective to the principle of living within one's means. It is argued that a typical UK individual is consuming enough resources to require three and a half planet Earths (Thorpe, 2015). Leaving aside the question of the reliability of the data underpinning such an assertion, it is a powerful image that helps one visualise a fact that few would question, that humanity is working its way through the planet's resources at an unsustainable rate. OPD planning applications require the submission of an Ecological Footprint Assessment (EFA). This way of quantifying one's environmental impact uses expenditure to estimate ecological footprint. Although this can only provide approximations based on certain assumptions, it does at least expand the scope beyond the carbon footprinting tools that have previously been the standard metric. Given that climate change is only one of many environmental threats, then despite the practical difficulties in quantifying such a complex measure as ecological footprint, the ef-

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fort to do so must be worthwhile. As Pooran Desai, the co-founder of Bioregional and One Planet Living argues: 'Science tells us we need to reinvent our relationship with the planet - the metrics of ecological footprint and planetary boundaries must be fundamental to our way of life. Now is the time to create new options. We have no option' (Desai, 2015).

For some, low impact lifestyles are more a question of necessity than choice. Those who are unable to access the funds or the credit needed to participate in the housing market, need to provide shelter for themselves as best they can, by making do with the limited resources they have available to them. With making do, necessity is the driver of creativity, instigating new ways of putting the world together. However, the necessity to improvise often places the person making do outside of the conventional parameters of mainstream society and challenges established notions of propriety and acceptable behaviour. When such norms are formalised into planning or building regulations then this inevitably results in conflict.

Conflict with the regulatory framework

Making do involves ad hoc processes that respond to needs as they arise. This organic approach to designing and adapting one's environment is central to the principles of permaculture, as commonly practiced in LIDs, but alien to the culture of the planning system. This is illustrated in Tolle's account of issues experienced at Tir y Gafel, otherwise known as Lammas:

> '…all residents described how they were rethinking their design to feedback from the land, e.g. experiences of frost pockets. But although an evolving process is fundamental to permaculture, every deviation from the planning permission could be revised. Thus, the expected visit of a planning inspector caused much tension.'
>
> (Tolle, 2011)

There is another fundamental cause for conflict between the worldview of the planning system and the requirements of making do. For some decades, the planning orthodoxy has been to rigorously control development in 'the open countryside', which is interpreted as outside a line called a 'settlement boundary' that the planning authority have drawn around everything they deem a settlement. This creates a split land market, with development land having a far greater value than land unlikely to receive planning approval. However, those needing to make do often find it easier to do so away from built-up areas. The low land

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values make the cost of owning or renting the land more affordable, and a degree of clutter that making do entails is often away from public view and tends not to draw complaints from those living in working rural communities. Even in cases where there is an approved dwelling on site, the type of site occupation typical of LID is often incompatible with the premises of the planning system. One example is the notion of a dwelling curtilage which is marked around the 'house', and which is intended for 'amenity' use. This is commonly understood as a garden, with mown lawn, ornamental planting and so on, whilst beyond this would be the 'agricultural land', commonly understood to be fields with crops or livestock. However, few such notions would have much relevance to an LID practitioner, and the idea of clear delineation between these zones goes against such permaculture principles as 'integrate rather than segregate' and 'use edges and value the marginal'.

The other major area of legislation that acts as a barrier to making do is the building regulations. The building regulations play an important role in ensuring buildings create healthy and safe environments, and their role in ensuring the safety of amateur self-builds is critical. However, recent issues that low impact developers have had with the enforcement of building regulations suggest that there is a risk of these regulations jeopardising the viability of low cost self-build. In 2011, Simon Dale and Jasmine Saville of Tir y Gafel wrote about their personal experience:

> It is apparent from our experience, as well as consideration of the wider matters involved, that there is at the very least a tension, if not an incompatibility, between the conventional application of the building regulations and LID.
>
> (Dale & Saville, 2011)

They cited the carrying of water to dwellings in containers, heating water on woodstoves, use of outdoor composting toilets and being off the electricity grid as examples of low impact living that they were practicing that the building inspectors had deemed to be contrary to regulations. However, while such examples might go against the expectations many in an industrialised society would have in terms of comfort and convenience, if the occupants choose to live in this way it is hard to see what justification there can be for them to be proscribed by the regulations. The process of delivery of a low impact self-build should not mean that it is any less safe than a conventionally delivered building, and this necessitates oversight by an building inspector. However, if the regulations that the inspectors are required to enforce place considerable financial burdens on a self-builder, then at some point either they will not be able to carry out the project or they will try to operate outside of the regulatory system. Neither of these eventualities is desirable.

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Conclusion

The difficulties that LID projects such as Lammas have faced in meeting the demands of the regulatory frameworks are derived from the profound difference in world views between LIDers and the writers and administrators of regulations. In her study of Lammas, Katherine Jones identified the types of knowledge required by the planning and building control systems to be based on 'dualism, reductionism and positivism' (Jones, 2015). In this context, the whole system thinking based on permaculture principles as practiced by the residents of Tir y Gafel was not accepted as legitimate by a regulatory system that required knowledge to be 'compartmentalised and reduced to its component parts'.
It is clear that the regulatory system needs to adapt to a more ecological world view, whereby systems, including buildings, are understood to be more than the sum of their parts. However, it is unreasonable to expect, as some residents of Tir y Gafel hoped, that LID will be allowed exemption from regulations that are applied universally to other buildings. The answer instead needs to derive from a continued dialogue between those pioneering new approaches to building and living based on LID principles and those required to regulate them.

Since LID practitioners cannot escape the requirement to meet regulations, they need to be creative in the way they respond to them, whilst still meet their own goals or providing sustainable and affordable homes for themselves. Standardised solutions may seem counterintuitive to adherents to permaculture principles, but they do present significant benefits the LID practitioner, allowing them to minimise cost and disruption when moving on site and allowing them to focus on the crucial task of establishing their land management strategy. These might vary in degree from repeating techniques that have been found to be successful in the past to the use of entire prefabricated structures.

Another way that the challenge of embarking on an LID can be made easier is through direct support of communities that are geographically close. The recent approval of three OPD applications in close proximity to Tir y Gafel is bound to have beneficial effects for both the established plot holders and those whose journey is only just beginning. The fact that two of these planning applications, Gardd y Gafel and Parc y Dwr were approved at local level suggest that exposure to the practical realities of LID projects has engendered in the local community a greater openness to LID as an acceptable, even desirable, model of development and land use. Further information about all approved and current OPD planning applications is available from the OPC website (http://www.oneplanetcouncil.org.uk/applications/).

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Figure 4.
a - Pwll Broga: Megan Williams and Charlie Hague's retrospective planning application for their 'hobbit house' near to Tir y Gafel in north Pembrokeshire was approved on appeal in July 2015; Photos: Amanda Jackson
Source: http://www.oneplanetcouncil.org.uk/approved-applications/ and https://charlieandmegshouse.wordpress.com

The sharing of knowledge is of critical importance in reducing the burden of satisfying the authorities. In the short period since its establishment in 2014, the One Planet Council (OPC) has been instrumental in supporting those wishing to follow the OPD route, as well as providing information to local authorities about the policy. In the summer of 2015, the OPC ran a successful series of training courses both for prospective applicants and for planning officers and professionals. The receptiveness of those charged with administering the regulations to the goals of OPD policy demonstrates the benefits of an active process of dialogue between the parties involved. The responsibility for finding sustainable solutions to the environmental crisis is a shared one, and the only realistic option is a strengthening and deepening of the processes of engagement and communication.

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Projecting the concept of sustainability on the mathematical model of the "fold"

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Abstract

In order to discuss the term Sustainability, we will draw from the field of mathematics, especially differential topology and the model of the Fold which the natural philosopher and mathematician R.Thom introduces during the 70's. R. Thom presents this model as a descriptive model of structural stable or Sustainable productive processes. The terms "differential topology", the area which includes this mathematical model, points out the emergence of a reality in continuous variable state which is considered as the central ontological progress of our time. The model of the "fold" indicates the prevalence of the abstract and complex character of the elementary elements it involves. Thus moving away from a deterministic view and attempting to incorporate unpredictability, randomness and improvisation.

Our aim is to contribute to an understanding of the concept of Sustainability and its impact on the general contemporary cultural context. We will acknowledge the interconnections among different scientific and artistic fields that ultimately converge to the notion of landscape through the contemporary ecological sense that points to energetic, metabolic approaches.

The term sustainability envelops the ability of resilient formations and permanence through the transformations of the underlying structure, finally exhibiting multiple and variable formal results, which seems it can be modeled by the differential topological qualitative approach.

Keywords

Sustainability; topology; imagery; landscape; the fold.

Note

Part of this text is a revised edition of an original paper titled "Methodological approach to the contemporary procedural real-time informed constructions of imagery concerning inter- and cross- border branding " presented in the "Changing Cities: Spatial, Design, Landscape & Socio-economic Dimensions" International Conference in Porto Heli, Peloponnese, Greece, organized by the Department of Planning and Regional Development, University of Thessaly, under the aegis of the Greek Ministry of Environment, Energy & Climate Change on June 2015. Both texts are part of a work-in-progress doctoral dissertation under the supervision of Prof. Konstantinos Moraitis at the School of Architecture of N.T.U. of Athens. The research is being funded by IKY Fellowships of Excellence for Postgraduate studies in Greece – Siemens Program.

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1. Introduction

We will transfer the discussion on Sustainability in the field of mathematics. We will observe that this "rigid" field seems also to be transformed according to the contemporary worldview that – as we will claim – further refers to a landscape model. The term landscape as perceived today concerns a complex cultural construction, and bares meaning attributed to it through epistemological developments concerning an energetic or "ecological" conception of place. Landscape, is considered as a system that is in a continuous state of change due to the exchanges between the subsystems from which is constituted. This view concerns a concept of "resilience" which allows the overall system to maintain through internal and external adjustments. The overall system maintains basic features of its structure while exhibiting alternative formal appearances – the phenotype – through a dynamic time-sensitive systemic conception. The Systemic conception, examines the flexibility to adaptation of complex structures and not simple objects. Those may also include theoretical constructions and design approaches. Systems theory is linked with the development of the mathematical field of Topology and its current use as research and editing tool to different scientific disciplines. Moreover, systems theory underlies the "ecological" aspect of the landscape.

Topology examines relations (functions) or networks of relations between complex objects considered as elementary. Emphasizing on relations is establishing the condition of homeomorphism and further it concerns about the formation of transitional relations as we will see to be expressed though the "Fold" model.

Through the lens of topological mathematics which is providing the methodological approach of this research, the concept of Sustainability is considered projected on an active substrate of distinctive subthemes with which it begins to associate. For this operation we will use the term mapping, drawn from the field of mathematics and particularly functional analysis. In the field of computation another term might also visualize that approach, the terms "projection mapping". More formally, projection mapping is "the display of an image on a non-flat or non-white surface". Thus we will attempt to map these relations arising from the projection of the term Sustainability, therefore we used the determination "mapping" in individual sections of this article.

The term sustainability in the usual sense largely concerns the interactions between man-made and natural environments and indicates a major concern to maintain and preserve resources that will ensure human living comfort and in the worst case scenario the survival of the planet and its ecosystems. However the concept of sustainability seems to have been expanded so that it can determine correlations among different disciplines from mathematics to theoretical formulations and their cultural environment. Finally results in a multiplicity of expressive approaches both in design practices, especially in the landscape design practices and in the rigid areas of "hard" sciences.
In order to provide a definition of the concept of Sustainability we will draw from the theory of complex adaptive systems (Gunderson and Holling, 2002) which seem to correspond to the overall intake of the term throughout different disciplines. According to this theory, Sustainability refers to systems (social, economic, ecological or other) and procedures capable of developing resilient behavior to adapt to an ever - changing environment in which they are embedded while they modify also the internal relationships between their constituent parts. In order for the system to adapt to the changes mentioned above it is considered as evolving. Thus it is considered as if it has a mechanism for self-organization and as it is evolving it can direct the system to new organizations (Forms) which demonstrate some degree of stability. (Holland, 1992; Chan 2001; Gunderson and Pritchard, 2002)

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Figure 1.
Dali, S. (1983) Topological Abduction of Europe – Homage to R. Thom.

Source: [Online]. Availiable from: http://www.wikiart.org [last accessed Dec 6, 2015].

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In the context of this theory, Sustainability is incorporating a number of other terms like evolutionary processes, self organization and else that are traversing vertically diverse disciplines yielding the content of the term interdisciplinarity and more generally the view of cross-border conditions for both the development of thought and the design expressions. R.Thom remarks that "the validity of this type of dynamic description exceeds by far the biological realm, and may be applied to all morphological processes whether animate or inanimate" (Thom, 1969, p.313)

The mathematician F. Zalamea generalizes the definition of Sustainability to include scientific disciplines making the following statement: in order to survive, a discipline is adapting to the internal relations of its constituent parts due to the changes in its cultural environment (Zalamea, 2012). We might suggest that Zalamea's formulation is reminding of the earlier one, by J. Cavailles in the field of the philosophy of mathematics. Cavailles argues that "the definition of the theory include incompleteness and evolution" (Webb, 2004, p10). Sustainability finally points to the fact that cultural expression and production is characterized by a vitalistic power which supports spontaneous and expressive creativity. That is why freedom of thought cannot happen within the context of "closed" but of adaptive systems Cavailles further concludes (Webb, 2004).

Another important outcome of the above mentioned it appears to be the correlation of mathematics and science with philosophy, finally yielding the coupling of phenomenology and rationalism. This "paradoxical" composition is marked with the invention and use of terms such as "historical a priori" by M. Foucault in the "Archaeology of Knowledge", "transcendental empiricism" by G. Deleuze in "Pure Immanence, A Life" and to the strict area of mathematics by the terms "mathematical phenomenology" coined by R Thom in "Structural Stability and Morphogenesis". It is typical that R. Thom introduces himself as natural philosopher, restoring a term which had been idle since the 19th century.

1.1 An Outline of the Mathematical Premises of the "Fold"

The contemporary –so called – scientific paradigm attempts to describe the requirement of scientific validity in the areas of philosophy and "soft" human sciences such as sociology, anthropology, history and else (Olkofsky, 2014). Other scholars refers to as the naturalistic paradigm (Dosse, 1998), thus attributing vitalism to the scientific enterprises. But what is considered as "hard" science finally opens up to a space of intuitive approaches – as it is already been reflected in the discovery or invention of non-Euclidean geometries and later on the term «Emergence» will also refer to the production of mathematical objects. The term "soft" transfers from the pliability of the material to the flexibility of the system, thus connecting the term Sustainability with systems theory. Among the characteristics of this change which "softens" the area of mathematics we will note the following as central to the discussion that concern us.

(1) The introduction of the empirical dimension. The mathematician C. F Gauss, driven by his interest in geodesy and cartography, reaches a conclusion concerning the local character of the validity of mathematical structures. Until then mathematical truths had been considered valid as universal laws, now are shifting to what in another formulation

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can be summarized in the concept of "locally true" as the result of the empirical testing of mathematical "truths" in the real world. However mathematics which are concerning formations corresponding to a transcendental order that is controlling the mathematical objects, since then, are referring to an empirical or phenomenological dimension (Webb, 2004). The empirical dimension refers also to the physicomathematical approaches or the procedure of testing the mathematical objects according to the scientific events concerning natural phenomena or the physical real (Lautman, 2011).

(2) The development of topological mathematics. The abstract nature of the objects or phenomena being studied, which moreover can refer to alternative conceptual contents. This approach is supported by the topological mathematics and especially point-wise topology. Therefore the adoption and exploitation of the topological mathematics in the area of philosophy and especially from the philosophical approach of M. Foucault and G. Deleuze (Webb, 2005), emphasizes the spatial theoretical formulation and the synchronic or diachronic aspect of the respective structuralistic approaches. Additionally they are linked to the design research in the field of the architectural practice, and particularly to the construction of architectural imagery.

(3) The global (universal) dimension attributed to the field of mathematics refers to an ever-expanding outline enveloping the a posteriori production of new mathematical objects. The a posteriori or retrospective classification of mathematical objects considered to develop in an evolutionary process and according to a productive logic which refers to the limits of that subject area. This third observation - as general and simplified it might be as offered in this limited presentation - refers to an "ecological" conception of the field of mathematics with the content that corresponds to it today. This framework as it is configured in mathematical interactions with physics and biology, ultimately characterized by terms of vitality (Webb, 2005).

We are attempting to define the terms "cultural landscape" in the context of the scientific / naturalistic paradigm, attributing to it an ecological dimension and its connection with the concept of the "fold" that summarizes the correlative character between different disciplines. We mention the "ecological" dimensions here as a metaphor for systems theory exhibiting the interrelations and exchanges of theoretical constructions with their cultural environment.

The interdisciplinarity as a condition referring to exchanges between different disciplines and which through the concept of the "fold" could be represented as relational figure / ground formation, meaning the interrelation between environment and design or theoretical object. The relational figure/ground formation refers to forms of temporal material nature which emerge from an active background. We will note here that the temporal nature of the model of the "fold", in the field of epistemology, refers to a "return of history" (Dosse, 1998), that is, the perception of retrospective reflection updated within the conditions of understanding of the present era. Thus, it is intertwined with the technological possibilities that extending the limits of human cognition. The perception of physical space in energy flow terms – that is the ecological dimension with the metabolic contemporary notion – intangible and physical networks, all focuses on the transitional dynamic relations as active interfaces. With the contribution of new technologies, are finally blurring the perception of virtual and real (Shelden and Witt, 2011).

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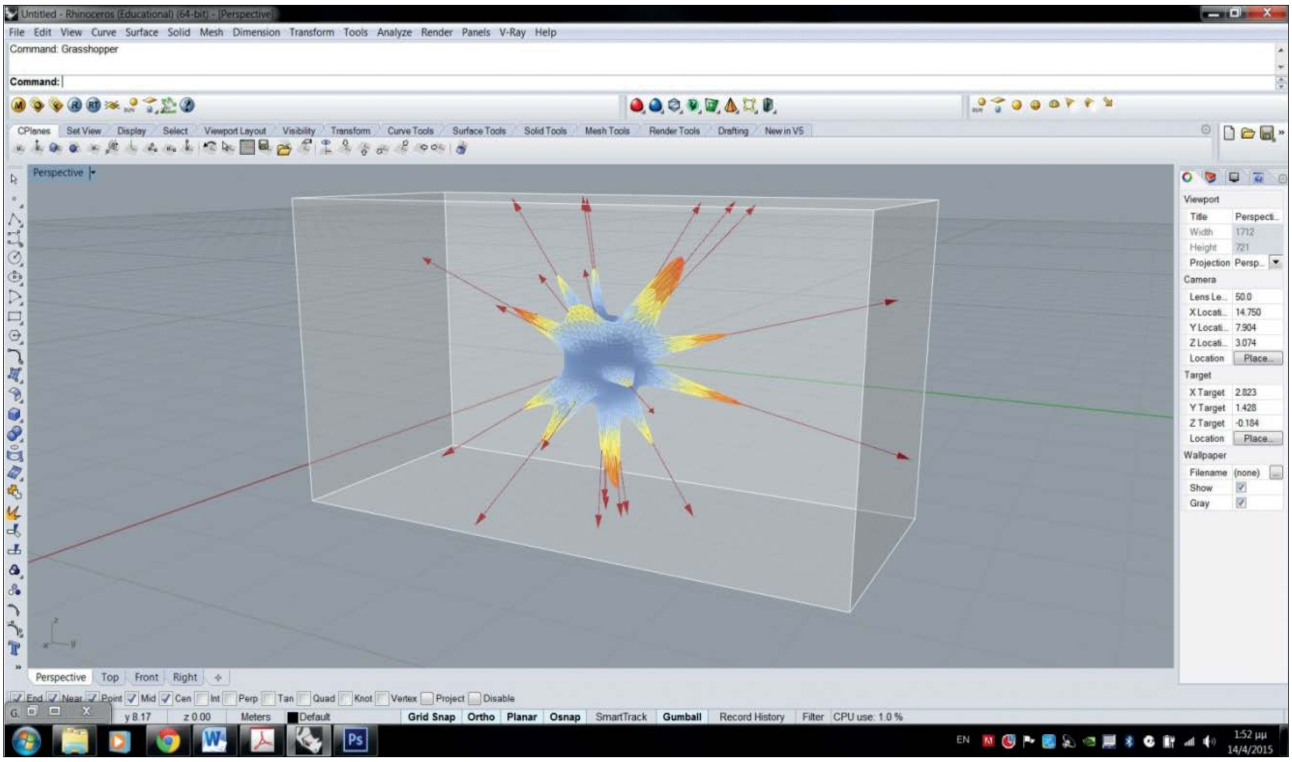

Figure 2.
Morphing: Mesh Volume Deform
Source: formDEcode, 2014

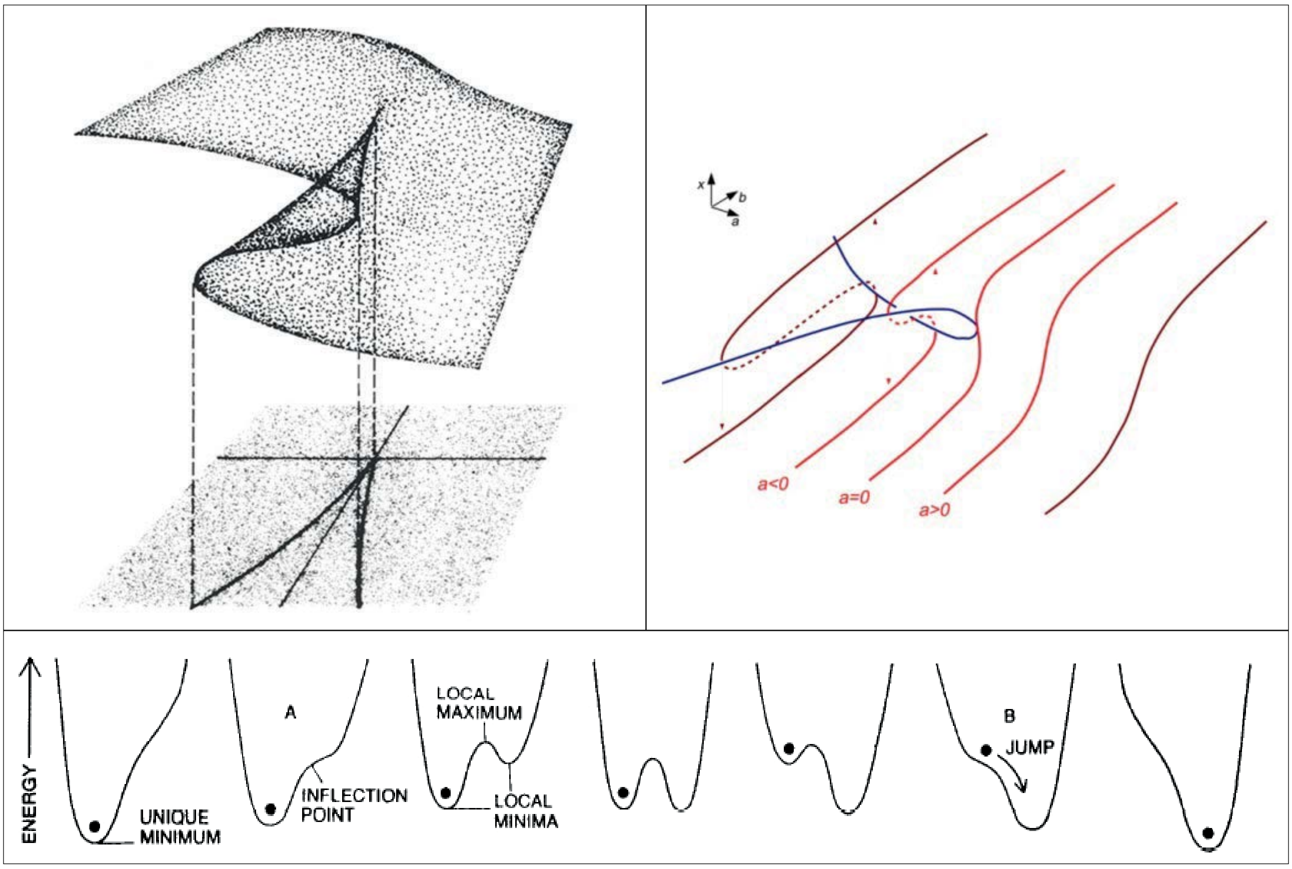

Figure 3.
Fold or Cusp Catastrophe model

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The energetic perception of the natural space within the mentally conceived model of landscape, the relational figure / ground formations yields boundaries as active interfaces affecting and providing gradient relations as opposed to a previously valid Euclidean approach. Through the "biological" paradigm leads us to the perception of a real genesis, a real production and constitutes a methodological contribution which will attribute the boundary conditions in terms of continuity in a topological sense. And that topological sense constitute a geometric order.

In order to provide an example – a schematic representation of these relational formations and the local aspect within the universal outline within which the former is confined, we will refer to the area of visualized programming and specifically in the area of algorithmic design and to a procedure that is called "Morphing" [Figure 1]. Morphing is a term initially referring to the smooth transition of forms elaborated from the field of animation. "Morphing" (Khabazi, 2012) as a tool available in the software of associative design, can be contribute to the understanding of the universal as an outline -- a border which refer to the transcendental or universal plane – which is elastic and which encloses spontaneous formation activity or formation processes, within its disciplinary boundaries. The local condition refers to events which are considered uncontrollable and unpredictable and that are able of producing new objects, after traversing an energy threshold. This might conclude to the transition to a new organization of the whole system, thus summarizing the energetic conception of landscape.

We cannot further develop these comments in the context of this limited presentation, but we will move directly to the concept of the "fold" as it is perceived within the area of mathematics that is called differential topology.

2. Mapping the virtual: Catastrophe theory

Catastrophe theory – we will not outstretch its technical description here – and the differential topology approach in general, is an intuitive mathematical approach. By including ruptures in a perception of continuity is contrasting to topology which persists to the "integrity" of a "plastic or rubber" surface. Moreover, the differential topological approach refers to time-sensitive procedures, therefore they can include transformations and transitions or even disasters in a time span – yielding to these geometrical or spatial articulation – summarized by the term "fold". In this paper we will focus on some features of the theory considered as interesting for the subject under consideration:

(1) Catastrophe theory provides interpretative descriptive models, that is, describing observed phenomena , and not proof or solution-finding models. As R. Thom notes it is no longer possible, due to the indeterminacy of the phenomena to provide a global theory so to envelope the universe (Thom, 1989). Thus, R. Thom is renouncing "dogmatic" scientific approaches, privileging the creative expressing production of interpretative models, he considers as a form of art. This has been a main target of the criticism against the theory.

(2) Secondly it refers to events which are incidents that are unknown in nature, occur-

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ring in unknown time. We might say that this way catastrophe theory includes parts of empirical reality as such, that are considered irreducible to mathematical control. As R.Thom formulates "they form kinds of islands of determinism, separated by zones of instability or indeterminacy". (Thom, 1969, p.321). These "islands" concerning also a straight reference to the intuition of real physical space as indicated by the use of terms such as "hills", "valleys", (attractor's) "basins", we will risk to mention them as a "picturesque" reference. The "Fold" being a surface sensitive to external perturbations as it is embedded in a multidimensional environment, for which Catastrophe theory presents algebraic-geometrical description. [Figure 2] The fusion of the "picturesque" and the mathematical description provided it yields the coupling of mental and phenomenal. "The latter attributes with content R.Thom's terms "mathematical phenomenology". We would say that this last phrase best describes the condition of the "Fold". To take a step further we will suggest that is also providing a certain relation among science and philosophy. The same mathematical terms are used and guide the philosophy of Deleuze as indicated by his scholar Manuel Delanda in the book "Intensive Science and Virtual Philosophy" (Delanda, 2002).

(3) Thirdly if the nature and the time of action of perturbations or events to a system it is unknown then equally unpredictable are the effects upon the system, so final results reported here are referring to the term bifurcation. Catastrophe model is a surface upon which the behavior of a singularity is unfolding. In another formulation, singularity is considered as a local unpredictable event and equally unpredictable is the nature of the final results as assigned to the corresponding mathematical model, that is what the term bifurcation introduces. (Thom, 1990).

Another observation concerns the fact that the elementary catastrophe models refer to a limited number of parameters and it is worth mentioning that from the third model on, no visualization possibility is provided. But with the introduction of a larger number of parameters, catastrophe theory purports to describe the whole reality. A "vivid" reality in constant transformation, in which man is understood as an active agent. If this is considered as a cognitive activity, it "curves" the surfaces of knowledge producing mental landscapes, as meaningful places. Places of "orgiastic meaning" that encloses all the knowledge past and current - this is the point that "fold" refers to history - referring to their retrospective reflection and their adaptation to the present context of understanding.

Clearly, mathematics which are providing models (Thom, 1969), constitutes a reductive delimitation of reality but which ever widens its outline for example in the topological abstract approaches to include and classify a posteriori the creative production of new mathematical objects (Buhlmann, 2014).

3. Landscape projections: the image of thought

In Catastrophe Theory the perception of relational figure / ground formations is mathematically associated with the change of the kinetic energy of a body as the terrain is also altered. (Thom, 1990). Respectively landscape can be considered as a

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projection space where our conceptions emerge as a reational figure / ground formation. This is also suggested through the post-structuralistic theoretical approaches. Also by the mathematical notion of product spaces (Shelden and Witt, 2011).

The perception of the "fold" also summarizes the historical approaches and projecting them in place or the perception of landscape. So in conclusion we can say that landscape-meaning and historical «substratum» coincide in the interpretation and the display of both in the real place or site. Relations that emerging from a retrospective reflective approach. Further it is associated with developments concerning the sustainability of the mathematical objects, and the expansion of their specific field so to include new objects considered to be as the result of an autonomous productive process.

This intermediate interstice reflection, the image of thought is introducing the concept of "soft" or weightless and the perception of matter as a matter of expression. As this mental structure is then folded and displayed/projected or mapped as we have seen in the real physical space, it refers to what R. Thom calls "mental landscapes" (Thom, 1990). "Mental landscapes" constitute a model where the real and the mental are folded one onto the other.

The reference to landscape as a model or the fundamental metaphor -or projection -- represents a simplistic abstract approach that enables the understanding of complex phenomena considered as elementary for this abstract mathematical approach (Kosona, 2012). When referring to the landscape, the degrees of freedom are increasing, complexity and diversity becoming key words. The abstract mathematical representations or models are performing a variety of connections with different fields of knowledge. So the term metaphor in the context of an ethos that is shaped within the boundaries of the scientific paradigm – marking the removal of the linguistic model --should be attributed to corresponding mathematical terms such as projection or mapping of a real phenomenon on a model. And if the term model, seems to be teleological or deterministic it may be argued that it is not static but evolving. Due to this observation we may eventually lift the teleology inherent in the mathematical approaches, because they are constantly broadens their disciplinary boundaries in order to include new mathematical objects emerging - through a creative intuitive production (Buhlmann, 2014). That ultimately allows this rigorous discipline to share the terms sustainability, self-organization processes, evolutionary development and else, with the ecological approach - dominant in the naturalistic example - in which it seems to fit.
Finally our approach attempts to explain how the concept of 'identity' of a place is constructed in the context of the contemporary scientific paradigm and that the terms active interface are inherent in the concept of sustainability and generally the creative, productive expressive approach.

4. Transitional atmospheric mappings and the architectural imagery

We will provide an example from the field of landscape architectural practice, in order to exemplify how the notions we have previously presented are incorporating in the design practices. The selection being made for this approach, which is an expressive one,

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seems to share certain characteristics with Catastrophe Theory. Also because of the interdisciplinarity involved and because it demonstrates the fusion of phenomenal that is the picturesque (textures) and engineering controlled design aspects concluding to environmental sensitivity of producing energy among other features.

We are referring to the example of the LCLA's project "Energy Park Weatherfield" in Abu Dhabi and we will argue that the architecture of "atmospherics" of the LCLA office (Callejas, 2012) presents an analogy with catastrophe theory and moreover we will observe that we are no longer obliged to the depiction of folded surfaces as our understanding evolves while we move forward into the "naturalistic" paradigm.

We will very briefly mention what we find interesting in the design of the energy park: the capture of fleeting / intangible wind and its utilization for energy production through the patented invention of parakites. The above highlighting the cooperation between experts of many fields of expertise, the management both of the intangible and the material environment and ultimately the opening in the area of architectural design of a new research field that refers also to the renewal of imagery construction methods [Figure 3].

As we have already mentioned the relational figure / ground approach in the perception of the "fold" is no longer bounded to the visual representation of the folded surface. That is, it does not refer to direct transcription of the corresponding mathematical model. Rather, trying to find new ways of representation in the practice of landscape architecture. The digital assisted design facilitates the possible blending or folding of the layers referring to multiple alternative readings of the site. But the construction of architectural imagery, has as main characteristic the gradient or scalar field relations - relations that we can understand through painting and mostly through the term "texture". The application of colors and the volatility of their perception, the transformation that occurs in their vicinity are a good example of diffusion in order to describe the movement from the clear demarcations in relational transitions marked by their provisional character. If the correlations with art are so clear and the digital tools offers the ability to "spread" their understanding in a much wider community –this may also refer to the visualization of complex conceptual constructions.

5. Mapping the real

If the folds of thought concerning a real-time mapping, someone could further claim that describes our wandering in a foggy landscape. In the area of computational approaches, the representation of mapping cognitive processes, ultimately yielding with creative emphasis as "landscape geometries", in the example of the landscape analogy of generic problem – solving algorithms. This being suggested by the famous software designer and architect D. Rutten (Rutten, 2014). [Figure 4]
Such an approach of the expressive possibility already inherently registered as a potential, ultimately transforms every material into material of expression, provides determination of soft or "weightless" perception of materiality, that is, the possibility of opening a space in which we can think or a space of thought (Deleuze, 1990). In other words, to Problematize, that is formulating a problem and its conditions That space is multidimensional, plastic and adaptive. Emphasizing the terms interstitial, transitional and through

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Figure 4.
Project: Abu-Dhabi-Weatherfield.
Source: Callejas, L. with Lateral Office (2008).

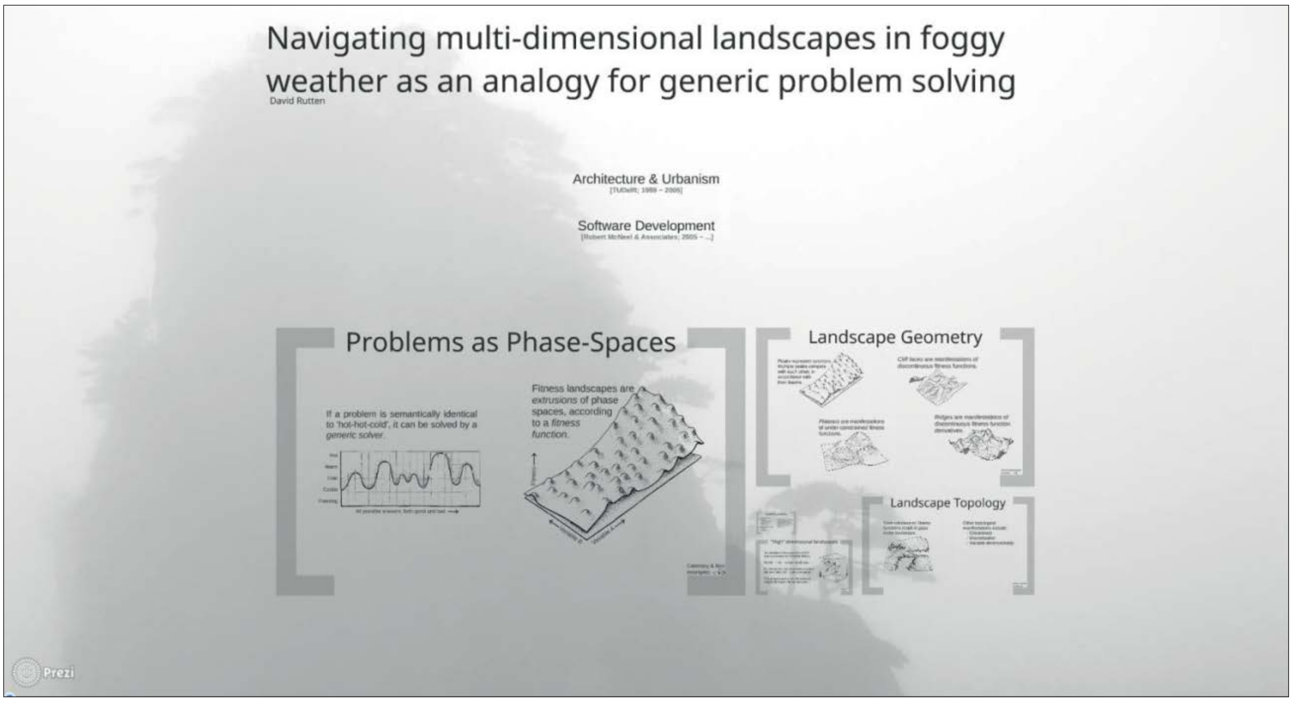

Figure 5.
Landscape geometries

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the notion of the "fold" we can extend this transitional conditions to interdisciplinary exchanges, and provide the construction of diverse and expressive identity of sites. Providing alternative enfolding of the term Sustainability. And we might further suggest an alternative term which we consider as interwoven with our previous observations, to the notion of landscape as ecologically evolving process, that is the term seeding. The latter enfolds all the possibilities of creative cultivated expressions.

Another important final observation is that landscape as cultural identification of place (Moraitis, 2005) exemplifies both theoretical and mathematical processing. Attempting to approach an ecologically coherent perception, transverses all the different areas of human knowledge, reflecting the content of the term interdisciplinarity. This term refers to methodological approaches that allow the import and geometric translation of data from many different areas, as we have already mentioned. It is also intersecting with architectural design and meets the contemporary construction of site imagery.

All previous concludes to the promotion of open negotiating boundary conditions, whether relating to real places - that refer to local vicinity conditions - or due to a quasi-- deterministic mathematical (Zalamea, 2012) treatment that can be applied to places geographically remote. Thus trying to imply consistency condition as the deepest content of the concept of topos, emphasizing on its specific features or singularities and intensities in terms of a topological approach. They ultimately produce approximated representations of reality which does not cease to be expressive approaches of the imaginary.

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A simulation of impact of micro-climate change and neighbourhood morphology on building energy demand

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Abstract

The aim of this study is to explore the impact of microclimate change, especially air temperature change, on the energy demand of buildings compared with other neighbourhood morphology parameters through simulation with tools-HTB2 and Virvil Plugin. The simulation is conducted with five models: a Standard Model, and four other models which consider one parameter for each model as follows: 1) building density; 2) building compactness; 3) building vertical layout; 4) air temperature change. The case is selected from a 250 m x 200 m site in Chengdu, which is a typical neighbourhood scale project in a city complex. The simulation result indicates a quantitative correlation between microclimate change and the energy performance of buildings at a neighbourhood scale. The study provides several perspectives for developers to reduce the energy demand at an early planning stage.

Keywords

Building energy demand, microclimate, urban morphology, urban neighbourhood scale projects.

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Introduction

Building energy consumption has been widely investigated, research has focused on energy efficiency and building materials (Liu et al., 2015), producing more efficient building services and thermal insulated building envelopes in practice (Li et al., 2014). However, energy consumption of buildings is closely related to the microclimate which is a local atmospheric zone in micrometeorological scale range that differs from the surrounding area. Microclimates exist almost everywhere we live. Water bodies such as pools, rivers and big fountains cool the local air temperature in a process called evaporative cooling. In most big cities concrete and asphalt are widely used and these built surface materials absorb short-wave solar radiation heating up the local atmosphere. In return, they emit long-wave radiation, heating up the surfaces that are not sunlit (Allegrini, Dorer and Carmeliet, 2012). This process leads to the well-known effect of the urban heat island effect.

The microclimate is an interaction of various physical parameters that include the airflow velocity, air temperature, relative humidity, solar radiation intensity, pollutant concentration, noise pollution and so on (Li et al., 2012). The parameters affect the microclimate in different ways while they interact with one another at the same time. Solar radiation heats up materials and other objects such as building façades and air when it hits them. The air is heated by solar radiation in two ways: in a direct way by solar radiation, and an indirect way by the transfer of heat from 'hot' surfaces absorbing solar radiation. The heating up of air causes temperature variations that lead to changes in air pressure and accelerate the movement of air, increasing wind velocity. The wind, in return, cools the ground and building surfaces, thereby rebalancing the local air temperature. The wind also brings air with different humidity, which alters the relative humidity in the local air. Therefore, the evaporative cooling process is effected by the wind effect which influences relative humidity. More specifically, the difference in wet bulb and dry bulb temperatures of the air decides the potential for evaporative cooling. Humid air with high relative humidity has limited capability to evaporate moisture, and the effectiveness of the cooling process will be decreased in comparison with a drier air with low relative humidity. So, the microclimate not only describes the average atmospheric condition but also indicates the recurring phenomena process.

The urban microclimate characterized as the urban heat island effect (UHIE), temperature and humidity effect (THE) and cumulative effect (CE) has significant influences on building energy consumption, especially on cooling loads (Li et al., 2014). UHIE increases the air-conditioning load by which more waste heat is produced and emitted into the urban area, and in turn, the extra heat accumulates, contributing to the UHIE. To some extent, at an urban scale as a more widely implemented proposal, mitigating the UHIE is an effective way to minimize the impact of extra energy consumption due to air temperature variation, while at the same time reducing the waste heat emitted, which contributes mitigating effects to UHIE (Li et al., 2014).

Ambient Temperature and Building Energy Consumption

As a topical point of public interest, the general effect of UHIE on increasing the summer cooling load and reducing the winter heating load is widely studied. In the Athens area, the summer cooling load of urban buildings in the city centre is recorded as double the amount of that in suburban areas due to the UHIE, while the winter heating load is reduced by up to 30-55% (Fung et al., 2006). When considering all characteristics of the microclimate (CE, UHIE, THE), which all affect the cooling load of urban buildings, a 1°C decrease in the average daily temperature of the urban district in

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the summer results in a 12.8% decrease in building energy consumption (Li et al., 2014).

Among all the parameters of microclimate, the outdoor ambient temperature is a primary factor governing urban energy consumption, some studies show it accounts for about 73% of the total variance among the parameters of microclimates (Fung et al., 2006). This is due to the internal temperature, which determines the heating and cooling energy demands, being driven by the external air temperature (Cox et al., 2015). A 1°C increase in monthly ambient temperature was observed with an annual electricity consumption increase of 9.2% in the domestic sector, 3% in the commercial sector and 2.4% in the industrial sector (Fung et al., 2006).

Other parameters show weaker correlations with building energy demand. In the study of Cox et al. (2015), a 10% change is applied in proposed parameters: solar radiation, air humidity, and wind velocity: the results show less than 6% corresponding change in the cooling load of the sampled building, and even less than 5% for relative humidity and wind velocity. Yan (1998) found that compared to the average temperature, the vapor pressure of air is further less correlated with residential electricity consumption. The United States Environmental Protect Agency (1992) reported 0.5% to 3% increases in peak cooling electricity loads in US cities due to 0.6°C increases in ambient temperature.

Urban Morphology and Building Energy Demand

Urban morphology impacts building energy demand in two ways: the choice of building geometry (building density, plot layout, building height), and potential effects to the UHIE (Lee and Lee, 2014) (Strømann-Andersen and Sattrup, 2011). The building shape significantly determines the daylight availability in terms of horizontal and vertical randomness (Cheng et al., 2006). The unit building density, as a better measure of building morphology (Galster et al., 2001; Lowry and Lowry, 2014), shows the highest correlations with building energy consumption in a site (Hachem, Athienitis and Fazio, 2012). Optimizing urban morphology is another strategy to mitigate UHIE, which provides more scope for reducing building energy demand. Building density and plot layout are initial factors of urban canyon geometry and orientation, which significantly impact the UHIE intensity (Oke and Cleugh, 1987). Urban morphology alters the thermal properties of urban surfaces, thereby affecting UHIE intensity (Lee and Lee, 2014).

Current Situation in China and Introduction of Study Site

In China, a series of actions on energy saving have been taken in the architecture industry. Considered as the pioneer of China's energy labelling programme, the first Management Method of Energy Efficiency Label in China was issued by the National Development and Reform Commission (NDRC) and the State Quality Supervision-Inspection-Quarantine Administration (SQSIQA) in 2005 (Zhang, 2011). This method promoted technical reform of energy-conserving and energy efficiency in building services, including domestic electric refrigerator and air-conditioning devices. Shortly after in 2006, China announced its first Evaluation Standards for Green Building (GB/T 50378-2006). The national policy of "The Twelfth Five-Year Plan" (Xinhua News Agency, 2011) was adopted in October

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2010 with the objective of reducing energy consumption and CO2 emissions per unit of GDP by16% and 17% respectively by 2015.

The study case is in the city of Chengdu which is the capital city of the Sichuan Provence and a major city in western China. It is located at 30°39'31"N, 104°03'53"E, with 2,174.6 km2 city areas hosting 7,415,590 citizens. The city is in a humid subtropical climate zone with four distinct seasons, with hot summers and cold winters. The 24-hour daily mean temperature is 5.6°C in January and around 25°C in July and August, with an annual mean temperature of 16.14°C. The highest average monthly precipitation totals are 225 mm in July, and the lowest rainfall value of 5.2 mm occurred in December. There have been some studies on microclimate in Chengdu, especially on UHIE. The phenomenon of UHIE in Chengdu was first documented by Yang (1988). He revealed the equation to calculate the UHIE intensity in Chengdu, taking into account cloudiness, wind speed, temperature and humidity. In recent years, studies using GIS statistical analysis methods (Xia, Dan and Chen, 2007; Zhang et al., 2007; Dan et al., 2009; Liu, Yang and Chen, 2009), investigate the cause of UHIE and mitigation strategies for UHIE considering the effects of vegetation and transportation in Chengdu.

Methodology

In this paper, the bottom-up approach is used to simulate energy performance at a neighbourhood scale. First, local statistical information on the weather, building occupancy, materials and plot layouts of buildings, as well as other microenvironments, are considered in the prototype creation stage. Then four experimental models considering a different parameter each are compared using the prototype as a basis. The parameters are: building density, compactness, vertical layout, and local air temperature change. All the simulation results are then analyzed to compare the impacts on building energy performance due to different design and microclimate parameters, thereby obtaining simple design principles to decrease building energy demand at neighbourhood design scale in Chengdu.

The simulation at neighbourhood scale is implemented by Google SketchUp 15 Pro, HTB2 v2.10 (WSA, 2008), and Virvil Plugins (WSA, 2010). As one of the most reliable simulation core engines in the prediction of energy use and internal temperature, the HTB2 is highly recognized (Alexander, 2003). The Virvil Plugins are used as a connection of HTB2 with SketchUp to extend the scope of implementation into the urban scale.

The original model (shown in Figure 1) is created in a 220 m x 200 m site in Chengdu, China, where the neighbourhood scale projects in the form of a city complex are constructed (Le, 2010). The simulated buildings are simplified into 12 building boxes with two common building types –commercial and residential – in the neighbourhood scale project. In the standard model, the 12 buildings are created with 50 m in length, 40 m in width and 30 m height, and the floor area is 20,000 m2. No.1~No.6 buildings are defined to be commercial, No.7~No.12 buildings are residential ones, among which No.5 and No.8 buildings are located in the centre of this neighbourhood scale project surrounded by the other buildings. The basic construction settings, such as glazing ratio, indoor condition and building materials are used at default value in all four models,

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while all the settings satisfy the requirement of local planning regulations. The building density, building plot layout and air temperature change are adjusted in the four models. The Model-Density (shown in Figure 2) doubles the density of the standard model in terms of raising the height of buildings to 60 m. The more compact building settlement in the Model-Compactness is created (shown in Figure 3), wall-to-volume ratio in central buildings (No.5 and No.8) is 0.09, while the ratio in Building No.4, No.6, No.7 and No.9 is 0.13, the rest of the buildings (No.1, No.2, No.3, No.10, No.11 and No.12) are designed with a wall-to-volume ratio of 1.4. The randomness of the buildings in the vertical layout model (shown in Figure 4) is modified with two main 120 m high towers with 70,000 m2 in floor area and 15 m in height low surrounding buildings with a 10,000 floor area, while other parameters such as density and microclimate conditions remain with original values. In the air temperature model (shown in Figure 5), the physical structure of the simulated building is the same as that in the standard model, the only modification is on the weather file. A rise of 1°C is added on each value of meteorology data at each single collection time. Therefore, a new weather file is generated to simulate the variation of microclimate in terms of air ambient temperature.

Simulation result and analysis

The simulation results of the standard model have been compared with the other four models considering the parameters: building density, building compactness, vertical layout and air temperature change. Each parameter is analyzed in the following sections.

Building Density

In this simulation case, the building density is identified by floor area ratio, which directly affects the solar gain and energy demand of buildings (Robinson, 2006; Zhang et al., 2012). In local regulations, this parameter is strictly controlled by the city administration of urban planning, while the developers are keen to build projects with as high a density as possible to earn more economic interest. In the Model-Density, the floor area ratio is double that in the standard model, and simulates the high density building proposal in neighbourhood scale projects.

The results indicate that in both commercial and residential building types, the overall annual energy demands are higher in the higher density model (see Figure 6). For residential buildings, the cooling demand of buildings in the higher density model is 33.18 kWh/m^2/year, which is higher than that in the standard model, whereas the heating load is reduced by 9.95%. For commercial buildings, the cooling demand of buildings in the higher density model is 32.67 kWh/m^2/year with an 8.04% increase in comparison with the standard model's 30.24 kWh/m^2/year. The heating demand in commercial buildings with double density is reduced by 12.65% in comparison to that of the standard model. Due to the different indoor configuration (mechanical building services, services schedule, and building insulation conditions) the commercial buildings consume less energy in both heating and cooling compared to residential buildings in any single case. To sum up, in the Model-Density, denser buildings with greater building height increase the over-shading, where the shading effect significantly impacts the heating and cooling

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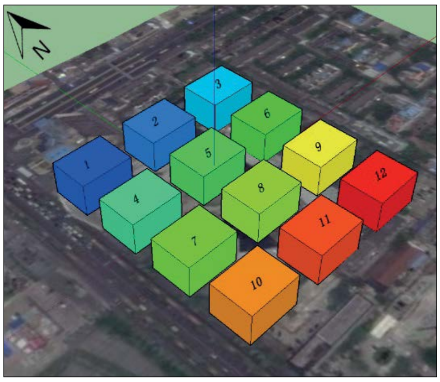

Figure 1. The standard model

Figure 2. Doubled density model

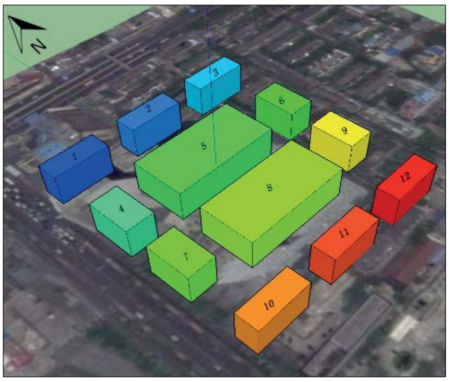

Figure 3. Compact building model

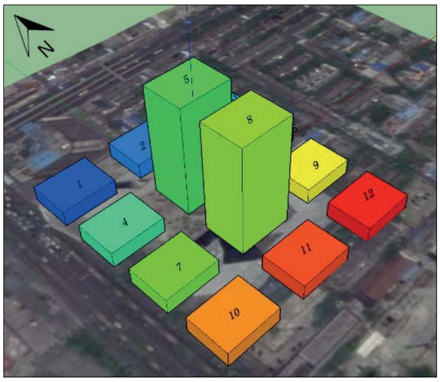

Figure 4. Vertical layout model

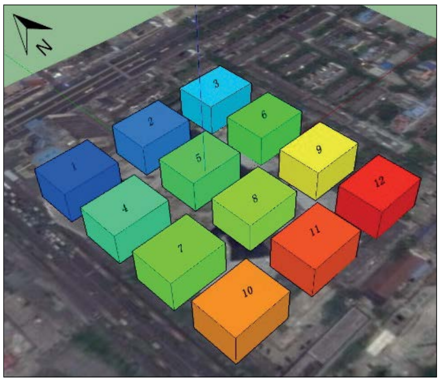

Figure 5. Changed air temperature model

Table 1.

Simulation result of heating demand (upper) and cooling demand (below) for each single building considering the difference between each experimental model and the standard model.

(kWh/m2/year)

Heating Demand	Commercial						Residential					
Building ID	1	2	3	4	5	6	7	8	9	10	11	12
Mode-Standard	9.06	9.45	9.13	9.56	**10.06**	9.65	19.29	**20.01**	19.43	18.03	18.56	18.10
Model-Density	-1.36	-1.18	-1.31	-1.18	**-0.99**	-1.15	-1.72	**-1.42**	-1.66	-2.22	-2.07	-2.22
Model-Compactness	+2.48	+2.71	+2.58	+2.42	**-2.64**	+2.50	+4.21	**-4.92**	+4.42	+5.33	+5.46	+5.27
Model-Vertical Layout	+3.55	+4.20	+3.76	+3.52	**-3.60**	+3.68	+4.83	**-6.01**	+4.80	+5.19	+5.18	+5.19
Model-Air Temp.	-2.39	-2.43	-2.38	-2.43	**-2.50**	-2.44	-4.00	**-4.05**	-4.00	-3.93	-3.97	-3.94

(kWh/m2/year)

Cooling Demand	Commercial						Residential					
Building ID	1	2	3	4	5	6	7	8	9	10	11	12
Mode-Standard	31.68	30.34	31.51	29.94	**28.30**	29.68	30.89	**29.07**	30.60	32.95	31.38	32.65
Model-Density	+3.11	+2.41	+2.94	+2.31	**+1.58**	+2.23	+1.74	**+0.95**	+1.64	+2.66	+1.98	+2.56
Model-Compactness	+3.97	+3.60	+3.94	+3.59	**-0.51**	+3.39	+3.96	**-0.38**	+3.70	+4.27	+3.87	+4.29
Model-Vertical Layout	-7.52	-7.60	-7.49	-7.39	**+10.21**	-7.45	-6.56	**+10.29**	-6.64	-6.56	-6.10	-6.38
Model-Air Temp.	+4.77	+4.65	+4.68	+4.61	**+4.54**	+4.60	+5.72	**+5.61**	+5.69	+5.83	+5.74	+5.81

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demands. A previous study (Liu et al., 2015) shows similar results in an Energy-Plus simulation under a similar circumstance, as the building density is increased from 0.04 to 0.44, the corresponding cooling energy consumption is increased by 32%, and heating energy consumption is decreased by 24%.

Building Compactness

Generally, the building form can be defined in five dimensions: compactness, centrality, complexity, porosity and density (Huang, Lu and Sellers, 2007). In this study, the compactness is chosen to represent the patterns in the horizontal direction. The simulation results show that the compact buildings demand more energy for cooling compared to the model with standard buildings (see Figure 7). It is observed there is a 3.01% increase in residential buildings to 32.2 kWh/m^2/year and an increase by 2.71% to 31.06 kWh/m^2/year for commercial buildings, while there are only minor differences in heating demand between the two models, which is less than 0.5 kWh/m^2/year for all types of buildings.

On the other hand, for individual buildings, the central buildings (No.5 and No.8) are modelled with a lower wall-to-volume ratio (0.06) in Model-Compactness than that of all buildings in the other four models (0.09). They have a lower cooling demand (0.51 kWh/m^2/year less than that in No.5 Building in the standard model and 0.38 kWh/m^2/year less than that in No.8 Building in the standard model). Figure 8 indicates a significant linear correlation with a 0.47 R2 value between the cooling demands in each building in Model-Compactness with its wall-to-volume, where reduction of wall-to-volume ratio is shown to reduce the cooling demand at neighbourhood scale.

Building Vertical Layout

The vertical layout of buildings refers to the geometrical characteristics of the buildings in the vertical direction. In this research, 120 m high towers with surrounding low buildings with a height of 15 m are created to simulate patterns of buildings in extreme conditions with a more random vertical layout and rising height. The simulation results show that the more random vertical layout of buildings, together with rising height, increases the cooling demand in summer times and reduces the heating load in winter times (see Figure 9). The difference between the two models in heating demand is within 0.8 kWh/m^2/year, but that in cooling demand are more significant, being 2.07 kWh/m^2/year for residential buildings and 1.73 kWh/m^2/year for commercial buildings, respectively. The greater absolute value in the increase of cooling demand than that in the reduction of heating demand increases the total annual energy demand. This is mainly due to excessive solar gains in summer times due to huge exposed building surfaces.

For each individual building due to higher randomness and greater height of the central buildings, the surrounding low buildings are observed to have different changes in heating and cooling demand for both two buildings types (see Table 1). During winter, the significant shading effect of Building No.5 on the surrounding low buildings and reduced building surface area decrease the accessibility of solar radiation to the surrounding buildings, therefore, more energy is needed due to the lower solar gains. The results from Table

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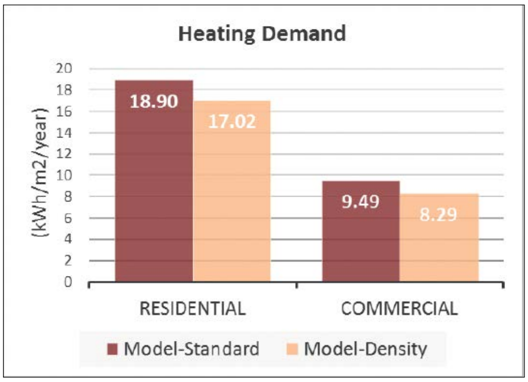


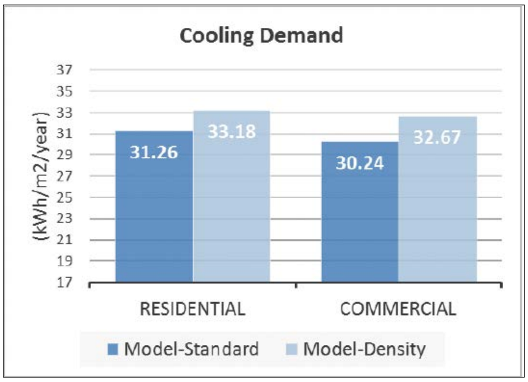
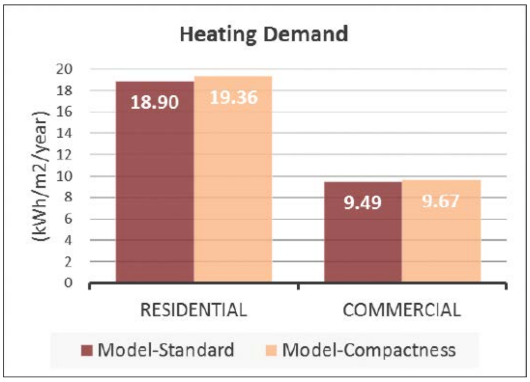


Figure 6. Comparison of energy demands between the standard model and the experimental model with different building density.



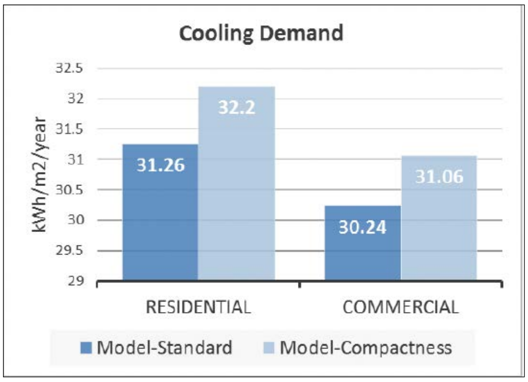


Figure 7. Comparison of energy demands between the standard model and the experimental model with different building compactness.

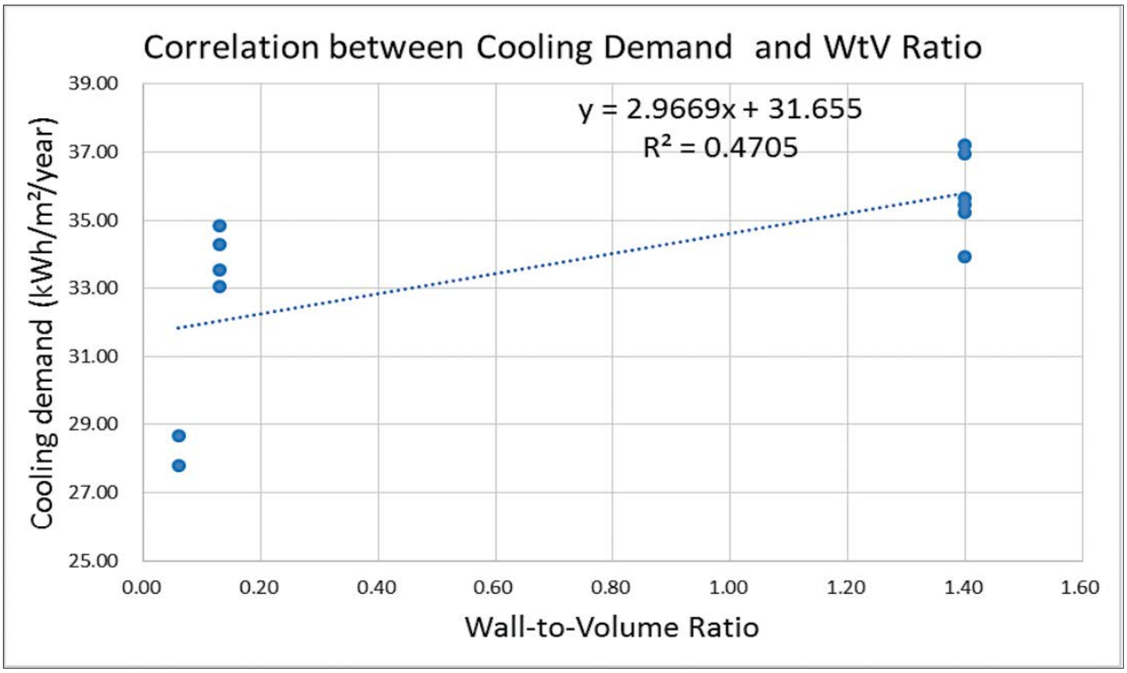


Figure 8. Comparison of energy demands between the standard model and the experimental model with different building compactness.

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1 indicate that compared to those buildings in the standard model, the heating demand in Building No.1, No.2, No.3, No.4 and No. 6 are shown with unusual increases of 3.51 kWh/m^2/year to 4.19 kWh/m^2/year for commercial, and 4.19 kWh/m^2/year to 5.79 kWh/m^2/year for residential. As the high central building enlarges the day-lighting area on building surfaces increasing the solar gain in this building, the heating demand is reduced by 3.49 kWh/m^2/year in No.5 Building, and 5.85 kWh/m^2/year in No.8 Building, respectively. During summer, the large solar exposure area in central buildings significantly increases the cooling demand, 9.95 kWh/m^2/year in No.5 Building and 10.03 kWh/m^2/year in No.8 Building. The lower solar gains mitigate the cooling demand in the surrounding buildings, and decreases ranging from 6.10 kWh/m^2/year to 7.76 kWh/m^2/year are achieved for the surrounding buildings.

Air Temperature Change

The parameter of air temperature change is another major issue which is chosen as a parameter representing the microclimate impaction on building energy demand. The previous researches on building energy demand change due to variations in air temperature are many (Fung et al., 2006; Hou et al., 2014; Li et al., 2014), but, none of them had studied the case in Chengdu. The results of this study illustrate the influence of the local air temperature on building demand. Figure 10 compares the energy demands between the standard model and the Model-Air Temp. In the Model-Air Temp., the temperature has risen by 1°C by modifying the loaded weather file.

Figure 10 indicates the overall heating and cooling demands, considering two air temperature conditions. In summer times, a rise of 1°C in air temperature leads to a significant increase in cooling demand by 18.33% for residential and by 15.34% for commercial. The annual heating demand for residential buildings in Model-Air Temp. is reduced by 3.98 kWh/m^2/year, whereas for commercial buildings, the decrease in heating demand is 2.43kWh/m^2/year.

Considering the shading effect of the surrounding buildings on the central buildings and the same geometry settlement in each individual building, the solar gain in central buildings is less than that of the surrounding buildings. Table 1 indicates that in No.5 Building for the commercial and No.8 Building for the residential, the heating demand in surrounding buildings is lower than the central building, whereas the cooling demand in these low buildings is higher than the central ones. The shading effect leads a similar trend in energy demand in Model-Air Temp.; the greatest reduction in heating demand and the smallest rise in cooling demand is observed in the two central buildings compared to the other five surrounding buildings of the same type due to the air temperature variation.

Summary

Firstly, in general, previous studies (Xu et al., 2013a; Xu et al., 2013b) on building energy consumption in hot summers and cold winters, which is the weather zone Chengdu is located in, show similar results in heating demand (34 kWh/m^2/year averaged by values in residential and commercial buildings) and average cooling demand (15 kWh/m^2/year

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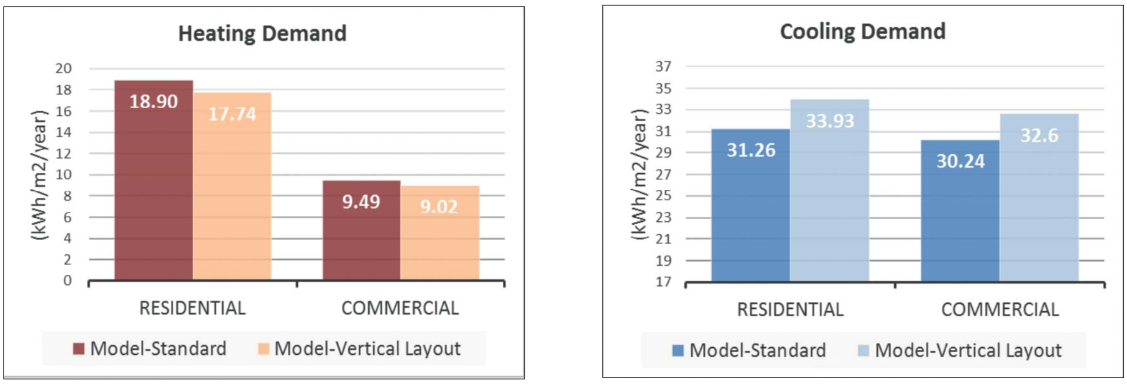

Figure 9. Comparison of energy demands between the standard model and the experimental models with different building vertical layout.

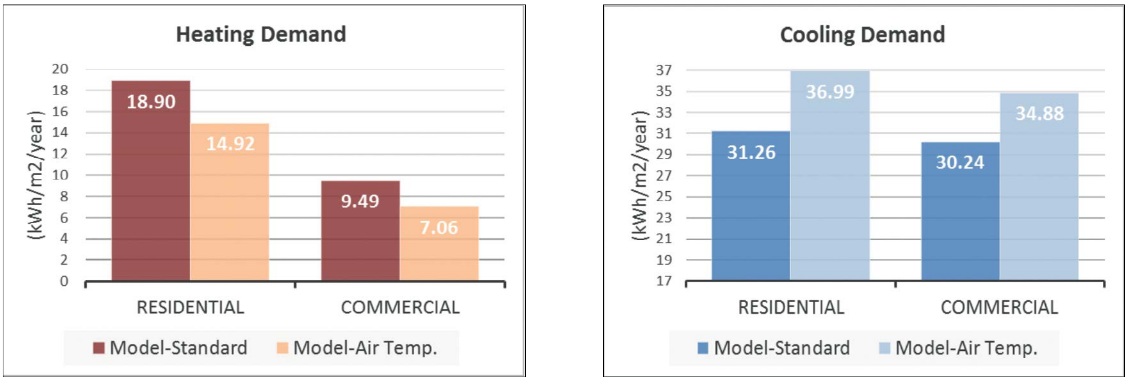

Figure 10. Comparison of energy demands between the standard model and the experimental model with different air temperature.

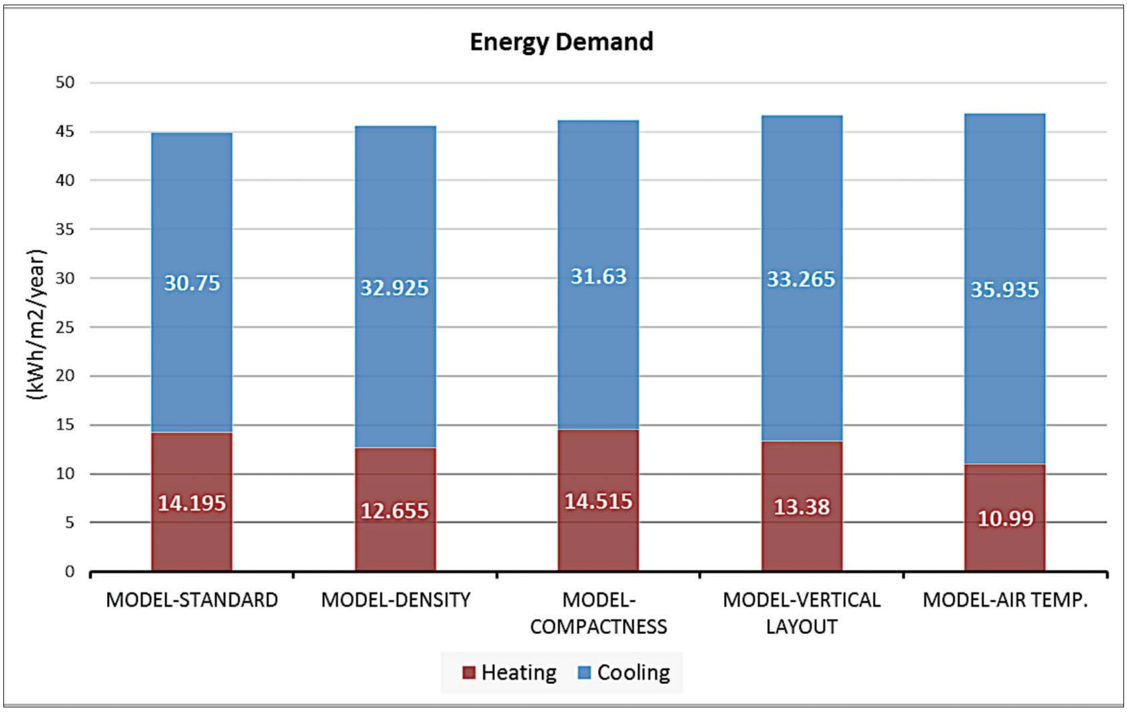

Figure 11. The comparison of annual energy demands between the prototype and experimental models.

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averaged by values in residential and commercial buildings), compared to the results as shown in Figure 8 in this study.

Most importantly, total energy demands in Model-Density, Model-Compactness, Model-Vertical Layout and Model-Air Temp. are higher than that in the standard model by 0.64 kWh/m^2/year, 1.7 kWh/m^2/year and 1.98 kWh/m^2/year, respectively. When considering the living habits in Chengdu where people seldom use heating services in winter times, the significant increases in the total cooling demand in each experimental model (2.18 kWh/m^2/year for Model-Density, 0.88 kWh/m^2/year for Model-Compactness, 2.52 kWh/m^2/year for Model-Vertical Layout and 5.19 kWh/m^2/year for Model-Air Temp., respectively) are of much practical meaning.

Lastly, based on the comparison of the study results for the standard model and the four experimental models, the following conclusions emerged: (1) Increase in building compactness is one of the most effective strategies for reducing the cooling demand at a building scale and achieving the least increase in cooling demand at a neighbourhood scale (see Figure 11), (2) reducing the outdoor air temperature is the most effective strategy to reduce building energy demand (especially in reducing the cooling demand) at neighbourhood scale, where a rise in air temperature of 1°C increases the cooling demand to the highest level and reduces the heating demand to the lowest level, (3) denser buildings with a larger floor area ratio and greater height are more effective strategies to achieve better energy performance, compared to compact building forms and more random vertical layouts with greater height. Furthermore, the exterior surface of the building significantly influences the building energy consumption due to convective heat transfer, and a lower wall-to-volume ratio leads to less heat transfer surface through which energy may be lost (Caldas, 2002; Liu et al., 2015). Considering this fact, in this study, the ratio of surface-to-volume of all buildings is the same in all experimental models and also in the standard model.

Conclusions

In this study, the energy performance of a neighbourhood scale project in Chengdu, southwest China, is simulated. The effects of building density, building compactness, vertical layout and air temperature change are investigated in four models and compared with the standard model. The results of comparison between each of the four target models and standard model indicate that denser buildings and more compact building plot layout increase the energy demand of buildings. Additionally, changing the outdoor air temperature has a detrimental effect on total building energy demand. Moreover, moderation in building density only achieves a weak effect on total energy demands for heating and cooling at a neighbourhood scale.

The study provides valuable design principles for achieving energy-efficient neighbourhoods at the urban planning stage and architectural scheme stage in cities within the weather zone of hot summers and cold winters. The initial recommendation based on results of this study is to mitigate temperature variation in the urban microclimate; thus, strategies such as choosing more reflective material for roofs and streets, more open spaces for water bodies and vegetation planting to increase the extent of water evap-

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oration and plants evapotranspiration, promoting energy efficiency in building services to reduce anthropogenic heat and lesser use of motorcars, are effective to reduce the building energy demand indirectly by mitigating the outdoor air temperature (Okeil, 2010). Furthermore, among all the urban morphology parameters selected in this study, building density is found to be the most effective one to directly optimize energy performance at neighbourhood scale; it impacts the outdoor air temperature in terms of Urban Heat Island effect by affecting the amount of stored heat in surfaces (Radhi, Fikry and Sharples, 2013), which is more effective than planting additional trees in outdoor spaces (Wong et al., 2011); therefore, optimization of urban morphology in terms of setting an appropriate density for a neighbourhood scale project is an effective strategy to improve energy performance in both direct and indirect ways. Finally, compacting of buildings by reducing the wall-to-volume ratio is shown to reduce the summer cooling demand of buildings.

Lastly, there are some limitations as follows. First, the simulation configuration in each of the experimental models is set with one condition, which hardly describes global configurations of each parameter; therefore, if other configuration conditions were considered, the suspected outcomes might be different. Second, the interactions among the selected parameters that affect the building energy demand are not discussed in this paper: the accumulative effect due to these parameters still needs to be investigated. Further studies should also consider other factors that influence building energy demand, with more comprehensive comparisons between these factors. Third, the weather condition and geo-location are based on the reality of Chengdu, China, and the findings might be inapplicable in other locations.

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Evaluating the impact of vertical greening systems on thermal comfort in low income residences in Lagos, Nigeria

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Abstract

Nigeria has a population of about 120million and is the most populated country in Africa. However there has been insufficient attention to developing sustainable ideas and materials to combat the issue of global warming which has resulted into extreme temperature rise within the country. This should be a concern because combating global warming and improving sustainability should be a collective worldwide effort.

This research took place in Lagos, Nigeria to evaluate the effect of vertical greening system on occupant's thermal comfort. With 70% of the population living below a dollar a day, the focus of the study were low income residences characterized by overcrowding and overheating of interior spaces due to choice of building materials and high ambient temperatures.

Vertical Greening Systems also called wall gardens are simply plants on walls. A VGS that was financially affordable, easy to erect and maintain was setup on selected low income residences. Continuous readings were taken with the tiny tag data logger over a period of 4 months from May to August across the two major seasons, Wet and dry.

The results reveal a significant reduction in the ambient temperature of the immediate surroundings of the VGS setup as well as a reduction in indoor temperatures.

Further research on VGS can be encouraged as complementary qualitative undertaken by the author has shown that majority of the target group are open to embracing sustainable strategies but only at minimum expenses. It is proposed that simulation of further VGS design scenarios using software's should now be explored, to evaluate the potential wider benefits of low cost alterations to the design and build of Low income group housing in Nigeria.

Finally, the importance of a worldwide collective effort towards sustainable houses and cities is extremely important for global reduction in carbon emission to be achieved.

Keywords

VGS, Vertical Greening Systems; Thermal Comfort; Passive Cooling.

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1. Introduction

The location and climatic characteristics of the City of Lagos is briefly discussed to establish the context of the research .This offers background knowledge of the City in order to understand the focus of the research; being the need to provide more sustainable means of providing passive cooling in the average low income residential building which is usually characterized by overcrowdings, overheating and poor ventilation. A brief review of the population characteristics of the city of Lagos is provided and introduces the Low income groups that inhabit the city. The focus is subsequently narrowed down to their housing morphology and characteristics as well as the potential effect on the overall well-being of the occupants.

This paper subsequently discusses the importance and the need for improvement particularly of thermal comfort in these houses, focusing on the potential impact of passive cooling through the use of vertical greening systems might have. The VGS type used are discussed to highlight the reasons behind the prototype choice as well as the factors considered before erecting them on selected low income housing residences. The form of measurements are reported as well as the results and future research possibilities.

1.1 Lagos, Nigeria

The study took place in Lagos, Nigeria, Located in West Africa, very close to the equator. The major characteristic of the climate is high temperature and high humidity, thus overheating in interior spaces is not uncommon (Akande and Adebamowo, 2010). The implication of this is further exacerbated by the tendency of the city to experience urban heat island effect (Akiyode, 2010). This negatively affects thermal comfort within interiors spaces.
n, launched by neurosciences in the recent years.

Figure 1. Location of Lagos, Nigeria
Source: Google Map, Accessed, July 2013

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1.2 Lagos climate and climate change

Lagos is classified as 'AM' (Equatorial, Monsoonal) Category under the Koppen-Geiger Climate Classification. Studies have shown that climate change is a global phenomenon, likewise its impacts, but the biting effects will be felt more by the developing countries, especially those in Africa, due to their limited levels of coping capabilities (Nwafor 2007; Jagtap 2007 cited in Odjugo, 2010). Nigeria is one such developing country.

For Lagos, the climate challenges are further exacerbated by the existing, and likely worsening urban heat island effect. UHI phenomenon can cause air temperature in the cities to be 2-5oC higher than those in the surrounding rural areas mainly caused by the amount of artificial surfaces (high albedo) compared with natural land cover (Taha, 1997 cited in Perini, 2011). Lagos lies on the gulf of Guinea, along the Bight of Benin, with a land area of about 356,861 Hectares (3568.6km2) representing only 0.4% of Nigeria's land area, (Lagos State Government Official Website,2012) 17% of the total land area consists of lagoons, creeks and waterways (Balogun, Odumosi and Ojo 1999, cited in Ilesanmi, 2009). Thus, the effect of UHI is enormously felt with overheating due to the dense population on a relatively small area of land.

1.3 Urbanization in Lagos

It is estimated that an average of 606 people enters Lagos per minute (Agbola, 2007). As a result of such uncontrolled urbanization, almost 75% of the urban dwellers live in slums in Lagos (Olotuah, 2005). The scenario of urbanization is stated below by Ogunsakin, 1998 cited in Olayiwola, 2005 'This massive flow of population and the existing poor level of city development and state of unpreparedness create profound disruptions and imbalances within the urban tissues. Simultaneously the inability of the city to integrate or absorb the new population socio-economically and in term of infrastructural provision became apparent and almost 'unavoidable'.

In other words, urbanization can be considered an unavoidable phenomenon in Lagos. It therefore falls to designers and researchers to explore viable means of coping with this significant issue, through efforts such as slum upgrading and renewal. Thus informing the context of this research.

2. Low income groups in Lagos

The Low Income Group (L.I.G) is an important part of the economic activities within the state, with the bulk of public transportation and informal trading undertaken by these groups. (Akinmoladun, 2007). UNDP (2008) estimates that 51% of men and 54% of women residing in Lagos survive on less than US$1 a day, with their average income being approximately N15, 000 a month (£55) (Aluko, 2012). These groups, also referred to as the 'urban poor', are further described by Olotuah, 2005 'These are the urban poor who are subjected to a life characterized by precarious conditions of lack of nutrition and health, little or no material possessions, substandard housing and a generally degraded environment. Their housing does not ensure dry shelter, safe water supply, drainage,

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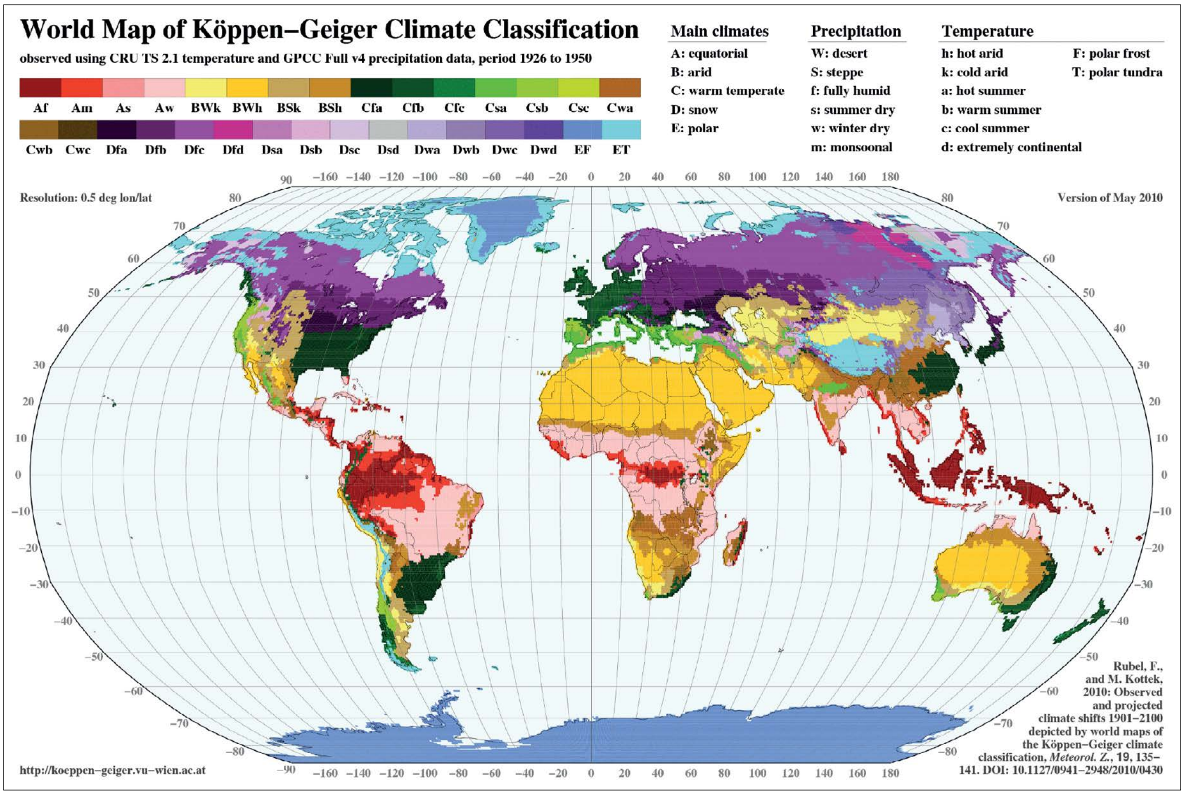

Figure 2. Koppen-Geiger Climate Classification

Source: Koppen-Geiger, Accessed, October, 2012 Lagos, Nigeria

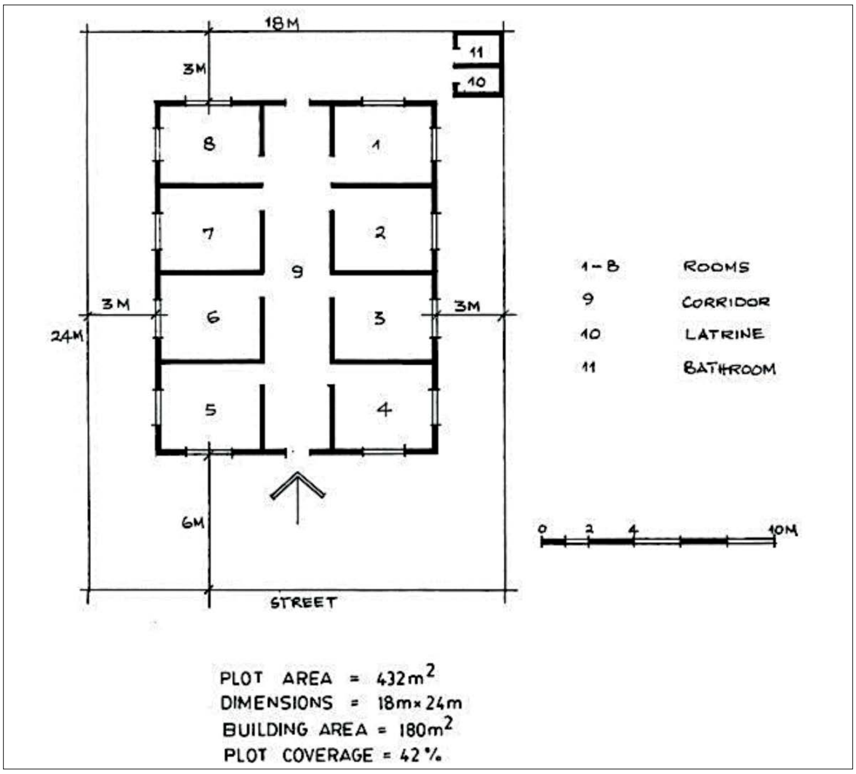

Figure 3. Typical Housing Morphology among Low income Groups in Lagos, Nigeria:

Source: Source Olusanya, 2012, Accessed June 2013

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sewerage and refuse disposal, as well as access roads. The houses constitute a health risk to its occupants'. This accurately captures the life and housing conditions of low income groups in the State.

2. Low income groups in Lagos

The Low Income Group (L.I.G) is an important part of the economic activities within the state, with the bulk of public transportation and informal trading undertaken by these groups. (Akinmoladun, 2007). UNDP (2008) estimates that 51% of men and 54% of women residing in Lagos survive on less than US$1 a day, with their average income being approximately N15, 000 a month (£55) (Aluko, 2012). These groups, also referred to as the 'urban poor', are further described by Olotuah, 2005 'These are the urban poor who are subjected to a life characterized by precarious conditions of lack of nutrition and health, little or no material possessions, substandard housing and a generally degraded environment. Their housing does not ensure dry shelter, safe water supply, drainage, sewerage and refuse disposal, as well as access roads. The houses constitute a health risk to its occupants'. This accurately captures the life and housing conditions of low income groups in the State

2.1 Housing Morphology of Low income Groups

Housing reflects the cultural, social and economic stance of any given society (Olukayode, 2003 et al cited in Gambo, 2012) .The quote by Mandelker cited in Akinmoladun, 2007 explains housing as, "being more than physical structures: housing has become a subject of highly charged emotional content: a matter of strong feeling. It is the symbol of status, of achievement, of social acceptance. It seems to control, in large measure the way in which the individual, the family perceives him/itself and is perceived by others". It encompasses the totality of the environment and infrastructure which provide human comfort, enhance people's health and productivity as well as enable them to sustain their psycho-social or psycho-pathological balance in the environment where they find themselves (Afolayan, 2007). Quality housing can be considered a litmus test of a developed society. This is because a house goes beyond provision of mere shelter; it is a place where people recuperate, rest and bond with family (Aluko, 2012).

Despite the acknowledged importance of housing to man, there are several housing problems throughout the world, and particularly in developing nations. These problems are both qualitative and quantitative in nature, manifesting in different shades of societal ills and decadence (Dogan, 2009 cited in Aduwo, 2011).

The most common form of Urban Housing in Lagos is the double banked Apartment block with rooms or flats on two sides opening to a common corridor leading to a stairwell. The corridor is generally narrow with poor lighting and ventilation. Cross ventilation is difficult to achieve within the flat because the door to the corridor is always locked for reason of security and windows do not open for security reasons. (Olusanya, 2012). This is also called 'Brazilian style housing' or the more informal term called 'face me I face you'. It is not unusual to find an average of 6 people in an 18m2 space. This is

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partly due to greed by the Landlords or squatting with friends and relatives.

2.2 Thermal comfort in low income houses

Thermal comfort can be considered to be a key factor in achieving housing quality, being one of the most important parameters that impact the satisfaction level of occupants (Adebamowo, 2008, cited in Akande, 2010). The definition of a good indoor climate is important to the success of a building, not only because it will make its occupants comfortable, but also because it will decide its energy consumption and thus influence its sustainability (Nicol and Humphreys', 2002).

For thermal comfort to be achieved in tropical Lagos (Adaptive thermal comfort standard), a reliance on mechanical cooling devices is often needed. This usually imposes financial burden on the target group in this study which are the Low income groups. In addition, the impact is felt at a larger scale through climate change due to burning of fossil fuels to generate the electricity required for cooling systems. Combustion of these fuels emits CO2 and other greenhouse gases harmful to the environment that contribute to turning the earth's atmosphere to a greenhouse with the harmful effect of producing global warming as well as causing localised air and noise pollution.

A significant amount of electricity generated is often used for cooling interior spaces. (Lagos State Government, 2012). Due to the poor electricity supply in the country, a huge number of people resort to the use of back up electricity in the form of petrol generators. These generators require petrol or diesel to run them, thus a huge amount of money is spent on powering the devices and proportionally higher quantities of CO2 are emitted into the atmosphere due to low efficiencies.

The potential of VGS to offer cooling for houses prone to overheating in the tropics is researched in this study. This is important due to the potential of financial savings and subsequent reduction in the effect of global warming it has to offer due to reduction in electricity demand for cooling. The reason for the relative scarcity of these systems in the city will be investigated, in terms of user acceptability/ awareness (which is not reported in this paper) to form a basis for future study that might take place in this area of research.

Overheating in interior spaces remains a challenge for buildings located in the tropics. The lifespan of anyone exposed to excessive heat for too long is often compromised. It also has adverse effect on the skin, internal organs and physical well-being which may include asthma, tuberculosis, dizziness, stress and restlessness (Ahianba et al, 2008) .This can lead to great discomfort and diseases such as asthma or even heat stroke in extreme cases.

The need for further research on potential passive cooling opportunities to promote thermal comfort in interior spaces remains paramount, especially among the low income groups in the city of Lagos, being the most vulnerable financially and more often feel unable to afford the cost of cooling their homes (Akinmoladun, 2007).

3. Vertical Greening Systems

Various studies have been undertaken to date on the impacts of Vertical Greening Systems (VGS) systems on indoor thermal comfort in Mediterranean climate, temperate climate and some parts of Asia with similar climatic conditions to those of Lagos, Nigeria. The resulting impact they have been found to have on indoor thermal comfort can be seen to vary from one research outcome to another. (Kontoleon and Eumorfopoulou, 2009) have reported a temperature cooling potential

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of plant covered walls in a Mediterranean climate: the effect was up to 10.8C of wall surface temperature. For a similar climate with Lagos, a study by Wong et al, 2010, through measurement on a free standing wall is Singapore with vertical greening types shows a maximum reduction of 11.6C. Alexandri and Jones in 2008 simulated a temperature decrease in an urban canyon with greened facades with a reduction of air temperature of 4.5C for the Mediterranean climate and 2.6C for the temperate climate.

There has been no reported research on the impact of VGS systems in tropical Africa. The results from countries with similar climatic conditions like Singapore and China have been reported to varying degrees of results on temperature reduction. However, factors peculiar to the tropical city of Lagos like overcrowding, inappropriate building orientation, building materials with high thermal conductivity are yet to be considered in research undertaken to date.

The figure on the right was gotten from the detailed literature review by Perez, 2014 who accurately described the location of VGS studies as well as their classification around the world, Clearly, the dearth of studies in Africa, Particularly Western Africa, where Solar radiation is very intense is highlighted above.

VGS has the potential to relieve the financial stress of attaining thermal comfort among these groups. This is due to non-demand for electricity by this system. However, while financial implications of erecting and maintaining these systems are not escapable, however, the VGS can be adapted to suit the financial levels of the low income groups
This research aimed to target an aspect of urban renewal as a means of coping with urbanization. This aspect has to do with the study of green walls and its effects. VGS are known for their ability to reduce indoor temperatures (albeit to varying degrees), clean indoor air, offer a means of planting crops and enhancing aesthetics. This research involves measuring the impact these systems can have on the interior temperature of L.I houses. The common challenges of overheating of indoor spaces in low income buildings could be tackled with these systems.

4. Experimental Setup: (Quantitative aspect of Research - 1st Phase of Research)

The choice of the Experimental set-up which involves monitoring the effect of VGS on occupant's thermal comfort through measurements by data loggers is in response to the primary aim of this research.

Convenience sampling that was also representative was selected from a sampling frame. This was the basis of selecting the case study residences to set-up the experimental prototype needed to represent the typical low income residence in Lagos, Nigeria. The inculcation of convenience sampling was important because of the need for co-operation by the landlords and occupant's (the survey involved an invasion of their personal space over a period of time) for a successful field work to be achieved.

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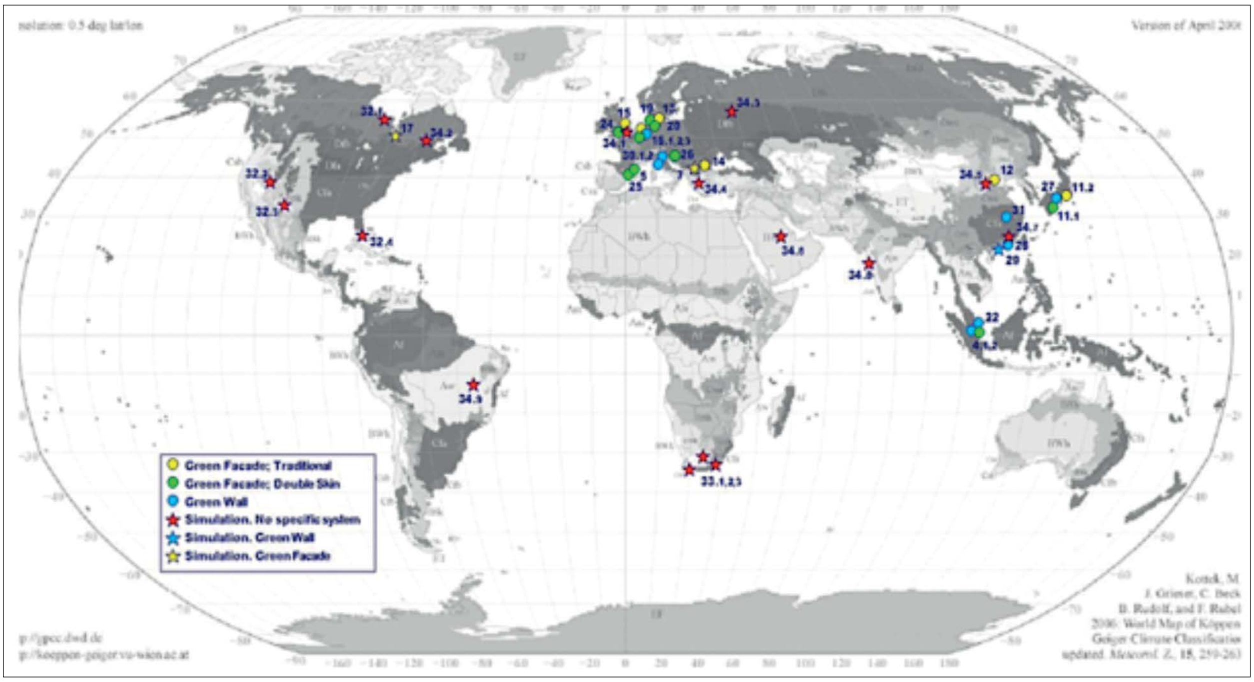

Figure 4.
Documented VGS studies and Classifications around the world.
Source: Perez, 2014.

Plate 1.
Vertical Greening System.

Source: kirhammond.wordpress.com. [Accessed January 2014].

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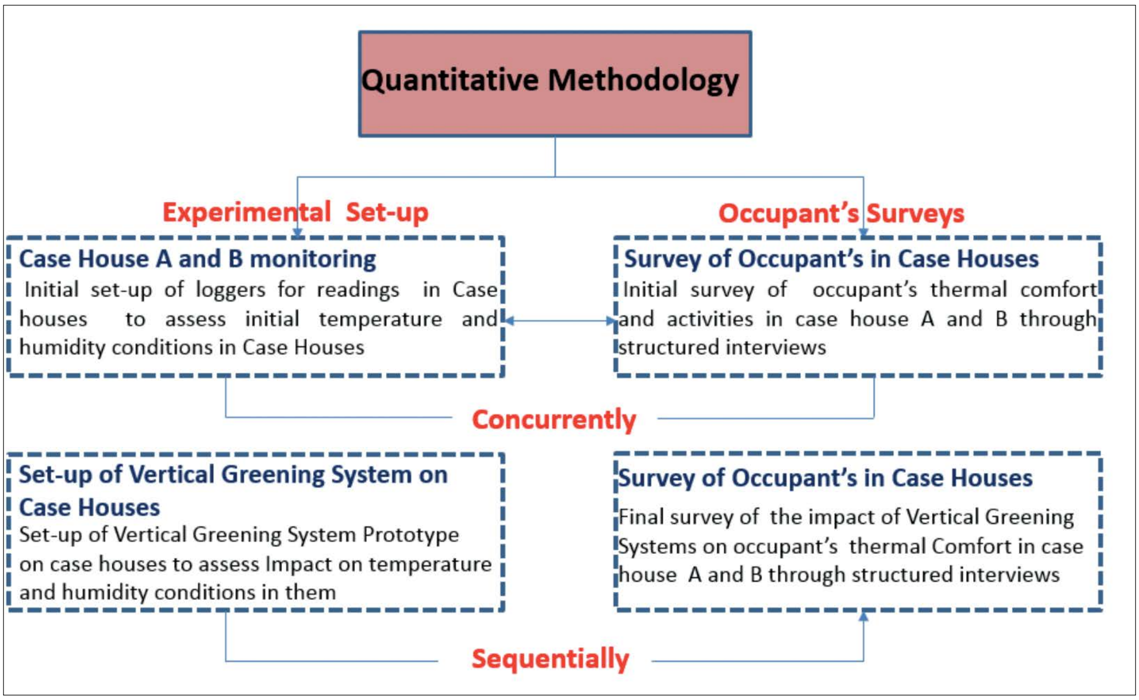

Figure 5.
Quantitative methodology and field experiment,.
Source: Author, 2015.

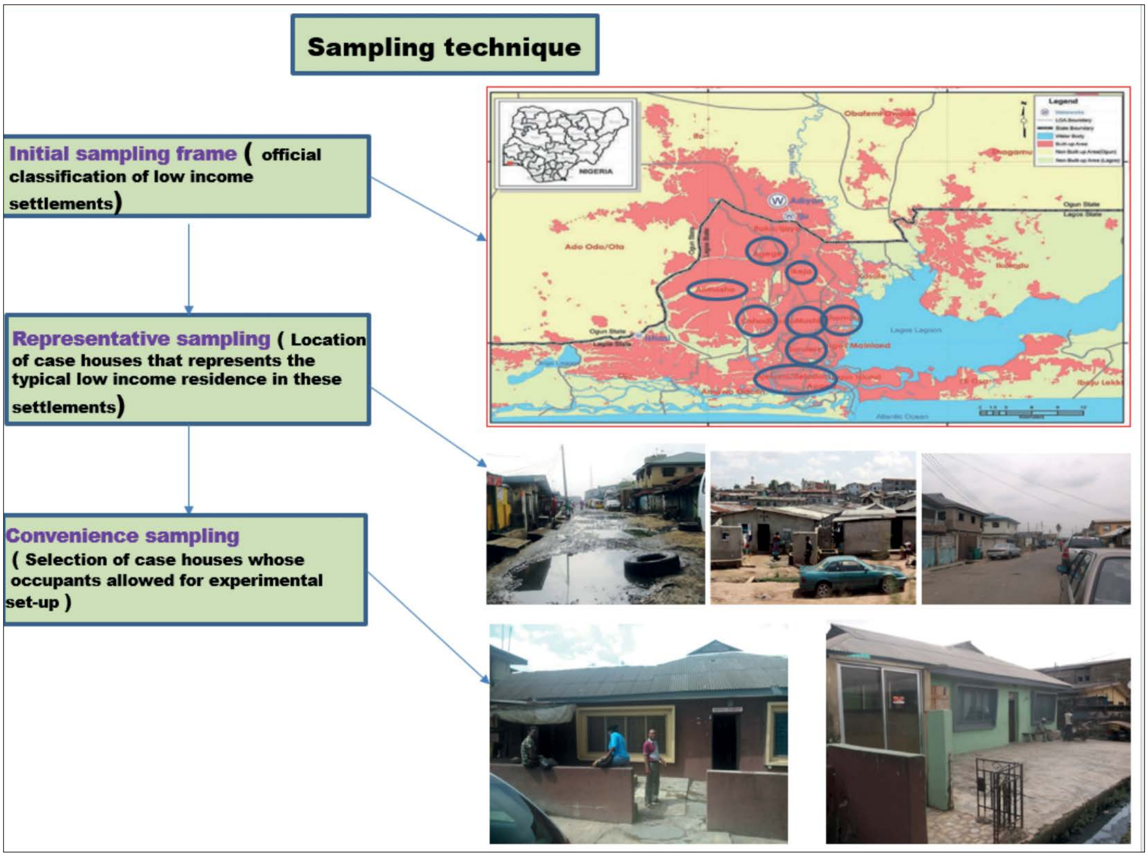

Figure 6.
Sampling technique.
Source: Author, 2015.

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4.1 Research setup

The total number of 'residences' were 10, 5 arranged on a long row or corridor and the other 5 arranged opposite it. The implications of this was a long dark poorly lit corridor and only 1 of the 10 rooms were cross ventilated, (Room 5) and this caused the residences to be overheated and uncomfortable for the residents (this was confirmed through the measurement and subsequent interviews). Each room was approximately 3m x 3m in size, 9m2 in area. Each room was populated by a minimum of 4 people (Details on this are given later in this chapter).

At the back of the building, a small kitchenette and bathroom was located at the left side of the house and a small 1 bedroom apartment was located on the right side of the house. Total length of the main building was 15m, while the total width was 7.5m.

Room 1 and 10 were used for the experimental set-up. Room1 was set-up with the VGS while Room 10 was used as the 'control room', as done in similar studies by Wong et al, 2010: Price, 2010 and Susorova, 2013. This was due to the walls receiving the most solar radiation (in this case, the westerly solar exposure as it entails that the wall receiving this is conducting heat into the interior space). This was also used as basis for experimental set up in studies by Eumorfopoulou and Kontoleon (2009): Price (2010): Susorova et al (2013): Chen et al, 2013.

Measurements of the surrounding environment (both indoors and outdoors) and within the VGS of temperatures and humidity was continuously recorded for a total of 5 months (with data mea-

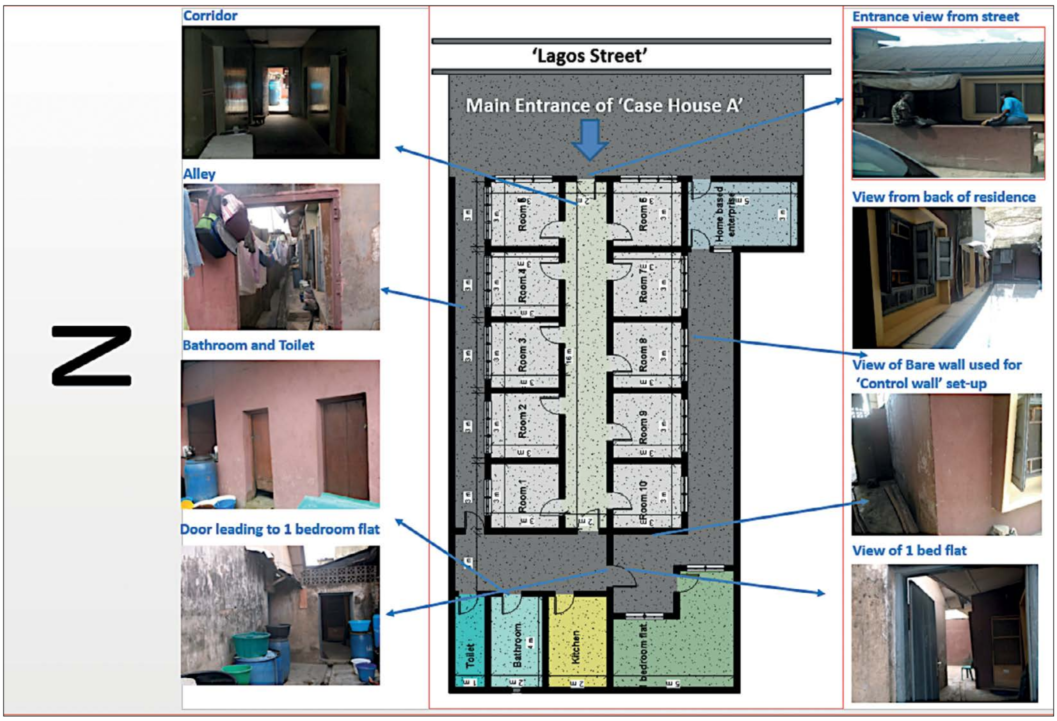

Figure 7.
Floor plan of Case House A.
Source: Author, 2015.

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Details of Building Morphology , Case House A

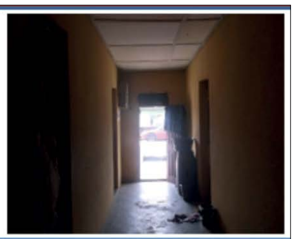
Wall	• 225mm thick • Hollow concrete block • Plastered with 5mm of cement	The walls were 225mm thick, built from hollow concrete block and plastered with 5mm of cement. On confirming the age of the building with the landlord and caretaker, it was listed as 55 years. This was apparent in the decay of the façade located at the back of the building		
Floor	• Built of concrete and screeded with cement • Depth of 20mm	The floors were built entirely of cement. This was through 'screeding' of cement. The same material Was used on the exterior floor		
Ceiling	• Built from suspended ceiling tiles	The ceiling finish was built from suspended asbestos tiles, some of which were missing		
Roof	• Aluminum roofing sheet	The roofing material was aluminum roofing sheet discolored with age. The roofs project outwards by 450m (eaves). This provides some shading from the sun. However, solar radiation still falls on part of the building at different times of day, thus the shading provided by the roof was not significant enough to prevent the sun ray from hitting all parts of the building. A 300mm fascia board was also used on the façade of the building		
Doors	• Treated hardwood	The doors were built from treated hardwood		
Windows	• Louvre windows	The windows were 600mm X600mm .The rooms at the entrances had windows of 1800mm and 2400mm in width at the façade respectively, while the windows in the rest of the houses were 1800mm in width. Apart from one residence at the façade, none was cross ventilated. The windows used are called louvers		

Figure 8.
Details of Building Morphology,.
Source: Author, 2015.

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sured and gathered during specific times (every 10 minutes), diurnally and nocturnally alongside with ambient climatic data.
An optimized experimental installation was set up on the selected residences (typical low income houses) in Lagos, Nigeria. In each location, two residences were selected side by side with the exact number of rooms and same number of occupants (with a minimum of 3 occupants in each room), same materials used in construction (concrete blocks), same morphology and plan layout as well as building orientation. Consideration was given to the times in which the rooms were fully occupied. The west side of each of the two apartments was set up with a VGS. This is due to both walls receiving westerly solar radiation.

Indoor temperatures, mean radiant temperatures and humidity were recorded concurrently from May 2014 (to establish that the two rooms used for the experimental set-up were similar) to September 2014 (When the VGS was fully grown and Leaf area index was maximum). Particular focus on the readings presented here is on those taken between July-September, with particular attention in the month of August when the plants were fully grown and the ambient temperature was at its highest. This involved the design and assembly of two appropriate low cost VGS prototypes. The appropriate VGS prototype to the Low income group is characterized by

- Financial affordability
- Ease of erecting the systems
- Sustainable Material choices
- Edible plant types to provide an alternative of vertical farming and possible financial succour through selling of fresh vegetables. These included west indies plants, Fluted pumpkin plants (Telfairia occidentalis), Cymbopogon citrates (Lemongrass/ antisnake), Corchorus plants and sanseviera trifasciata
- Insect repelling plants

The VGS were located on surfaces with direct solar access as the situation permitted. A partnership with a horticulturist ensured appropriate planting was selected and well maintained. Measurements of the surrounding environment (both indoors and outdoors) and within the VGS for temperatures and humidity were continuously recorded for a total of 3 months and across the two major seasons in the city, wet and dry . Data was collected continuously at 10 minute intervals with attention paid to when occupants where in the rooms at the same times, alongside with collection of ambient climatic data. This ensured that adequate data during various times in the day was well documented.

4.2 Assembling of Prototypes (HDPE plastic VGS)

A design and assemble of an appropriate low cost VGS prototype with valuable financially saving ideas from the Residents and neighbors (Which was the intention of adopting the holistic research approach) was achieved. The HDPE pipes were sourced from a nearby construction site as recommended by the residents. that would anchor the HDPE pipes to the hardwood.

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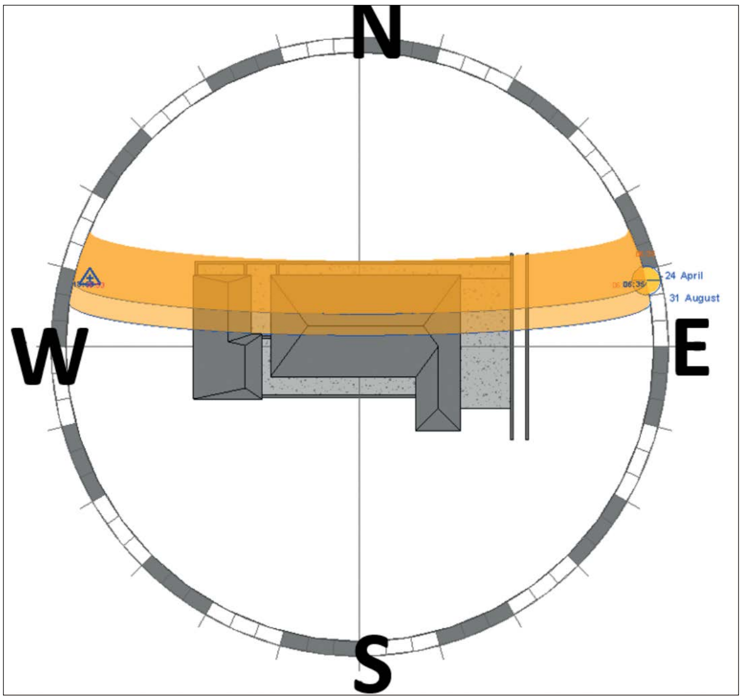

Figure 9.
Sun path movement in Lagos, Nigeria.
Source: Ecotect, 2015.

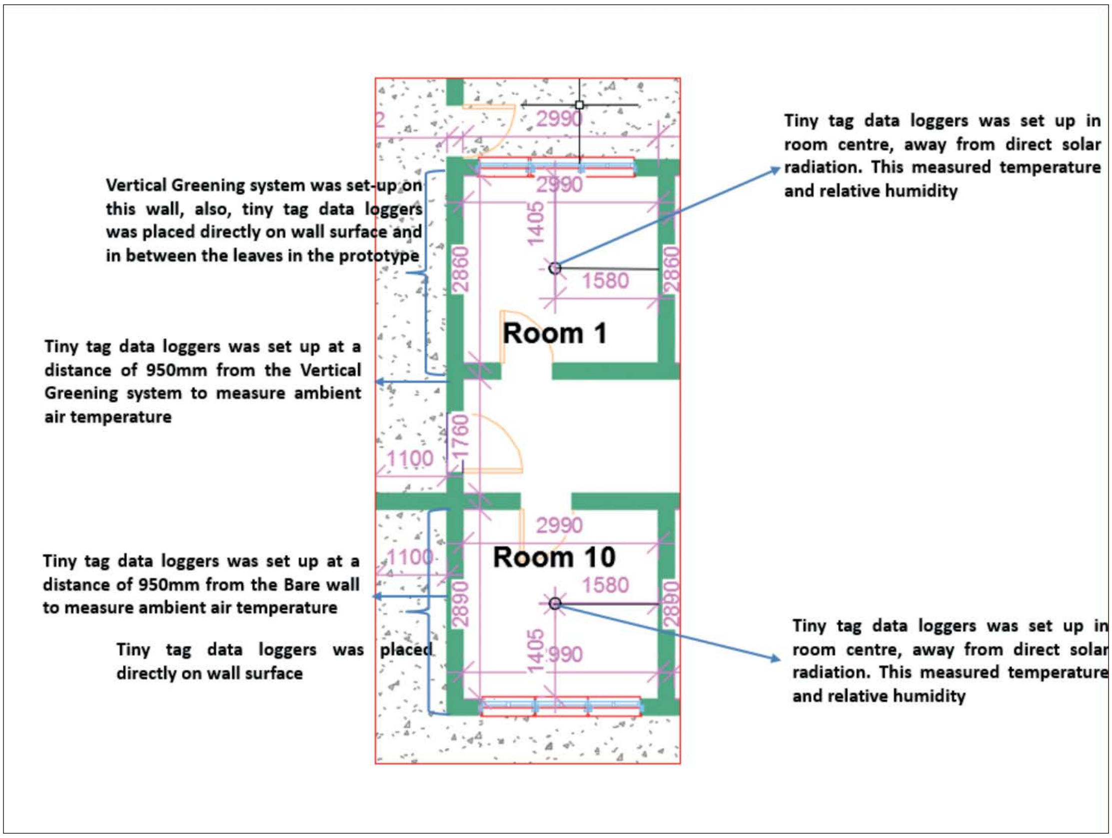

Figure 10.
Location of Loggers in rooms used for experimental set-up.

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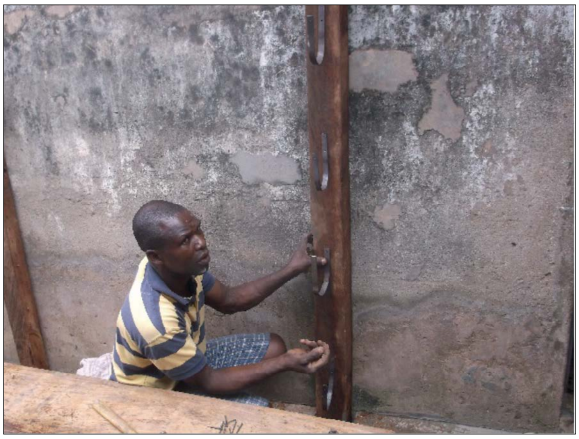

Plate 2. Vertical Greening System assembly
Source: Author, 2014.

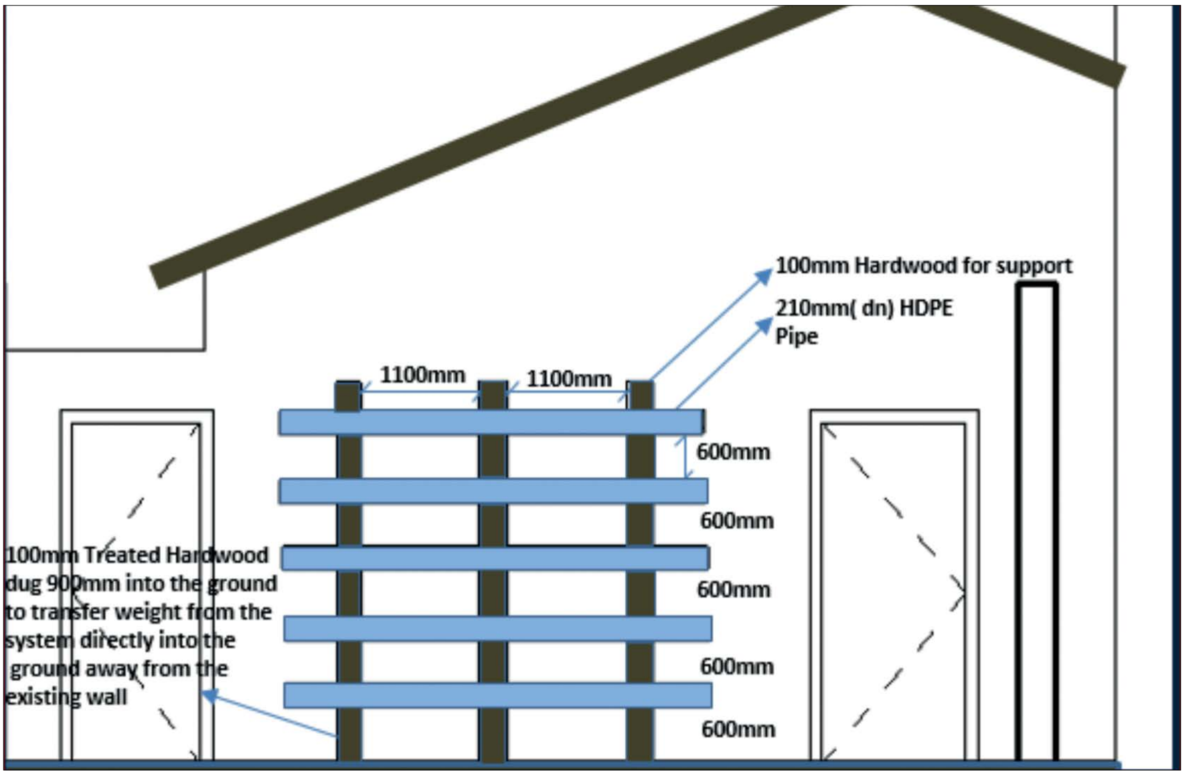

Figure 11. Detailed elevation view of the HDPE VGS prototype
Source: Author 2015

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Plate 3. Plant growth in prototype, July 1st 2014.
Source: Author, 2014.

Plate 4. Close up view of Corchorus plant (another edible plant type).
Source: Author, 2014.

Plate 5. View of fully grown plant in Prototype, August 2nd.
Source: Author 2015

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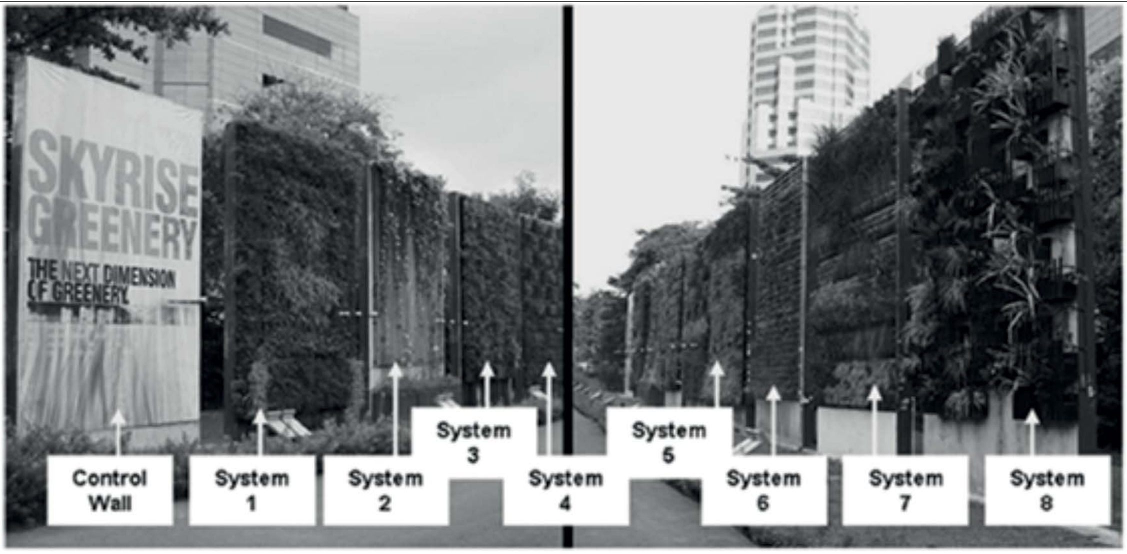

b

VGS	System typology	Description	Plant size
1	Living wall – Modular panel, vertical interface, mixed substrate	Combination of 2 systems: the versicell-based and 'plug-in' slot planter system. Versicell planters have drainage cells with selected mixture of green roof and soil planting media wrapped in geo-textile membrane while the slotted planters are mainly planter cages system.	Small to medium
2	Green façade – Modular trellis	Climber plants in planters forming green screens across mesh panels on the wall.	Climber plants
3	Living wall – Grid and modular, vertical interface, mixed substrate	Plant panels embedded within stainless steel mesh panels inserted into fitting frames.	Small
4	Living wall – Modular panel, vertical interface, inorganic substrate	Employed the Parabienta system with a patented growing medium (composite peat moss) as a planting media inlay. The peat moss panel encased in a stainless steel cage is hung onto supports lined with integrated irrigation.	Small
5	Living wall – Planter panel, angled interface, green roof substrate	This system uses a UV-treated plastic as a molded base panel with integrated horizontal planting bays.	Small
6	Living wall – Framed mini planters, horizontal interface, soil substrate	Individual mini planters placed and secured onto stainless steel frame.	Small
7	Living wall – Vertical moss-tile, vertical interface, inorganic substrate	Patented ceramic tiles shipped with pre-grown moss species. Suitable for creating tiling designs	Small, custom-grown on tiles
7a	Living wall – Flexible mat tapestry, horizontal interface, soil substrate	Lightweight panel comprising 2 layers of moisture retention mats secured onto a supporting grating or mesh. Plants slotted and pre-grown in between mats. Suitable for flat and curved surfaces. Allows ease of change.	Small to medium
8	Living wall – Plant cassette, horizontal interface, soil substrate	Use of planters to hold wider variety of plant types and of larger sizes. Planters are secured onto the wall through hinges. Lightweight growing medium is used.	Small to medium-large

Figure 12. Overview of VGS prototypes.
Source: Perez, 2014.

4.3 VGS prototype as compared to previous studies

The figure above compares various VGS prototypes derived from various studies as put together by Perez, 2014. In relation to the target group in this research, the need to invent a system that was relatively simple to erect, maintain and whose materials was extremely cheap and easy to obtain was paramount. The VGS prototypes eventually used in the study was put together by the Author and certain construction ideas were proposed by the residents while this was being erected. It is safe to say that inputs by the target group while erecting them made the VGS a lot cheaper than the initial budget. This is another factor that distinguishes the study from previous works that have included simulations etc. All instruments were heat friendly in order to minimize errors/discrepancies in reading data. They were protected from rain by a water repelling material (Nylon) to avoid damages which might lead to errors in data recordings. The readings were recorded at 10 minutes intervals. They included the temperature data loggers and humidity loggers. They were located in the exact areas in the spaces, within the VGS and hung in the centre of the rooms. For the wall surfaces, they were embedded on the surface with the same concrete materials of the walls. Sources of heat gain in the rooms include: Human body heat, Convective heat Gain from aluminum roof and building materials and Heat Gain from solar radiation.

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5. Results

There was a maximum reduction of 4oC in the interior temperature of the room with the VGS mounted on the wall surface as compared to the room without the VGS. The readings were noted when activities in both rooms were nearly equal, i.e. the occupants were in the rooms as at the time of the readings and the number of occupants were the same in number. The Occupants also confirmed a slight difference in temperature in the room through the separate structured interviews which is not reported here.

The difference in indoor temperature was likely due to the photosynthetic activities of the plants in the VGS absorbing solar radiation before the remaining heat is gained into the walls subsequently entering the rooms, hence the lower temperatures recorded in the room with the VGS. Also, the Leaf area index forming a shading to the wall thus preventing the solar radiation from penetrating the walls directly,

This result is promising in that questions like if more VGS prototypes were set up around the rest of the building, would the reduction in the room temperature be more significant? This will be further explored by simulation.

6. Discussion and conclusions

For architecture in the tropics, the key to achieving thermal comfort in buildings (without mechanical cooling devices) has been through basic design rules such as cross ventilation, building orientation, roof overhangs etc, however, overpopulation and overcrowding has limited the efficacy of following such design principles.

The need to research on alternative sustainable ideas particularly on passive cooling for free running houses is important. The results of the small set up of the VGS show its potentials to offer passive cooling. Further analysis will be explored using simulation to review multitude of scenarios the VGS prototype can influence thermal comfort in free running buildings. This will also involve analysis of the microclimate around these residential buildings. Further investigation on user acceptability among Low income Groups and Professional Architects was also conducted to assess if VGS will be accepted to be used on large scale within the city of Lagos. The results showing the Plastic VGS prototype offering the best results could direct further research on the development of the plastic VGS prototype for low income Houses. Also, further analysis on Humidity and wall surface temperature has been done in the research which was not discussed in this paper due to the focus on temperature differences in interior spaces.

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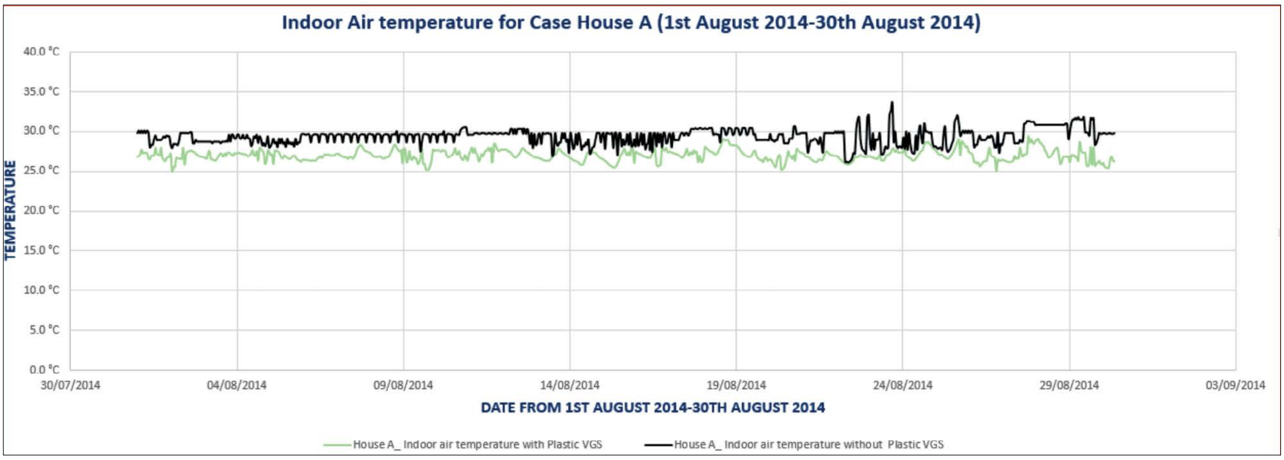

Figure 13. Indoor air temperature of Room1 (without VGS and Room 10 with VGS)

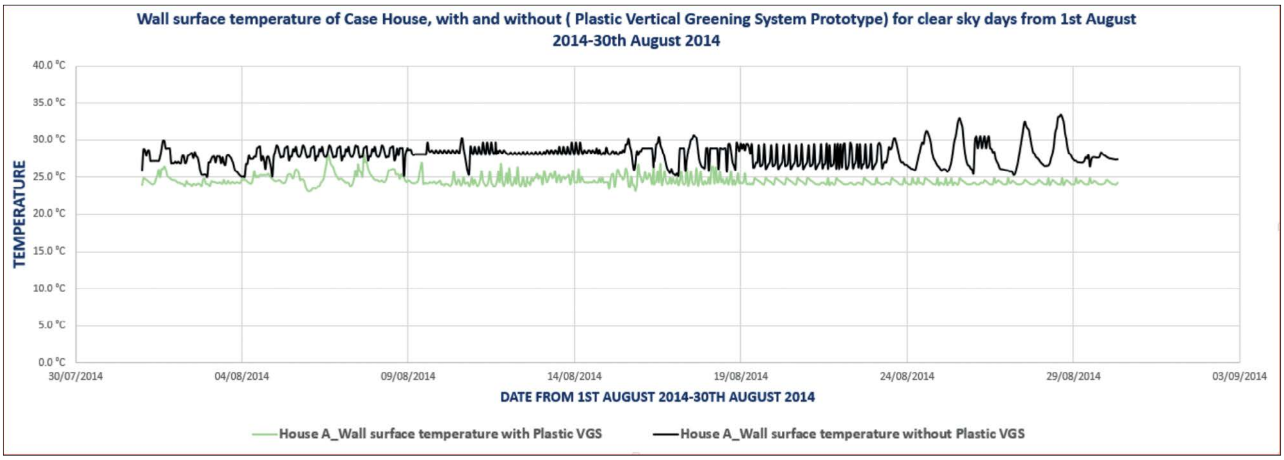

Figure 14. Wall surface temperature of Room1 (without VGS and Room 10 with VGS)

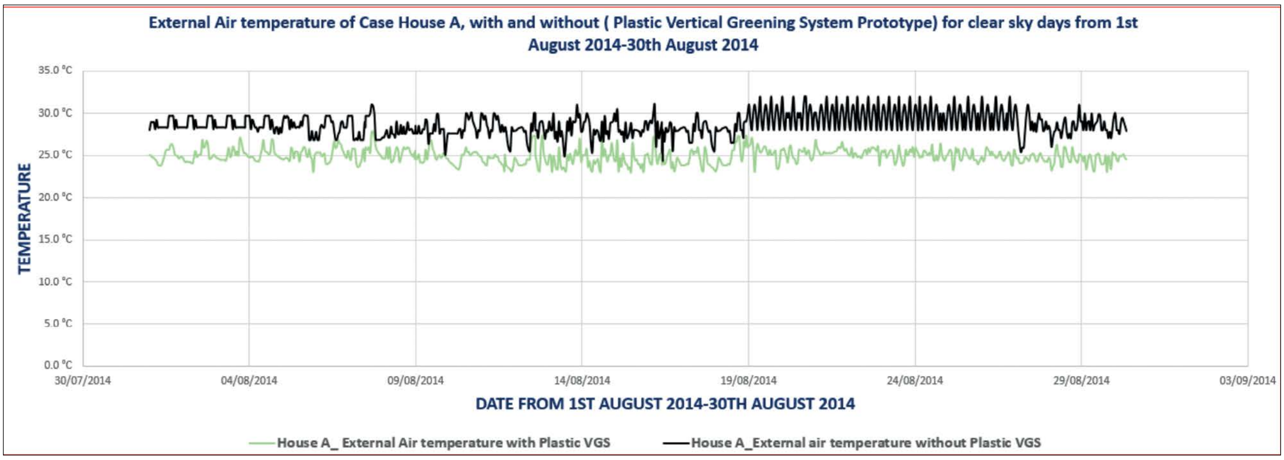

Figure 15. External air temperature of Room1 (without VGS and Room 10 with VGS)

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Architectural Detailing and Energy Performance of Envelopes with Building Integrated Photovoltaics (BIPVs)

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Abstract

This study describes the potential of the photovoltaic (PV) technology in the built environment, as an alternative to fossil fuels. Building Integrated Photovoltaics (BIPVs) replace conventional building materials on the building's envelope, as a principal or ancillary source of electrical power. Architects need to have a good knowledge of the available products, relevant technologies and development processes in order to integrate the PV cells into the building envelope, with architectural criteria. Nowadays, the demand for energy efficient or zero-energy buildings is higher than ever, in order to reduce energy consumption and CO2 emissions. Designing an energy efficient building is a task which requires the combined forces of a multidisciplinary team. The architect's contribution in the design process is vital, but the addition of energy generating features, such as photovoltaics, brings performance alongside the design process. Most PV systems are installed on top of the building envelope, resulting in aesthetically poor and costly results. Architectural detailing, in the form of typical construction sections, offers a clear view of the building envelope which functions as a solar energy generator, by replacing conventional construction materials.

Keywords

Building Integrated Photovoltaics (BIPVs); architectural criteria; building envelope; SWOT analysis; architectural detailing; zero-energy buildings.

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Introduction

Current legislation aims to ensure that the European Union meets its ambitious climate and energy targets for 2020. These targets, known as the "20-20-20" targets, set three (3) key objectives:

a. A 20% reduction in EU greenhouse gas emissions (from 1990 levels).
b. A 20% improvement in the EU's energy efficiency.
c. Raising the share of EU energy consumption produced from renewable energy resources (RES) to 20%.

(http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm [25 June 2015]).

According to the National Renewable Energy Laboratory (NREL) "more energy from the sun falls on the earth in one hour than is used by everyone in the whole world in one year" (http://www.nrel.gov/learning/re_solar.html [25 June 2015]). Our energy demands increase continually, while the need for new and clean energy sources makes solar the fastest-growing energy technology. The PV industry is one of the most growing and innovative industries worldwide. Despite the current energy scenario, it is estimated that over the next 30-40 years the sun will provide 25% of the global energy needs. Therefore, it is important to explore the potential of energy performance of envelopes with BIPVs, within the urban environments (Lüling, 2009).

The term 'photovoltaic' has been in use since 1849. It derives from the Greek word "phos" meaning 'light', and 'volt', the unit of electro-motive force, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the electrochemical cell - or battery (Smee, 1849).

Photovoltaic cells utilise the electromagnetic radiation emitted by the sun. Photons hit the photovoltaic cell and cause electrons to be ejected from the atoms of the material in the cell. The light causes other substances in the cell to accept those electrons that flow through a conductor, generating electricity (Baggs, 1996).

The use of BIPVs in the urban environment has the potential to help towards this approach. Photovoltaic energy technologies and innovation techniques for integration on the building envelopes, can help to drive growth in many levels (design, construction, industry, projects etc), while leading to the creation of thousands of new jobs.
(http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm [25 June 2015]).

Smart materials and intelligent environments

Material is a universal language of culture and civilisation that carries a reciprocal relationship between the material itself and humans, affecting their psychology (Mori, 2002). It can be accessed and understood by everyone. It carries with it information about its place of origin, history, performance, economic value and its life-cycle (Mori, 2002).

Millions of years ago, stone and wood created two very different building types (stonework and timber-frame buildings). These two typical construction materials were completely opposite in their construction methods, hence created facades that were fundamentally different in terms of aesthetics and function. An integrated PV system creates a contemporary design language that has a morphic flexibility and a modest technological existence (Lüling, 2009).

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The relationship between architecture and materials had been quite clear until the Industrial Revolution during the 18th century. After this, architects began to experiment with engineering materials, with the widespread use of steel and glass. Nowadays, CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) technologies allow an unprecedented range of building facades and forms. Smart materials are often considered to be a logical evolution toward a more selective and specialised performance. Smart material performances can now be engineered and perfected according to demand, while their properties can be modified in order to replace conventional building materials (Addington and Schodek, 2005).

Building as energy generator

Building envelopes are being affected by environmental factors, such as noise, wind, precipitation, air temperature and radiation from the sun. Energy-efficient building envelopes affect the amount of energy used for heating, lighting, cooling and ventilation systems, as well as the size of technical building management systems. These in turn reduce energy consumption, pollution, investment and operation costs (by reducing the payback time of the initial installation cost). Depending on its location, the building envelope provides the potential for the use of renewable energies, in order to generate energy at the point of demand (Schüco, Issue 05, 2005).

The integration of solar energy in buildings has an impact on its form. Technology affects architecture, offering a wide range of proven high-performance solutions. But there is a gap at the intersection between architecture and solar technology, in order to achieve what is known as "solar design" (Schittich, 2001). For the integration of solar energy system technologies, the building envelope is the most important interface between architecture and solar technology. To create a technical and energy-efficient design (that is also aesthetically convincing), requires a combined knowledge of the technological functional mechanisms, an understanding of building typologies and the ability to translate all the above into an executable design (Schittich, 2001). The potential of PV use in architecture is shown in Table 1.

PV generations and efficiencies

During the last decade, photovoltaic products show an average growth of around 40% per annum, while manufacturing costs decrease on a steady rate. Typical solar cells are made from silicon or other high-tech materials. Their technologies are divided into three (3) main categories, known as 'Generations' (Green, 2006), as shown in Figure 1.

First Generation (1G): This technology has matured and is widely used, representing approximately 80% of the worldwide solar cell production, in 2014 (NREL, 2014). They are based on silicon wafers (Figure 2), each of which can produce 2-3 Watts of solar electricity. These cells are assembled in large-area solar panels, using a single layer p-n junction (the positive/negative boundary or interface between two types of material, inside a single crystal of semiconductor). Their production costs are still relatively high compared to the overall energy output (Green, 2006).

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Advantages of photovoltaics	Disadvantages of photovoltaics
No need for fuel	Battery or grid storage required for night-time use
No pollution (after manufacturing)	
The energy source (sun) is free and available everywhere	May need to be used with another power source (or grid connected instead)
Reliability (no moving parts)	Relatively high initial capital cost for modules (though this is reducing fast)
Noiseless	
Maintainability	Toxic and corrosive chemicals used in manufacture
Long-life performance	
Short time required from planning to installing the system	Cleaning required for optimum performance
Once installed, using them costs little over their lifetime	Manufacture of cells controlled by a small number of large corporations
Safe alternative to more combustible energy sources	Legislation can sometimes become a burden for investors and stakeholders
Can be used in both new and existing building envelopes	
Visually unobtrusive (variety of products, colours and integration techniques)	
Modular and expandable	
Flexibility in terms of use or application	

Table 1. The potential of photovoltaics (author's own)

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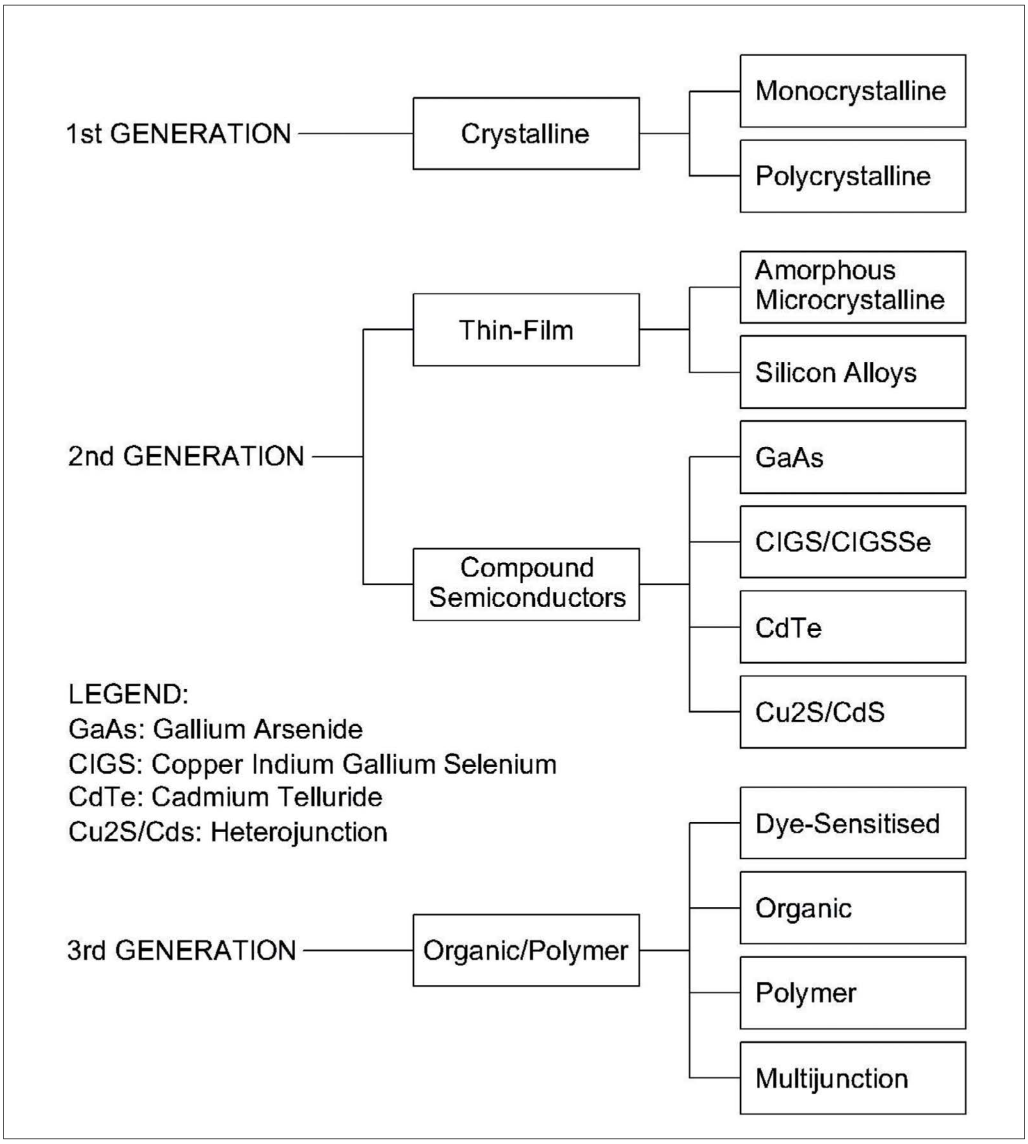

Figure 1. Main current PV technologies.
Source: Sullivan, 2013.

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Second Generation (2G): This generation of PV materials is based on the use of thin-film deposits of silicon and a wide range of compound semiconductors, minimizing the mass of material required for every cell and the total weight of solar panels. This contributes to the reduction of manufacturing costs, making this technology suitable for use on light or flexible materials, even textiles. Thin-film technology offers significant advantages, such as the increased size of the manufacturing glass sheet units, by about 100 times larger than silicon wafers. On the efficiency front, this technology steadily closes the performance gap compared to crystalline silicon cells. Second generation BIPV systems replace parts of the building envelope and partially take over its functions (Green, 2006).

Third Generation (3G): These cells are novel technologies designed as low-cost and high-performance ultrathin photovoltaic products. The new devices include photoelectrochemical, organic or polymer (Figure 3), dye-sensitized and nanocrystal solar cells. These concepts are promising, aiming to achieve high-efficiency devices by the implementation of 2G (thin film) deposition methods and the usage of nontoxic and not limited in abundance materials (Conibeer, 2007). This generation of cells is not available on the market yet, but the solar industry is working with researchers to develop prototypes which could be in-line manufactured in order to provide a cheaper alternative to typical PV systems. This expectation is feasible over the long term because alternative solar cell technologies require less material input and can be made using less expensive production methods (Lüling, 2009).

Ravi Silva (Advanced Technology Institute at the University of Surrey), recently outlined the definition for a new 4th Generation (4G) of photovoltaic technology, based on 'inorganics-in-organics'. It offers improved power conversion efficiency to current 3G PV cells, while maintaining the low-cost base and flexibility of conducting polymer organic films with the lifetime stability of novel inorganic nanostructures. (Silva et al, 2013). The efficiency range of the PV generations is shown in Table 2.

PV integration

The installed PV components are expected to become an integral part of the building envelope, to fulfil functional and structural tasks, while replacing typical building materials, in order to minimise the cost of the initial installation. The integration of PV systems must guarantee that the installation does not conflict with the requirements and characteristics of the building envelope, but complements and supports them in terms of architectural and structural integration (Figure 4). When it comes to the task of integration, many buildings display a lack of sensitivity or an absence of character, resulting in a poor adaptation into the building structure. This illustrates the necessity to consider design principles, while dealing with the more practical and technical aspects of the construction process. Decisions with regard to detail and component dimensions, design of connecting geometries and profile sections, all influence the visual appearance (Figure 5) of the building envelope and must be evaluated as to their impact on the structural layout and overall integration (Schittich, 2001).

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Figure 2. Typical silicon wafer PV cell.
Source: Lüling, 2009.

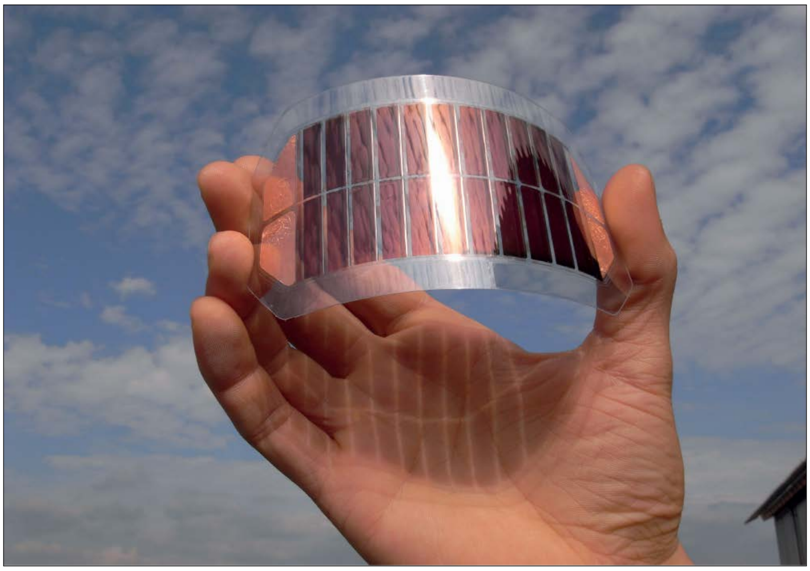

Figure 3. Third Generation (3G) organic PV cell.
Source: Lüling, 2009.

Table 2. Efficiencies of PV materials and technologies.
Source: NREL, 2014.

PHOTOVOLTAIC (PV) MATERIALS AND TECHNOLOGIES	THEORETICAL EFFICIENCY (CELL)	LABORATORY EFFICIENCY (CELL)	PRODUCT EFFICIENCY (MODULE)	AREA NEEDED per kW (MODULE)
1st GENERATION PV (Crystalline Silicon)				
Monocrystalline Silicon (m-Si or c-Si)	29%	21-28%	14-20%	~ 6m2
Polycrystalline Silicon (p-Si or m-Si)	25%	17-20%	12-17%	~ 7m2
2nd GENERATION PV (Thin Film and Compound Semiconductors)				
Amorphous Silicon (a-Si or a-Si:H)	27%	12-13%	6-10%	~ 13m2
Silicon Alloys (a-SiGe, a-SiC)	29%	13%	9-15%	~ 9m2
Gallium Arsenide (GaAs)	31%	25-26%	26-28%	~ 4m2
Copper Indium Gallium Selenium (CIGS)	29%	16-17%	12-14%	~ 10m2
Cadmium Telluride (CdTe)	31%	10-16%	10-12%	~ 10m2
Heterojunction (Cu2S/CdS)	24%	10%	N.A.	N.A.
3rd GENERATION PV (Advanced Thin-film, Organic and Polymer)				
Dye-sensitised (DSSC, DSC or DYSC)	25%	10-13,4%	2-5%	~ 30m2
Organic (OPV)	30%	10-12%	2-4%	~ 30m2
Polymer (solid or liquid)	10%	2,5%	N.A.	N.A.
Multijunction (CPV)	63%	44,7%	N.A.	N.A.
4th GENERATION PV (Inorganics-in-Organics)				
Inorganics in-Organics (HTL/ETL)	18%	5-9%	N.A.	N.A.

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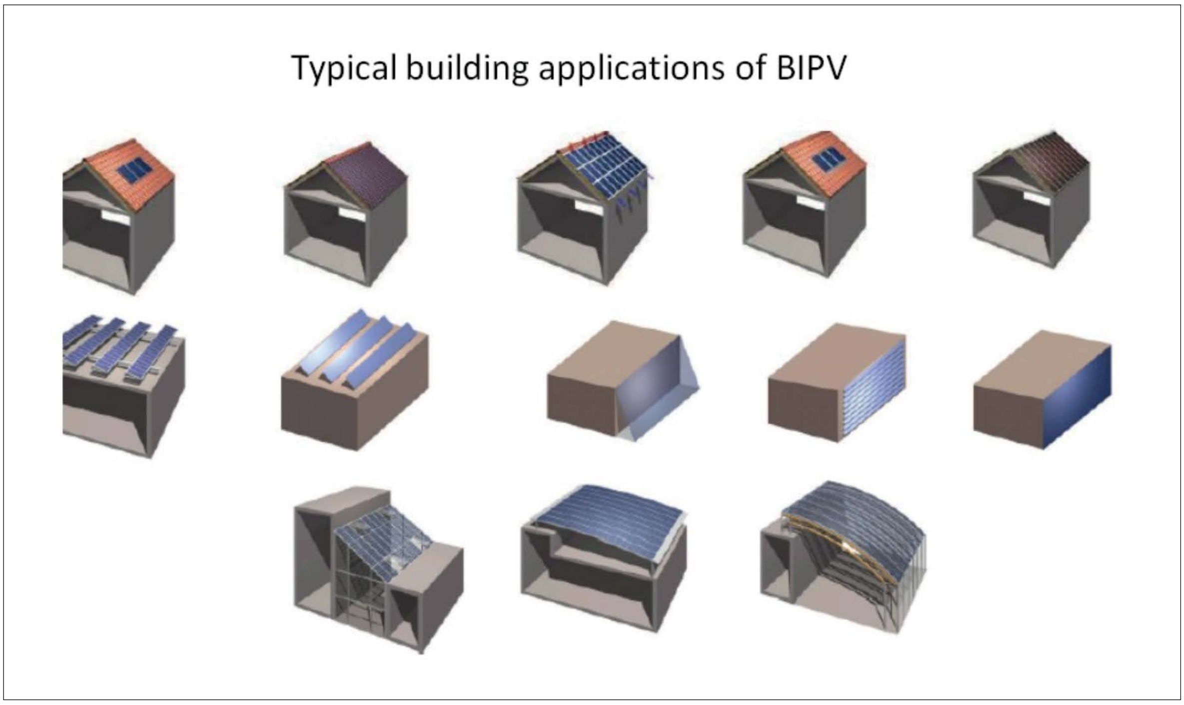

Figure 4. Typical Building applications of BIPV.
Source: Lüling, 2009.

Figure 5. Greenpix (Beijing) Zero-Energy Media Wall, with the largest color LED display and the first polycrystalline photovoltaic cells system, integrated into a glass curtain wall
Source: http://www.archdaily.com/245/greenpix-zero-energy-media-wall [27 June 2015].

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The solar cells are clean, safe and efficient devices, suitable for electricity generation on building envelopes (Figure 6). PV systems can be successfully integrated into the envelope of most building types, displacing standard building components. In retrofit applications, PV systems can also be used to camouflage unattractive or degraded building exteriors (Moyra, 2012). Photovoltaics (PV) can be used in any area of the building envelope that is exposed to direct sunlight (Weller, Hemmerle, Jakubetz and Unnewehr, 2010).

The building envelope is also known as shell or skin. The building skin plays an important role on the building itself, as it protects the occupants from the elements, defines properties and creates privacy. The building skin (especially the facade which draws more attention than any other building component) is a calling card for the building and its designer. Set into an urban environment, it characterises the face of the city. Sometimes, the facade is separated from the load-bearing structure and becomes a curtain or an artificial skin. This functions as a multi-layered system which responds to climate, affects energy consumption and additionally could be used to produce energy at the point of demand, the building itself (Schittich, 2001).

The International Energy Agency (IEA) has implemented several programs to investigate the potential application of the PVs in buildings, with the participation of many developed countries. In the program "Task 7" (2001), working groups of architects managed to identify the characteristics of a successful integration. They resulted on the criteria which set the baseline for integration of a certain architectural quality. These are:

Natural integration, referring in the way a PV system is used as an integral part of the building envelope, while the PV system completes the building.

Architecturally pleasing, relating to how the PV system highlights a good design. This is a fairly subjective matter, which can be formed over time by experience in the design process.

Good composition of colours and textures, which need to be in balance with the other external construction materials. For this reason, BIPV products are being manufactured with specific technical characteristics, in order to achieve the desired transparency, shape and colour.

Grid and dimensional composition, which should be in harmony with the proportions and grid of the building.

Contextuality, meaning that the applied PV system is in consistency with the architectural concept and the overall image of the building.

Well engineered, which refers to the elegance of the design details, but not about the watertightness of the components.

Pioneering and innovative design, asking for architectural ideas (smart products) to enhance the PV market, adding value to the buildings (Figure 7).

Along with all the theoretical considerations, the main contribution of this paper is to

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Figure 6. Multi-colored transparent PV façades.
Source: Haberlin, 2012.

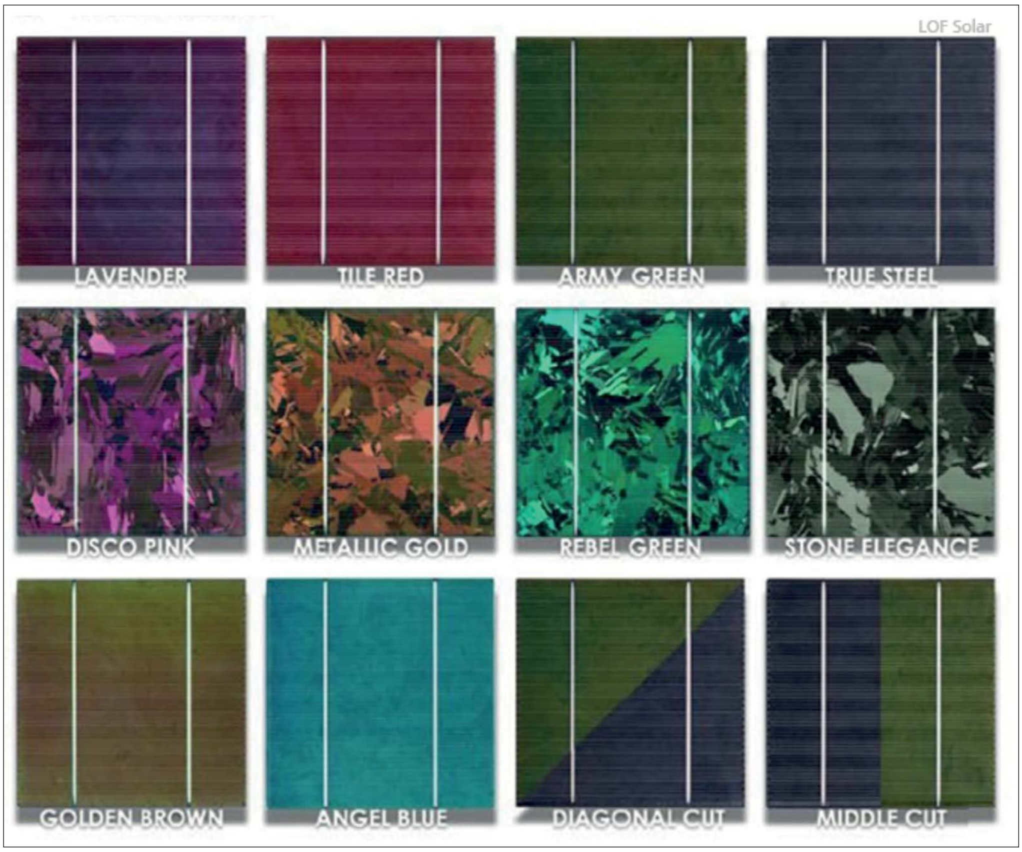

Figure 7. Color variety of PV cells.
Source: http://www.soltecenergy.com/PV.html [27 June 2015].

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understand the significance of proper installation of PV products on the building envelope, by replacing conventional materials. This helps to reduce the initial cost of installation and hence minimize the payback time of the investment. Figures 8, 9, 10 and 11 demonstrate installation detailing on a typical dwelling. A series of construction details have been created, by implementing the IEA criteria for architectural quality (author's own).

The installation of photovoltaic systems on building envelopes is a new concept in architecture. But most of the solar panels are applied on top of the building envelope (over roof tiles or external cladding etc), which is a rather expensive solution, usually without any aesthetic quality, known as Building Applied Photovoltaics (BAPVs). On the other hand, Building Integrated Photovoltaics (BIPVs), replace conventional materials on the building envelope, hence minimizing the initial installation costs. A series of typical architectural construction details is produced to assist the building industry to get it right on site. They offer the ability to design unique envelope components with integrated PVs, guide the builder on site and ensure effectiveness and optimum energy output, without any aesthetic compromise.

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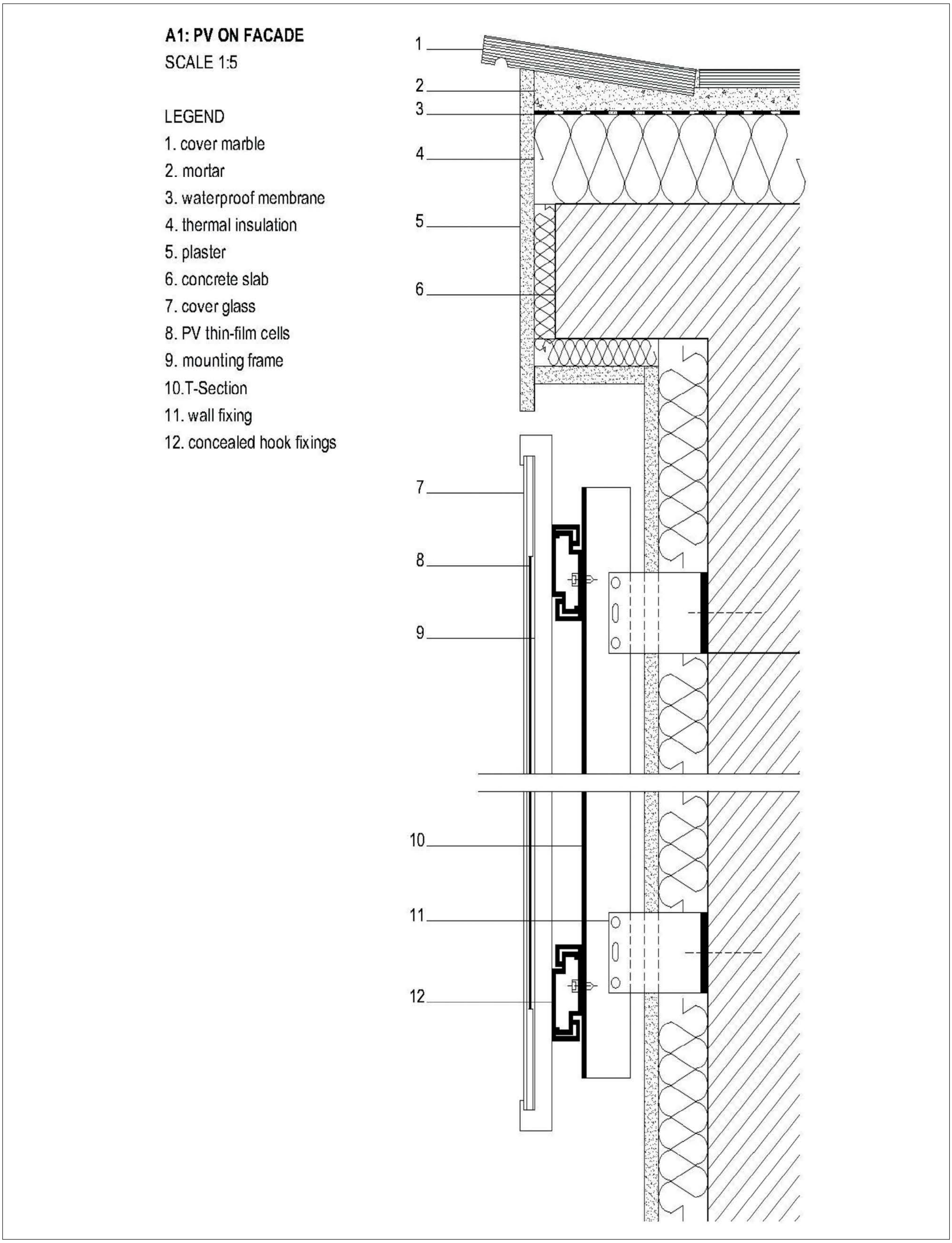

Figure 8. PV cells on a typical façade (author's own).

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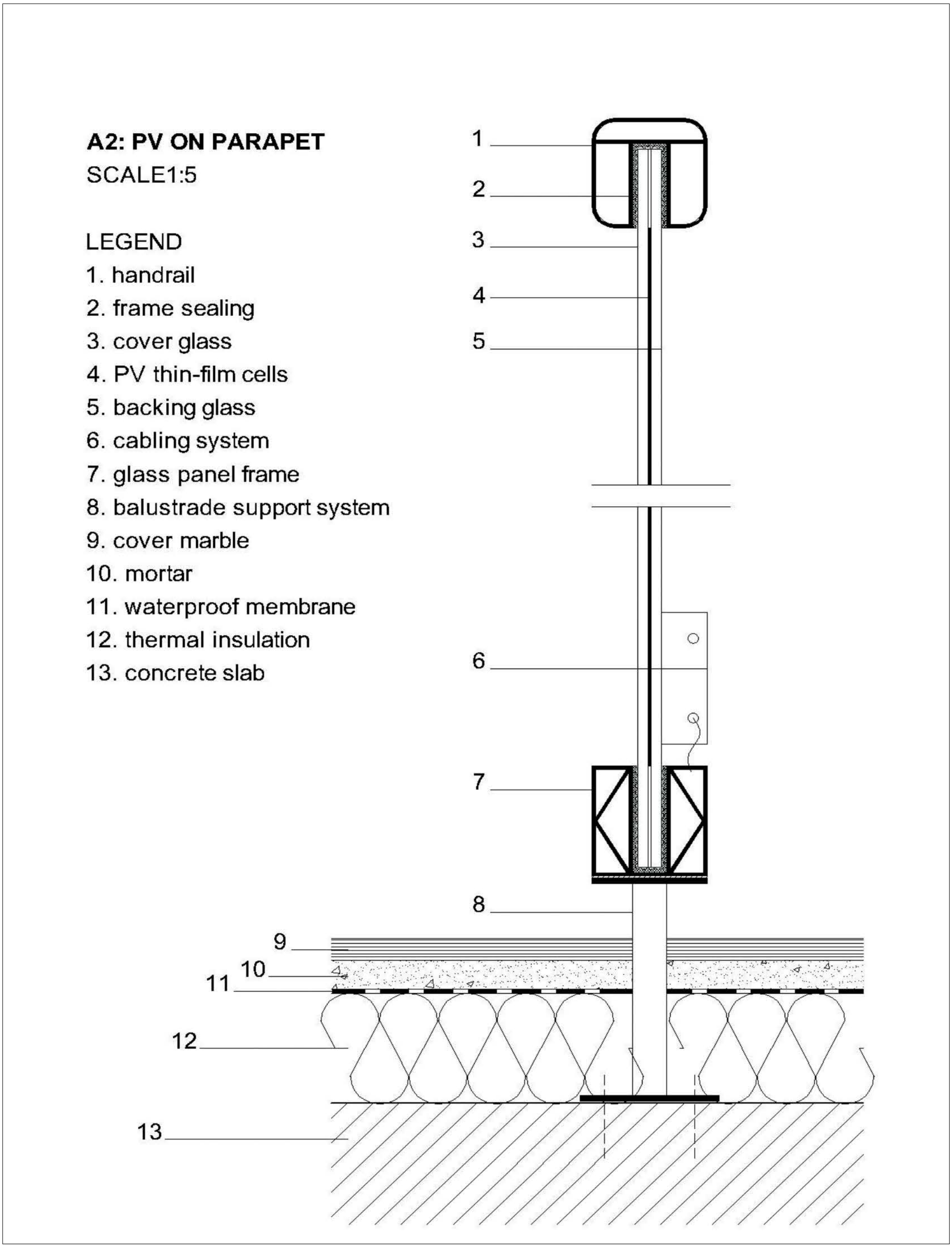

Figure 9. PV cells on a parapet (author's own).

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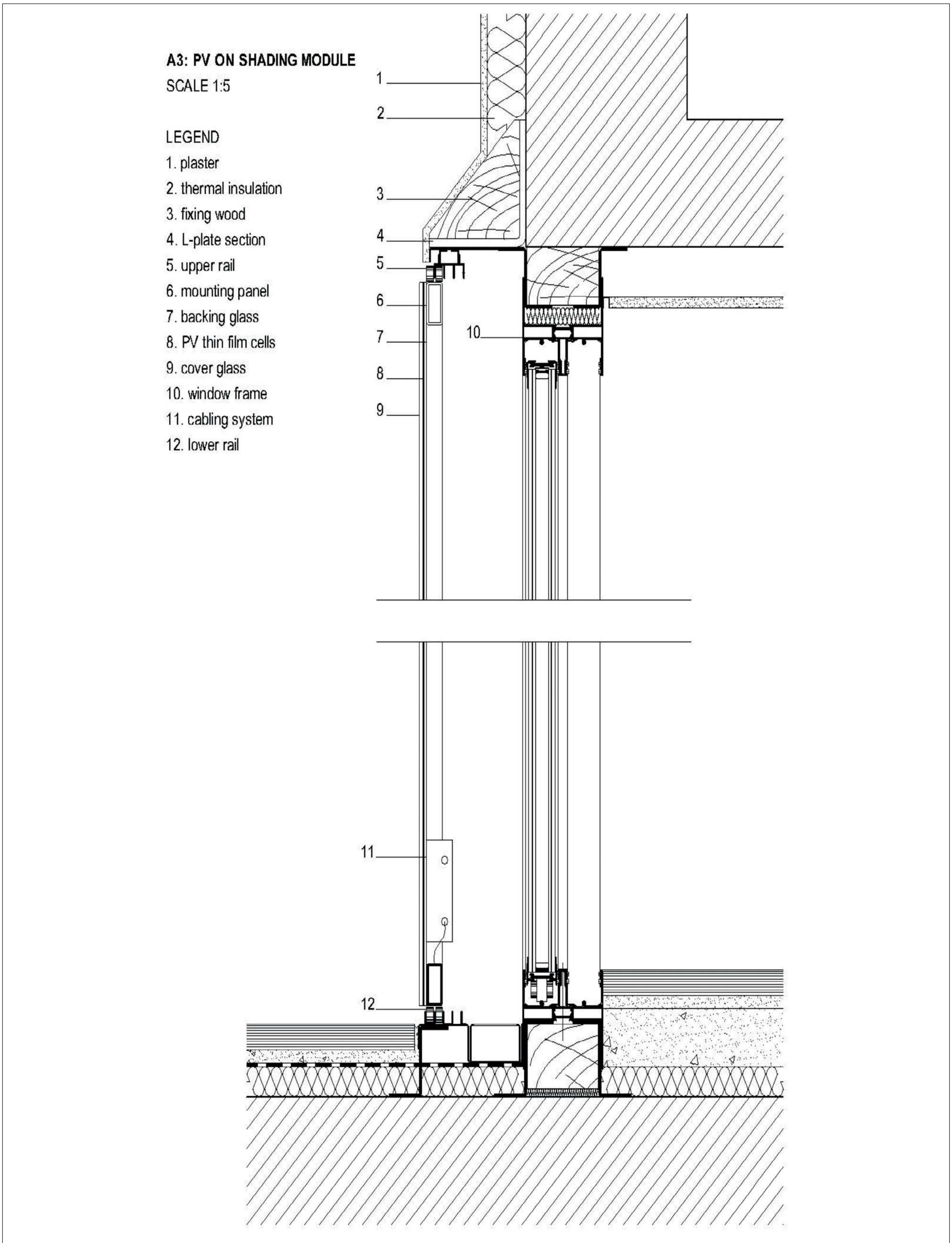

Figure 10. PV as a shading module (author's own).

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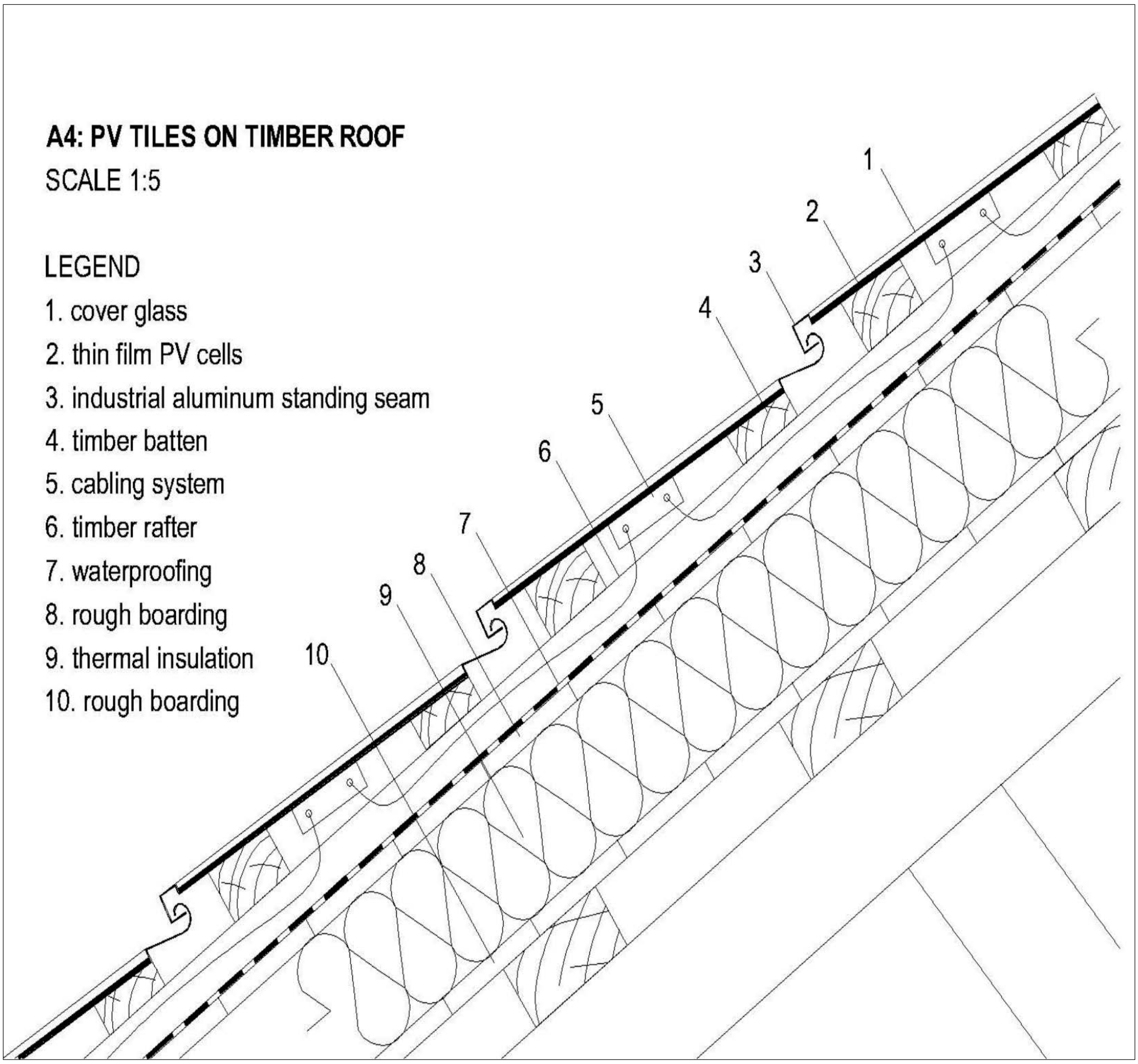

Figure 11. PV tiles on timber roof (author's own).

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SWOT analysis of BIPVs

The SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of BIPVs, provides an effective means of evaluating the current situation, understanding the potential and identifying future development opportunities in the urban environments (Sullivan, 2013).

Strengths
• BIPV offers larger collection surfaces and allows for more building types to be suitable for solar electricity generation. The technology applications in roofs and facades in particular dramatically increase the surface area of the building envelope available for electricity generation.
• BIPV is more cost effective than conventional Building Applied Photovoltaic (BAPV) solutions, as typical building materials (and the labour costs for installation) are being replaced by suitable PV modules.
• The manufacturing costs and market prices of PV technologies decline steadily. This combined with the improved performances of PV cells and inverters could make BIPVs the most attractive option for electricity generation in the built environment.
• BIPV can be functionally and visually integrated into the building envelope, making a low aesthetic impact or even creating a new challenging architectural language. These factors can improve the perceived value of the system and increase the scope of buildings that would consider installing a PV system over that of a conventional system (Sullivan, 2013).
Weaknesses
• Currently, there are no standards and certification material to support BIPV, which leads to difficulties for practitioners to implement solutions, creating a 'grey zone' of regulatory requirements.
• BIPV presents additional complexity in building design. That is, requirement for additional materials (i.e. heat-resistant layers), design of modified conventional products (i.e. window frames) and additional design elements (i.e. the circuitry required for electrical connection).
• BIPV requires a great number of different participants to carry the process through from design to installation or integration (as it is described in the outcomes of the IEA Task 7 investigations 16 "active involvement of urban planners, architects and building engineers is required").
• BIPV systems are significantly more complex to design than BAPV systems, due to a combination of factors (except those mentioned in the point above), such as orientation and shading impacts. For instance, BAPV solutions are optimized and designed to minimize shading impacts, which reduces the power output, but this is not always achievable with PV systems integrated into the building envelope. Shading reduces energy generation because PV cells derive the majority of the energy from direct insolation. Partial shading of strings could lead to irregularities in power output and to a decreased efficiency (Sullivan, 2013).
Opportunities
• BIPV holds a small segment of the PV market at present. However, this segment is rapidly expanding, especially as a retrofit solution for existing buildings.
• BIPV can create energy generator buildings, achieve neutrality (zero-energy buildings) or transform them into net exporters of solar electricity, due to the possible increase of the system sizing, thus reducing emissions for the building sector.

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• The increased utility costs will inevitably put ongoing pressure towards the development of alternative power sources. BIPV can be installed in a way that power is delivered over a broader spectrum of the day, potentially allowing energy generation to better match on-site supply requirements and hence offset poor Feed-in-Tariffs (FiTs) scenarios.
• The parallel development of technologies may facilitate and accelerate the adoption of BIPV technology, creating tangible improvements in the financial aspects (Sullivan, 2013).
Threats
• As with any developing technologies there are many factors that may threaten the adoption of BIPV into mainstream practice. Depending on how the energy industry and government respond to the changing circumstances, there may be an increased risk for PV manufacturers and installers, with negative impacts on market development, as represented by declining FiTs.
• Failure to establish common standards in the industry for BIPVs, could result in ongoing challenges for architects and constructors to incorporate the technology into their projects. Without these standards, the users are not easily convinced about the potential of PV systems for electricity generation.
• Due to the limited standards relating to the specific conditions of BIPV, there may be as yet unrealized hazards from the integration of PVs into the building envelope.
• BIPV requires the collaboration of a number of professionals and specialties within the construction and energy sectors, a fact that raises the bar for adoption of this technology (Sullivan, 2013).
The different stages of BIPV implementation in building envelopes, involves a variety of stakeholders which face a series of challenges, as shown in Table 3.

Conclusion

Solar, as an energy source, has the theoretical potential to cover our energy demands, as it is free and available almost everywhere. Photovoltaic technology converts radiant energy into electricity (hence minimizing the dependency on fossil fuels) and is capable of reducing energy consumption and CO_2 emissions in the building sector. BIPV in particular, offers the advantage of architectural integration in the building envelopes, hence minimizing the payback time of the initial installation costs, by replacing conventional building materials. Solar design transforms buildings into energy generators at the point of demand, towards a zero-energy urban environment. Detailing is crucial to understand integration techniques, while complying with the architectural criteria, set by IEA. A series of typical construction sections assists architects for best installation methods, while achieving maximum system performance

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STAGE	STAKEHOLDER	CHALLENGE	MEASURES
Design concept	Developer	Lack of knowledge for BIPV solutions and the use of relevant software	Improved communication of available products and use of easy to use software/tools
	Architect		
Detailed design	Developer	Broad range of BIPV technologies	Formalization of BIPV standards
	Architect/building engineer	Uncertainty of regulatory requirements	Creation of BIPV regulations and typical construction drawings
	Services engineer	Poor design principles	Establishment of designs to assist implementation
Building construction	Building engineer	Unclear delineation between trades in installation	Connecting BIPV technology solutions to discrete trades
	Constructors	Poor or missing skills in implementing systems	Expansion of training available for trades
	Electrician		Amendment of relevant standards
PV integration	DNSP (Distribution Network Service Provider)	Poor regulatory support for connection of large systems	Improvements to energy system regulations to streamline grid connection
	Electrician		

Table 3. Critical decision points in various stages of PV integration into building envelopes with suggesting measures to overcome any hurdles. Source: Sullivan, 2013.

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Maria Voyatzaki is associate professor of architectural design and building technology at the School of Architecture of Aristotle University of Thessaloniki (Greece) since 2001. Her PhD at the University of Bath, School of Architecture (1996) supervised by Chris Williams and Edmund Happold investigated the design process of non-standard architecture entitled "An Insight into the Design Process of Unconventional Structures". Her research and respective published work focuses on the integration of an idea and its materiality aiming at enhancing the quality of architecture through this integration. She has taught for over 11 years in the United Kingdom and for a semester in Denmark (Aarhus School of Architecture). She has organised and participated in a great number of international student workshops and international conferences for architecture educators. She has been the editor of over 25 volumes of international conference proceedings. Her work is published in international journals and conference proceedings. She is the Coordinator of the European Network of Construction Teachers since 2001. She is a free-lance architect with experience in practices like Buro Happold. She is also the coordinator of a number of European funded programmes on architectural education, with the most recent one being the two-year funded Lifelong Learning Multilateral Project, continuum: from the school lab to the factory workshop that investigates new pedagogic protocols for teaching students on a file-to-factory logic. She is the Editor-in-Chief of e-archidoct (http://www.enhsa.net/archidoct/). She has been a Council Member of the European Association for Architectural Education (2000-2007). She lectures abroad and sits at design juries around the world. She is a chartered architect and member of the Royal Institute of British Architects and ARB.

Mark Waghorn is an architect with over fifteen years post-qualification experience, and has been a successful practice director for over ten years. He studied architecture at Cambridge University and the University of North London. He worked for seven years at DGA Architects, becoming Associate in 2003. During this time he gained experience in private, commercial and public sectors, with projects ranging in scale from residential refurbishments to urban design. In 2003, Mark was appointed Project Architect for Christ Church Primary School in Chelsea. On completion in 2005, this refurbishment and extension to a historic Victorian school received the Environment Award from the Royal Borough of Kensington and Chelsea as an outstanding contribution to the urban environment. From 2006 to 2010 Mark co-directed Waghorn Gwynne Architects. Here, Mark continued developing his passion for sustainable design, producing ground-breaking designs for a number of carbon-neutral houses around the country. In 2010, Mark founded Mark Waghorn Architects in order to further develop his design philosophy based on the responsible use of materials and resources to create comfortable and inspiring spaces that actively enhance the quality of the environment. He moved to Wales in 2012, inspired by the country's goal to become a One Planet nation within a generation. As a Director of the Calon Cymru Network he is contributing to radical proposals for sustainable economic regeneration in rural Wales, based on One Planet and low impact principles. He is also currently undertaking a PhD research project on the process of making do in ad hoc self-builds in rural Wales.

Anthie Verykiou was born, lives and works in Athens. She is a PhD can-

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didate at the School of Architecture, NTUA. Her doctoral research is supported by the program: IKY Fellowships of Excellence for Postgraduate Studies in Greece - Siemens Program. Her studies are including a Diploma Degree in Civil Engineering at DUTH and Architect Engineering at NTUA and a Master of Philosophy Degree from the Inter-departmental Postgraduate Program "Design-Space-Culture" of the School of Architecture of the NTUA. She has worked as Teaching Assistant for the Design Studios of the School of Architecture of the NTUA and specifically on Urban Design and Public Spaces Design Studios. She has participated as a tutor at workshops with various subjects emphasizing on Landscape approaches in Urban Design. She has presented her research in Conferences in Greece and abroad.

Xi Deng is a structural engineer with a B.Eng in Civil Engineering from Chongqing University, China (2010), and an architectural engineer with a MSc in Architectural Engineering from Politecnico Di Milano, Italy (2012). His current PhD in Architecture is supported by a Cardiff University International Scholarship. During his Civil Engineering studies he focused on engineering with aspects of architectural design. He was awarded the honour of being selected as one of the 'Ten Most Outstanding Youths of Chongqing University', appearing in an official interview by Chongqing University Monthly. After graduating from Chongqing University he was admitted to the MSc of Architectural Engineering at Politecnico Di Milano with a full scholarship in 2010. The experience of project designs, design workshops and design competitions in Europe improved his architectural design skills and deepened his understanding of the relationship between architecture and engineering through the whole building process. He has a general research interest in Low Carbon & Sustainable Design and is trying to build an effective bridge for academic communications between UK and China, and to increase the development of Low Carbon & Sustainable City in China.

Oluwafeyikemi Akinwolemiwa is an architect with interest in integrating plants within buildings for passive cooling and sustainable farming in the tropics. other interests include building simulation and generating achievable policies for practicing sustainable architecture. Other experiences include practice in Landscape architecture and Lecturing.

Stefanos Gazeas was born in Thessaloniki, Greece. Even as a teenager, he got involved in his father's business, who was a civil engineer and run his own practice in Kastoria. He studied Architecture at the University of Nottingham, UK (B.Arch 1996 and Dip.Arch 1998 with honors). The following year, he was granted a Master's Degree in Bioclimatic Architecture in Office Buildings (MA 1999). In that same year he started work in Thessaloniki for a renowned local architect and constructor. During 1999-2003, he also collaborated with several engineers for housing projects, sports centers, landscaping and energy efficiency in the building industry. In 2003, he moved into the public sector, being employed as an architect for the Technical Department, at the Municipality of Veria. Currently, he is the Head

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of the Planning Dept. and also a PhD candidate at the Aristotle University of Thessaloniki (AUTH), researching the performance of Building Integrated Photovoltaics (BIPVs). During 2004-2011 he served as an assistant lecturer for several modules, in the Architectural Dept. of AUTH. Stefanos is also active in the publishing world, having written a few articles related to his studies on photovoltaic technology. In his spare time, he is an amateur car designer, model car collector and restorer of "young-timer" historic vehicles, taking part in classic rallies.

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Information //

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Submission Policy

Archidoct is published two times a year, in July and January. The official language of the journal is English. Submitted manuscripts for review should not exceed 4500 words, including abstracts, references and image captions. The referring system will be the Harvard System. Text should be saved in a Microsoft Word or RTF file, while the supporting visual material (images, diagrams, sketches, tables and so on) should be sent as TIFF files with a resolution of at least 300 dpi. All visual material should be clearly indicated and numbered in the text, along with the respective image captions and credits. Additionally, all manuscripts should be submitted in A4 "camera-ready" .pdf format that gives an idea of how a finalized version looks like.

Archidoct only accepts manuscripts from PhD students. In order for an article submission to be considered for publication, the student must be a registered and active member of the ENHSA Observatory (www.enhsa.net/main/observatory), a PhD research portal created to facilitate communication and meaningful information exchange between architecture doctoral students.

Reviewing policy

The peer reviewers are all confirmed educators of architecture coming from different educational backgrounds, with different specialisations and expertise that share the common interest of their doctoral students: to encourage them to publish their work while improving their thinking processes towards academic research writings. Each submitted article is reviewed by two members of the journal's Scientific Committee anonymously.

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