Reduce, Reuse, Recycle, Recover – Rethink!

Exploring Sustainable Alternative Materials in Construction

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ABSTRACT

The construction industry is one of the main resource consumers and refuse generators, creating various environmental, social and economic impacts. The world and especially its resources are being overexploited; the rapid urbanization, the demand for materials and resources, and subsequently the production of inorganic waste that accompany it, make it crucial to adopt an architectural approach focused on sustainability.

Society still follows a linear mentality, based on extraction, production and consumption, leading to the inevitable discarding of materials and products. However, this should be replaced by a circular process, where the building construction follows the four R's principle: Reduce, Reuse, Recycle and Recover. This promotes a metabolic thinking, where no material should ever be seen as waste. Refuse is an ever growing resource that is being overlooked and suppressed by society, becoming, that way, an almost invisible problem and possible solution to the resource problematic.

The challenge is to change the perception of what is waste: from materials that end up in the garbage, to natural ones whose potential is being ignored. The aim is to introduce alternative construction materials as a viable solution for the future. To conclude, a project is developed – "Sustainable Urban Unit" – resulting from this research, as a solution for the above mentioned problems, showcasing the introduced materials' potential. The project is to be applied in developing countries, where population growth and urbanization rates estimates are the highest and which are least prepared to face this growth.

Key-words: Sustainability, Alternative Materials, four R's, Waste, Sustainable Urban Unit

1. INTRODUCTION

Currently society is exploiting and consuming natural resources at an extreme rhythm, not acknowledging its finite character. The current attitude of "Take, Make, Waste", regarding the exploitation of raw natural materials beyond their restoration capacity, has caused critical damages to the environment. The ever-increasing demands on our planet's natural resources is caused by the rapid growth of urban population and the accompanied construction necessity.

To solve the current crisis, a new sustainable approach is needed – one that goes beyond preventing further damages, but actually focuses on improving them, a post-sustainable approach. "Reduce, Reuse, Recycle and Recover" should become the new guideline of the construction industry. It is based on a responsible and balanced material use, where society's and the city's outcome – waste – is never regarded as such, but as a never ending resource.

Approaching these main themes – resources, materials, construction and waste – the present work intends to create awareness amongst the public to a possible future solution to the current problematic. The study was based on existing and selective research, the analysis of several reports and publications, presenting case studies and examples to illustrate various possibilities of recovered, reused and recycled building materials that reduce our need to further exploit natural resources. An architectural model is developed to demonstrate the potential of waste and alternative materials, as well as the importance of an adequate and sustainable construction process, that allow for a future closed material loop behaviour. Architecture is inevitably linked to materials and as such, should introduce bold alternatives, rethinking the present to come up with solutions for a post-sustainable future.

2. SUSTAINABLE CONSTRUCTION

Sustainable construction has emerged through a variety of concepts since the 20th century and developed a great deal since then. The common denominator amongst them are the role of material and energy efficiency. To summarize: both resources should be used in a way that promotes their intelligent consumption, prioritizes those of a renewable nature (incl. reused or recycled), minimizes the production of wasted resources and other environmental impacts (i.e. pollution), not dismissing the present and future needs of the users. When addressing sustainability in connection to the construction industry, one needs to address the whole built environment (the city), its current problems and future trends.

The conversion of the Earth's surface to urban uses is one of the most irreversible human impacts, for it represents a demographic, economic and land transformation process, that also lead to environmental problems (CO_2 emissions, waste production, reduction of biodiversity etc.). A city's impact will reach the lives of many generations to come, thus it is integrally linked with sustainability. The world is becoming increasingly urban, both in terms of human population and the earth's surface, more than ever before. More than half of the global population is concentrated in urban settlements (DESA, 2015). It is predicted that by the middle of this century, in 2050, about 70% of the population will live in these roughly 2% of the earth's surface (DESA, 2015). The global population is predicted to reach 9.3 billion in 2050, from which 6.3 billion will be the urban, mostly concentrated in Asia (52%) and Africa (21%). The developing world is where there is going to be a higher development of (Mega-) cities. By measuring the humanity's ecological footprint in comparison to the earth's biocapacity, one can conclude that by 2050, humanity will need two planets to support its population. This increase in global population will continue to grow, with in 2100 an expected number of 11 billion people worldwide: is this sustainable?

The rising of the urban population comes to prove that the future is urban. The urban realm has always had a clear identity and purpose, changing with the shift in the needs of humanity. Thus, the city of the future must contribute to solve society's current problems - environmental and resource challenges.

On the one hand, there already exist some concepts to promote a sustainable construction and urban development. One such phenomenon is "Urban Mining". This promotes the city to be seen as a resource, a raw material mine created by humans. The concept is simple: because material resources for construction are becoming increasingly scarce in the place of their natural origins, the demand for building construction is growing, already used or disposed of products can be reclaimed and retrieved from buildings, infrastructure or even landfills. In the case of buildings, they could even be designed to allow such a procedure in the future. This means, designing for urban mining: making it possible for building components, elements and materials to be easily recovered, without any or the least damages possible. This is known also as design for deconstruction or disassembly of a building, avoiding demolition and promoting the resource reuse and waste reduction.

On the other hand, visions of the future cities are and have since long been developed by architects, engineers and other artists. The idea is often described as utopic. But a new shift in urbanism is needed: today cities consume 75% of the earth's resources and produce about 80% of the total carbon emissions, with buildings and transports being the largest contributors (United Nations Human Settlements Program, 2012). This is not a path to keep following, for a change is needed due to all the alarming challenges our society is facing and it is undeniable that overpopulation, excessive resource consumption and resulting environmental issues are classified as such problems. Utopia is a necessary paradigm: it displays a kind of maximal answer to existing problems, without any limitations but our imaginations. The expressing of solutions, even if they may seem extreme or radical, are needed to solve n extreme predicament. Our future basically depends on the extent of our envisioned solutions, what one cannot foresee or imagine means one is unable to prepare for such an event. This stated: What is the key for ecological cities? When asking this, the visualization of such an urban design is inevitable, this includes the interconnection between urban plan and systems and the physical construction of buildings.

3. BUILDING TOWARDS MATERIAL

A complete understanding of the importance of building materials in the sustainable context must involve the full knowledge of which have been the consequences caused by raw material extraction and production. Additionally, in the construction field also lies the opportunity for a building material choice that considers sustainability. Even though there is no universally accepted definition of what are sustainable building materials, the ones with the following characteristics should be privileged: non-toxic, provided from renewable sources, promote a close-loop cycle and a life cycle thinking, as well as associated with low embodied energy.

In this context, the contribution of the construction sector is most relevant. One of the most pressing environmental issues is the exhaustion of non-renewable raw materials. The construction sector is responsible for the most extraction of material resources worldwide, being responsible for approx. 40% of raw material consumption. There are a range of well-known impacts related to processes of the building industry, such as global warming, ozone depletion, loss of natural habitat and biodiversity, soil erosion, the release of toxins and pollutants, etc. A serious and direct consequence of the resource exploitation undergone by the construction sector is the production of waste materials. The primary process for disposal of waste is still the shipping to landfills, which brings its own magnitude of further consequences. In the EU alone, the construction industry represents approx. 35% of the total waste generated. Society needs to rethink the linear model of resource exploitation it is following, for the production of waste and to see it as a dead-end scenario is a waste of natural resources in itself.

3.1 Rethinking Building Materials – Closing Loops

The rethinking of the management of building materials and thus, protecting the exploited resources, has been studied for the past decades by multiple researchers of different areas of expertise, all interested in transforming our current (economic) model. Today we allow a notion that materials and products are (for the majority) restricted to end up in disposal. However, there exists a possible after life, when considering that they can be recovered, reused or recycled. The key is to turn the current limited linear (consumption) system, into a resource transforming, never ending circular system. This includes the promotion of designing materials to allow them to be part of this closed-loop process. The key-words for the reduction of natural resource extraction are: Recycle, Remanufacture/Refurbish, Reuse and Recover.

The responsible material selection also influences the today's so popular wish for energy efficiency in the building sector. The "embodied energy" or "grey energy" is the energy required for all processes involved in the manufacture and trading of products: resource extraction, manufacturing, storage, transportation, sale/purchase, disposal and recycling, as well as all infrastructure necessary. Embodied Energy is an apt indicator of the overall environmental impact of building materials, assemblies or systems.

3.2 Life Cycle Approach

To establish the environmental impact of a building, focusing on minimizing them, one needs to analyse all aspects of the materials, elements and processes involved, based on a life cycle thinking. Within the building sector there exist tools for assessing the environmental impacts of a given material or product. The most internationally recognized and standardized tool is the Life Cycle Analysis (LCA, also known as Life Cycle Assessment and cradle-to-grave analysis). It consists of a technique to assess environmental impacts associated with all the stages of a material's life. The LCA looks at material supply chains to reveal the energy-related and ecological effect of materials, creating the basis for selecting building materials more responsibly, avoiding the overlook of the environmental priorities. However, there still are some major flaws and limits to this complex and time-consuming evaluation process. First, the method relies heavily on the available data on building materials and processes. Such data are not always complete or reliable. Another aspect of this same nature, is that the current databases represent and are based on conditions in industrialized countries. These may not be equal as the ones applicable on developing countries, leading to poor decisions in these countries. Finally, the LCA method only calculates and assess to a certain point in the future of a building material. It is not capable of tackling the disassembly option for a building and its materials, nor the recovering/ reusing/ recycling feature. Thus, it does not include the endless closed loop scenario. Nevertheless it is a useful tool in assessing building and material related environmental impacts, but would become more valuable and effective if it is complemented in the future with other tools that can deal with its limitations.

4. ALTERNATIVE CONSTRUCTION MATERIALS

The construction material palette of today is still composed of the same usual suspects since the industrial age – concrete (and cement), glass, metals and bricks. But the production of these, non-environmentally friendly materials leads to the production of harmful emissions and increases resource scarcity, promoting illegal exploitation practise, i.e. of aquatic sand. The monopolization of the construction industry, due to its abusing of certain materials is leading to visible impacts on our planet earth, impossible to further ignore. Furthermore, these construction materials have already well-documented shortcomings that need to start being acknowledged, i.e. concretes' damage when exposed to water and chemicals, etc. If we talk about the future city it becomes clear that it cannot be built with the resources the city of today are being built. This stated, alternative construction materials take into account the availability of the material and with it, their application in specific contextual settings. The "alternative" aspect emerges from an exploration of an innovative and entrepreneurial nature, taking advantage of new technologies to create new materials based on already existing, but undervalued, ones. The major research projects presented in this dissertation include:

4.1 Constructing Waste

"The future city makes no distinction between waste and supply" (Joachim, 2014). For centuries waste has been defined as an undesired, discarded by-product – a result of any human action and interaction, in which raw natural materials are transformed, by applying various forms of energy and skills. Considering the abundance of refuse, waste is actually an endless resource from which society should be able to profit: "Waste and its meticulous handling are valued gifts, offered by society to itself." (Angélil, 2010). In this sense, waste should be understood as an integral part of what is defined as a resource, which can be reformulated again and again.

This research aims to demonstrate and disclose the potential of waste as a recyclable material for the creation of new building products. It introduces around 15 examples and projects on how to transform waste into a resource for the building industry. The case studies are divided into five main groups, according to different processes that transform the waste into valuable reusable products – Densified, Reconfigured, Transformed, Designed, and Cultivated.

4.2 Bamboo - Alternatives

Bamboo has been used as a building material since antiquity, for it has enormous social, economic and material benefits: fast-growth, high tensile strength, flexible, earthquake-resistant and has the unrivalled capacity to capture high quantities of carbon dioxide from the atmosphere, playing an important role in reducing such emissions worldwide. From small structures to skyscraper or even entire modular cities – in recent years, architects have been trying to demonstrate that bamboo should be globally recognized as a high-performance building material.

Recently, bamboo is being investigated as an alternative material the abundantly used steel. The premise is that very few developing countries have the ability or resources to produce their own steel, forcing them into an import-relationship with the developed world, whilst bamboo is a growing material in the tropical zone, an area that coincides closely with the developing world. Steel is not irreplaceable. A bamboo reinforced composite should interest most developing countries, for it could strengthen local economy and lower their dependency on international markets. Bamboo is generally still limited to traditional applications: the culm as a structural component. The idea of bamboo as a reinforcement component in concrete is not entirely new. However, early attempts to use it as an untreated, non-composite reinforcement material in concrete were not successful. Researchers are working with the new developed technologies to explore new types of composite bamboo material. The principle is based on the extraction of the fibre from the natural bamboo, transforming it into a manageable industrial product, and introducing it as a viable building material, an alternative to steel and timber.

4.3 Sand - Alternatives

Sand is the world's most widely used solid raw material. But nonetheless it is still a finite resource. Not all sand is equal: for conventional constructions the sand used is mostly sourced from aquatic environments, so as to meet size and surface criteria. In contrast to this, there are materials being developed that use all types of sand. This is an important factor, for it includes the abundant and previously unusable desert sand. Biological driven materials, which use a bacteria and microorganisms as a binder are being exploited, with the potential to replace not only fired bricks, but also conventional cement.

Another recent development in technology – 3D printing and laser technology – allow to laser sinter materials like sand. The application of selective laser sintering to sand material yields new, lightweight and durable glass structures called Laser Sintered Sand structures (L3S). The, until now, undergone experimental test demonstrate the reach of compressive strength close to the one of concrete. The range of applications of sintered sand materials are vast and can be engineered to meet specific criteria such as weight, strength and durability in the field of aerospace, automotive, medical, building industries. Extensive chemical, physical and material tests are undergoing, for the L3S to be further researched and produced in the future. However, due to the size limitations of laser sintering machines and the production process, reaching the level of construction elements and other big-scale materials is still in the distant future. This new technology would allow architects and engineers to design each building component specifically to the required structural and material needs. The aim of the L3S is to allow future buildings to be made of glass from sintered desert sand; and as light as a feather.

5. PROPOSAL: SUSTAINABLE URBAN UNIT

The project SUU, an acronym for 'Sustainable Urban Unit', is about developing a new building concept for emerging countries, creating sufficient and adequate urban living spaces. A possibility for rapidly-growing urban settlements that allows the creation of an environmentally and socially responsible future for the developing areas. The problem needs to be tackled there because, first: the today less urbanized countries are the developing ones, however, they are also the ones that are expected to have more rapid rates of urbanization in the coming years (DESA, 2014). Secondly, emerging countries must develop their own models of urbanization and building approaches rather than, like until now, rely on imported and inadequate standards from various developed world countries. To succeed in an improved and efficient urban planning, not only are adequate infrastructures needed, but also the appropriated building systems and materials. The SUU focus is the implementing of locally available/produced materials in a new way, putting in practice the knowledge gained in the previous chapters.

The SUU project is to be implemented, more specifically, in African countries located in the equatorial climate zone. This is part of the so-called sub-Saharan Africa, which according to predicaments will make up around of 50% of the world's population by 2100. The SUU must, in order to be a viable project, adopt design strategies that respond to the characteristics of the defined/limited areas in question. The climate is characterized as hot and humid, having constant temperature (25–35°C) all year long and with seasonal variations dominated by heavy precipitation (MetOfiice, 2012).

5.1 Design Strategies

The presented alternative to standard mass-housing imported prototypes, is designed as a simple but efficient modular structure, very open to customization, proposing a stable and durable living space. All the following characteristics consider the need for versatility in the project, due to a hypothetical urban site within African countries around the equatorial zone. The concept is to think globally, acting locally. Some of the design considerations include:

5.1.1 SUU: Adaptability

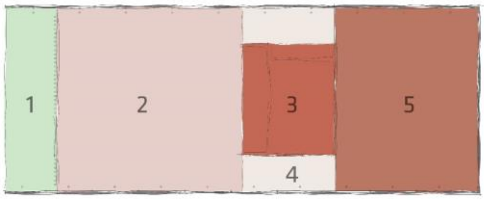

Figure 5.1 Schematic layout division of the SUU prototype model: 1. Exterior Area | 2. Public Area | 3. Central Core | 4. Transition. | 5. Private Area. Source: Rodrigues, Barbara

The modularity of the SUU gives it a flexible character, making the unit adaptable to any contextual change. The layout itself provides the basic needs, with open spaces that allow the freedom for the user to further adapt the unit according to their specific needs and wishes: a 4m x 10.26 m open plan with a central permanent core (services).

The modular structure of the unit allows for it to be arranged and combined in different ways, according to the needed space. In African countries this is an important aspect, given the high natality rates and families of considered sizes.

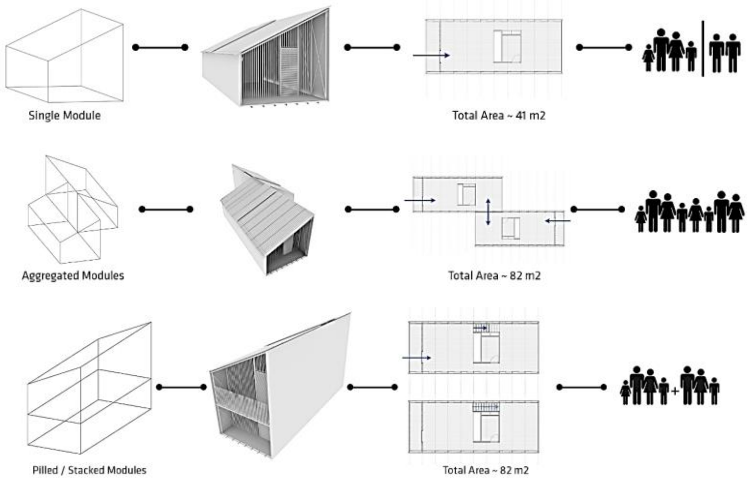

Figure 5.2 The different combinations of the unit: horizontal aggregation or stacking them vertically. Source: Rodrigues, Barbara

5.1.2 SUU: Materials

The SUU is built from the following materials: (1) structure and flooring: bamboo, a natural material abundant in the geographical zone in question and with outstanding material properties; (2) insulation: mushroom-grown panels, already tested and developed product that can be grown anywhere, in any desired shape, only needing a mould with the needed dimensions, mycelium mushroom, agricultural by-products and of course the know-how; (3) waterproofing – exterior layers and roofing: discarded beverage cartons, when shredded, compressed and submitted to heat create a new efficient material based on common trash (e.g. Tetra Pak); (4) windows and adjustable roof: polycarbonate sheets.

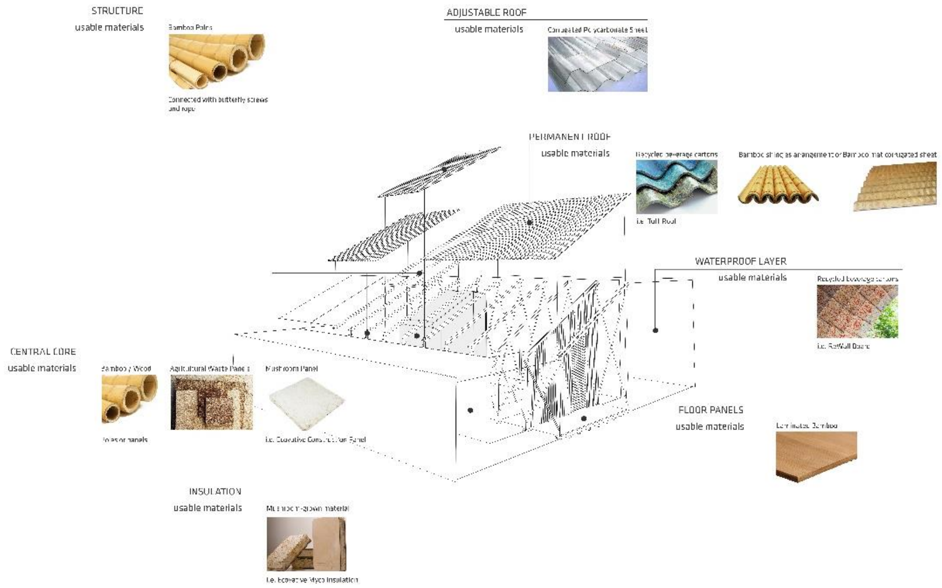

Figure 5.3 Detailing of a SUU and materials that can be used for the construction. Source: Rodrigues, Barbara

The limited material palette composed mostly from (natural) locally available sources – bamboo and mushroom being a renewable material, while the used refuse is from an abundant waste stream – contributing for low embodied energy materials, makes sourcing materials easier, more affordable and environmentally friendly. The use of non-renewable materials was minimized as much as possible. An important aspect is the fact that the used materials used in the SUU, mostly natural or waste-based, can be decomposed (i.e. insulation material) or re-integrated into the regular recycling process (i.e. waterproofing layers) after usage.

5.1.3 SUU: Profiting from available resources

The project explores the relationship between architecture and the climate, using the natural conditions (water, sun, wind) to achieve better indoor quality and in order to succeed in a more sustainable building unit.

Water: The mono-pitched roof allows for rainwater to be collected, the rainwater slides down the waterproofed façades, collecting it into a reservoir positioned and aligned on the ground. The water, after filtering, can be redirected to the central block.

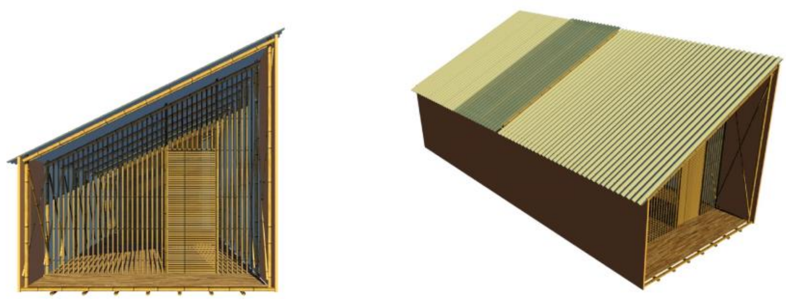

Figure 5.4 Right: Lateral (entry) façade with vertical smaller bamboo canes to achieve shading. Left: demonstrating the translucent part of the roof that allows for the entry of sunlight. Source: Rodrigues, Barbara

Sun: Flexible and reversible shading devices and various openings allow for a high quantity of daylight inside the space when needed. The lateral façade on the short side is made from polycarbonate fixed to a bamboo frame, both the sheet and the bamboo canes are removable, allowing as much sunlight/shadow as wished. The darkest are of the unit – the central core – is illuminated due to the part of the roof made out of the translucent material (polycarbonate).

Wind: Natural ventilation occurs from bellow to higher heights, more specifically from the main façade opening (window) placed in a lower level than the opening in the roof (higher level). The partial roof that allows for natural illumination is also adjustable. This means it can be opened when wished, allowing for natural ventilation of the unit and over the central core, avoiding overheating and providing fresh air. When both are opened, a combined ventilation system is created. When only the façade is opened, a single sided ventilation is possible.

5.1 Construction Concept

Reducing the environmental impacts of a building requires not only the use sustainable materials, but it is important to use the materials in a sustainable way.

At the centre of the unit is a permanent block, equipped with bathroom and kitchen and measures 2.4 x 2.0 meters. On the sides of this central block are the two main rooms – living area (public) and sleeping area (private) – which measure 4 x 4 meters and 3 x 4 meters, respectively. The structure consist of horizontal (floor), vertical (upright) and oblique (roof) bamboo poles with a diameter of 6 cm, following a one-meter metric. This is complemented with bamboo poles arranged in X, similar to the known truss structure, each with a 3 cm diameter. Every element is fixed together or through ropes or screws (butterfly), making an easy disassembly/deconstruction possible without damaging the materials.

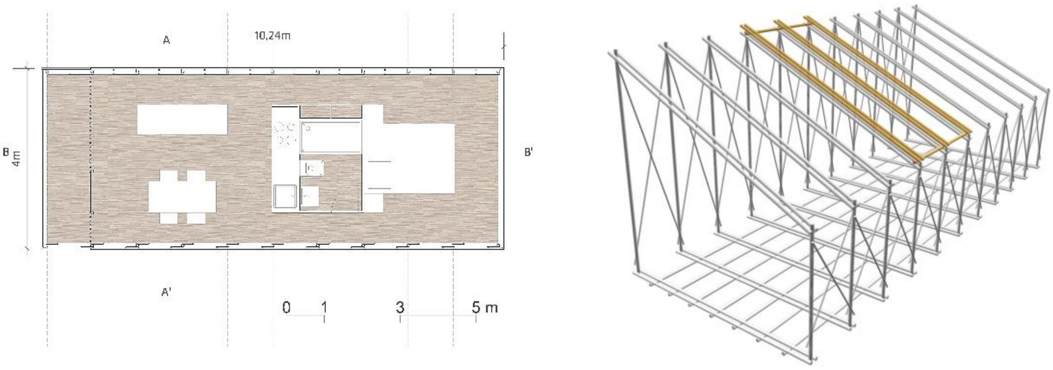

Figure 5.5 Left: Plan of the SUU. Right: Bamboo structure of the SUU, with the movable roofing highlighted in yellow. Source: Rodrigues, Barbara

The structure is lightweight and simple, ensuring that non-professionals, with prior given orientation and instructions, could undertake construction and assembly of the unit. The SUU follows the principle – Reduce, Reuse, Recycle, and Recover – by rethinking the materials and construction technique applied.

6. CONCLUSION

The current dissertation analyses and deepens the topic of sustainability and environmental concepts in connection to the construction industry. Today's scenario and problematics are disclosed, as well as currently existing and developing solutions that contribute to a sustainable use of natural resources – their preservation and reduction of environmental impacts.

Although today progress, especially technological, is progressing faster than ever before. It is crucial to not forget the simple, natural-based and inherent practices of sustainable practice and use the technological development in our favour. There are some constrains and complexities involved in assessing and applying a sustainable thinking into practice. The using of reused, recycled or recovered materials still cause, for the most part, a negative impact on the public, likely because of societies perception on the materials involved, as well as the higher initial investment cost associated with these sustainable solutions. However, this should not hinder innovative solutions to be developed.

The dissertation proposes a project, SUU, acronym for "Sustainable Urban Unit". The presented SUU is a model of a prototype to address rapid urbanization in developing countries and sustainable building approaches adequate to its location. The SUU project was developed with a hypothetical African urban site, program and construction process in mind. This means that, beyond the selected materials, applied structure and construction principle, many aspects can be more efficient if adopted to the conditions of an actual (future) selected site.

The SUU is a concept, a theoretical model that could be a solution to a real life problem. If there were to be any further research on the introduced topics and project it would be, for me, the natural continuing of this line of thought – go from the concept to the test and reach an actual realization. Finally, the Sustainable Urban Unit questions the role of the architect. The project provides only basic building elements such as a structural system, a roof, a rudimental infrastructural access to fresh water. In this stage, the structure would be inhabited. The users are empowered to decide to further develop the house according to their wishes, specific needs and financial possibilities. The unit dwelling would grow with the owners over the passing of time, being maintained and developed over the years, always controlled by basic established rules. The unit lacks a detailed infrastructure related to sewage, a crucial aspect that needs to be developed in further researches, depending on the existing network of the implementation site. In the end an experimental building prototype of a 1:1 scale should be built, to prove its feasibility in a real environment with real site conditions. Furthermore, the unit prototype is to have a self-built aspect to it, to allow local inhabitants to contribute with their own skills. This requires the need for the development of some general regulations, guide plans, details and simple straightforward manuals easily available in an open source document. The proposed project of the SUU therefore spans the responsibility of an architect from the social, spatial and constructive aspect towards developing processes to guarantee a desired urban development and growth, respecting sustainable alternative building materials and local culture.

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