REDUCE, REUSE, RECYCLE, RECOVER – NEED TO RETHINK 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 are being ignored. The aim is to introduce alternative construction materials as a viable solution for the future, by investigating different case studies. To conclude, a project is developed – "Sustainable Urban Unit" (SUU) – 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

alternative materials; recycle; reduce; sustainable urban unit

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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 [1]. The ever-increasing demands on our planet's natural resources is caused by the rapid growth of urban population and the subsequent construction necessity.

More than half of the global population is concentrated in urban settlements. This means that around 3.9 billion people are now living in the roughly 2% of the earth's surface [2]. Today cities consume 75% of the world's resources [3] and produce around 80% of our total carbon dioxide emissions [4]. Predictions show that in 2050 the world's population will increase to 9.3 billion, from which 70% will be living in cities [2]. Actual numbers and future predictions of urban population increase are alarming and accompanied by the growth in demand for materials and resources. When analysing the earth's capacity, studies demonstrate that by 2050 two planets will be needed to support the population's necessities [5].

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 recent publications, presenting case studies and examples to illustrate various possibilities of alternative building materials that reduce our need to further exploit natural resources. The rethinking in the design process about how a building construction should promote deconstruction and the reuse, recycling or recovery of the material, is also a focus of the research. 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 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. In this context, the contribution of the construction sector is most relevant.

The construction sector is responsible for the most extraction of material resources worldwide and it doesn't show any signs of decreasing its demands, being responsible for approx. 45% of raw material consumption [6]. 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 [7]. The large contribution of building to resource consumption is most relevant, for it is one of the largest consumers and therefore optimization potentials are equally great.

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.

The city has already grown passed the era of industrialisation, should overcome the present of consumerism and enter the age of recovery. The ambition would be to optimize our resources. At the moment, society still follows a linear approach to resources – extract, manufacture, consume and discard [1]. A building is only designed for the moment of construction, without thinking about its "death" and the "after-life" of its elements. Architecture does not end there. This requires a shift to an economic model that is based on the notion that materials and products are not restricted to be disposed of after their operational life span, but rather recovered, reused or recycled. This type of model has been for decades supported by numerous economists and even architects; called a circular or metabolic (economy) system [8]. The key to this system lies on turning the discarded material into a resource and therefore transforming the limited linear (consumption) system, that most of today's society follows, into a never ending circular system (recovery).

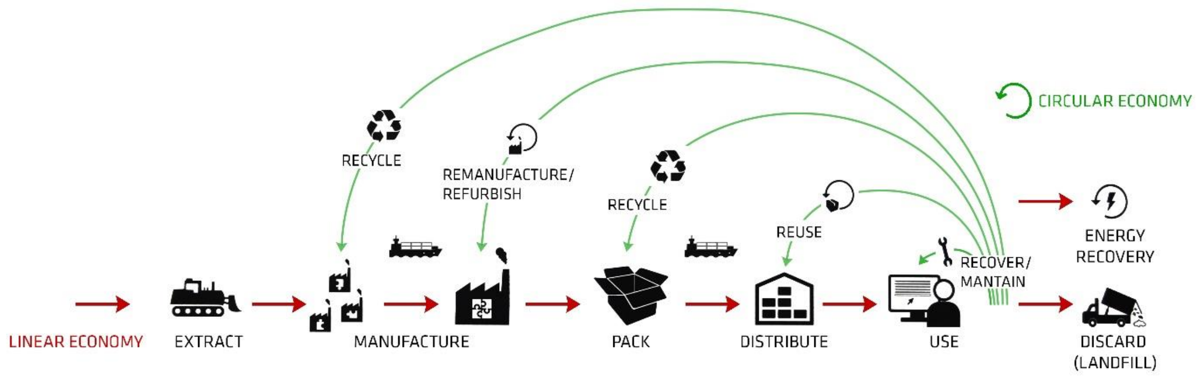

Fig.1: Linear versus Circular Economy. Source: Adopted from focus Terra Exposition 2015

This circular process promotes a key idea: that all materials introduced in the production (industrial and commercial) should be designed with the purpose to allow them to be part of a continuous recovery and reutilization process. The circular model conserves resources, reducing their depletion just through a simple rethinking of our present system into a closed-loop one, thereby playing a crucial role in protecting the environment, giving our economy a chance to achieve a sustainable growth. Figure 1 shows the key processes required for a circular process: Recycle, Remanufacture / Refurbish, Reuse and Recover/ Maintain.

On the one hand, there already exist some concepts to promote this circular approach in the 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 [9]. 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. Our built environment is perceived as an interim stage of material storage – a man-made resource reservoir, where materials can be retrieved instead of the already exhausted natural realm. All these ideas and principles stand for the premise that waste or wasted materials are actually resources.

3 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 [10]. 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, it is necessary to introduce alternative construction materials. "Alternative" materials because it is an exploration of innovative and entrepreneurial nature. Alternative materials because they take advantage of new technologies to create new materials based on existing ones. The latter are being wasted or undervalued, wasting their potential. The major research projects presented in this research include:

3.1 Constructing Waste

"The future city makes no distinction between waste and supply" [11]. 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 [12]. 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." [8]. 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 reusable and recyclable material for the creation of new building products. In the full investigation around 15 examples and projects on how to transform waste into a resource for the building industry.

3.1.1 Case Studies

The 'Agricultural Waste Panels' are a perfect example how an abundant resource – agricultural residues such as rice husks, barley husks, corn stalks, corn cobs, etc. – that is currently being wasted or even incinerated, has a huge potential as a construction material. Depending on the country and its agriculture, these raw materials represent an available and low-cost resource for new materials for building or furniture production, providing economic, environmental and socio-cultural advantages, being an apt substitute for some wood-based products. The material developed by the Berne University of Applied Sciences in Switzerland, can be manufactured using a low-tech approach. The standard production principle is based on mixing the raw material with a natural adhesive, this mixture is laid out on a mould and hot-pressed into a panel. The developed material, whether applied as construction (load-bearing), insulation, or furniture panel, has the advantage of being employed for affordable housing project and helps reduce deforestation, waste incinerations and the resulting air pollution.

'Tuff Roof' is a similar material, which takes an every-day product – Tetra Pak – and upcycles it, creating a construction material. The composition of a Tetra Pak container, its different layers of metal, paper and plastic, makes it extremely difficult and expensive to recycle. The company Daman Ganga Paper Mill (India) developed an alternative way to use this product, transforming it into a waterproof sheet. The simple process is based on shredding the cleaned beverage cartons, place them into moulds and activate the already inherent plastics and glues that function as the adhesive mass, with heat. No further materials are needed for its production and any shape can be created. In this case the result is a corrugated sheet for roofing. Because of their base material, in comparison to and unlike the known competing corrugated iron or cement sheets, Tuff Roof panels have the advantage of reflecting heat radiation, protecting the spaces underneath from overheating and are corrosion-free.

Another great product of an alternative nature is the 'Blood Brick', developed by the investigator J. Munro with A. Mamou-Mani and T. Burgess (UK). As the name suggests it is a construction material developed using animal blood. Animal blood was for a long time the main source of natural adhesive, before synthetic materials appeared, and it is an abundant resource that is being wasted, for it has no industrialized application in food production, being for the majority disposed of or incinerated. The Blood Brick takes advantage of the mechanical properties of the sand in combination with those of the blood as a binding agent. It is simple to produce, needing only blood, anticoagulant, a preservative and sand, poured into a mould and subjected to heat. The result is an inexpensive, surprisingly strong load-bearing building material. Like many other alternative construction materials presented here as case-studies, society needs to lose the negative prejudices and stigmas still associated with the waste materials to allow them to succeed and be implemented in the construction sector.

An emerging field is the combination of architecture with the advances in biotechnology. The Hy-Fi project, displayed at the PS1 (MoMA's satellite venue in Long Island City) and developed with the material Ecovative, is one example of a project built with organic grown tiles. The material can be produced with bacteria, for example, created or grown out of mushroom mycelium, whilst using corn stalk (agricultural residues) as their nourishment. Depending on the moulds – the form – and the initial bacteria, different material properties can be achieved, going from insulating to load-bearing materials. The advantage is, that it can be cultivated anywhere, only needing the initial bacteria and the knowledge to produce it. After deconstruction, the mushroom grown tiles can be decomposed, serving as compost or fertilizer, helping the next generation of similar material grow, thus promoting a cyclical usage. The organic material's production is waste as well as carbon emission free and doesn't need any additional energy beyond the natural environmental conditions.

3.2 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 by a team at the ETH Singapore's Future Cities Laboratory 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. The material is called bamboo composite material and should interest most developing countries, for it could strengthen local economy and lower their dependency on international markets. Steel is not irreplaceable, bamboo has the potential to replace steel as a reinforcing matrix for concrete and revolutionize the building sector. 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. Preliminary investigation results demonstrate that the bamboo composite has surpassed steel, in tensile capacity and in weight [13].

4 RESULT: PROPOSAL OF 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 [14]. 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 [2]. 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 (25–35ºC) all year long and with seasonal variations dominated by heavy precipitation [15].

4.1 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:

4.1.1 SUU: Adaptability

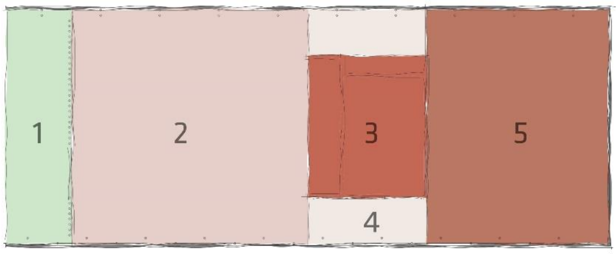

Fig. 2: Schematic layout division of the SUU prototype model: 1. Exterior Area | 2. Public Area | 3. Central Core | 4. Transition. | 5. Private Area. Source: Rodrigues, B.

The modularity of the SUU gives it a flexible character, making the unit adaptable to any contextual change. The layout itself, shown in figure 2, 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. Figure 3 demonstrates three possibilities, similar to a catalogue, however there are numerous options. These are to be applied according to their specific context and community. In African countries this is an important aspect, given the high natality rates and families of considered sizes.

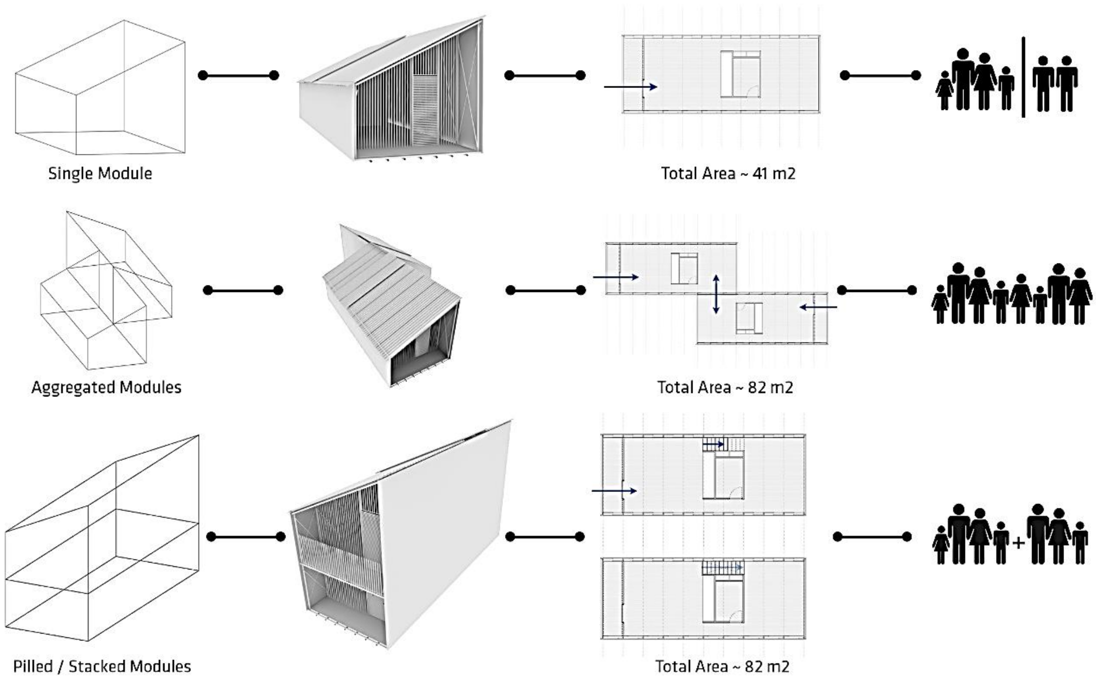

Fig. 3: The different combinations of the unit: horizontal aggregation or stacking them vertically. Source: Rodrigues, B.

4.1.2 SUU: Materials

The choice of materials was the main focus of the developed project, applying some of the investigated case studies, demonstrating their potential and viability in light of a new situation and possible future application.

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) openings and adjustable roof: polycarbonate sheets (Fig.4).

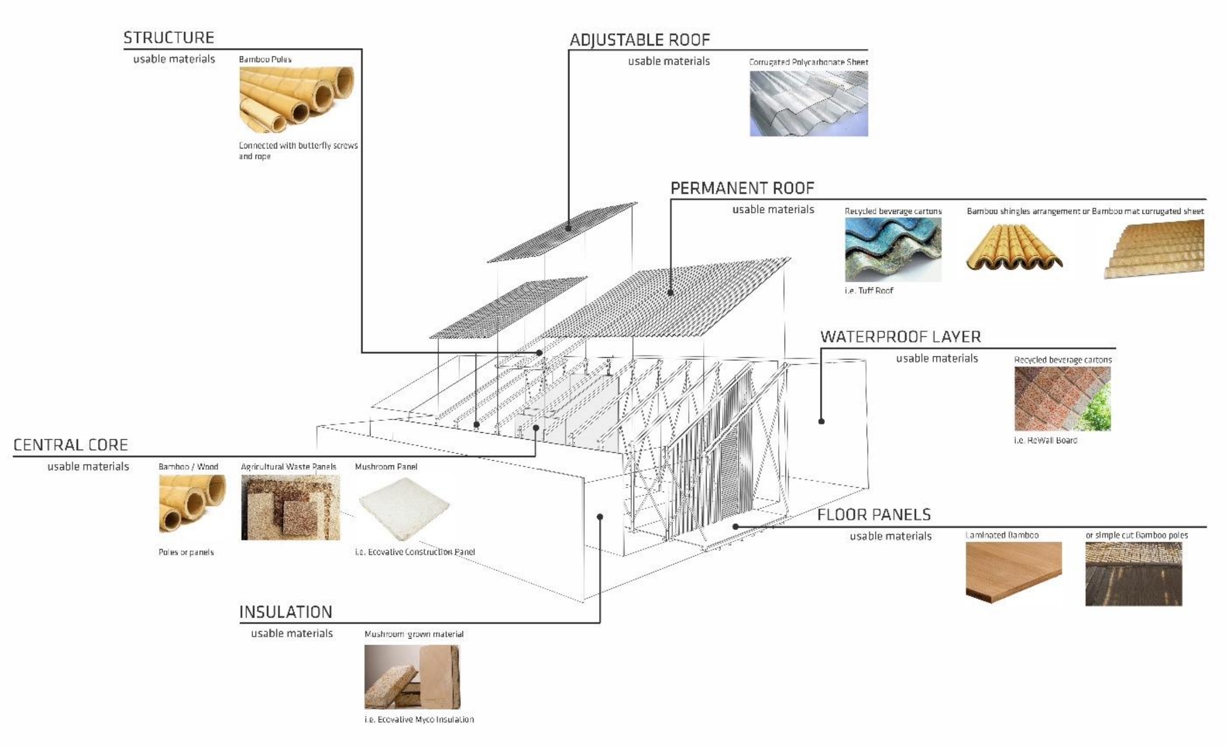

Fig. 4: Detailing of the SUU possible construction materials. Source: Rodrigues, B.

The limited material palette composed almost only 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, only suggesting the use of one of such nature. 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.

4.1.3 SUU: Profiting From Available Resources

The project explores the relationship between architecture and the climate, using the natural conditions (water, sun, wind) abundant in the proposed regions to achieve better indoor quality and in order to succeed in a more sustainable building unit. The design strategies adopted aim to reduce the buildings future energy consumption. This would allow for the building to adapt to the external environment, by using integrated architectural design as an influence.

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.

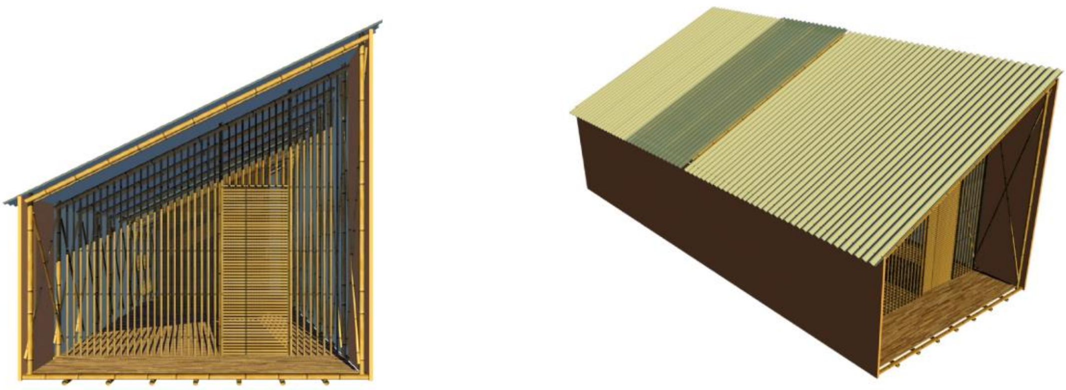

Figure 5: Left: Lateral (entry) façade with vertical small bamboo canes to achieve shading. Right: demonstrating the translucent part of the roof that allows the entry of sunlight. Source: Rodrigues, B.

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 (Fig. 5). The darkest area 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.

4.2 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 (Fig. 6). Every element is fixed together or through ropes or screws (butterfly), making an easy disassembly/deconstruction possible without damaging the materials.

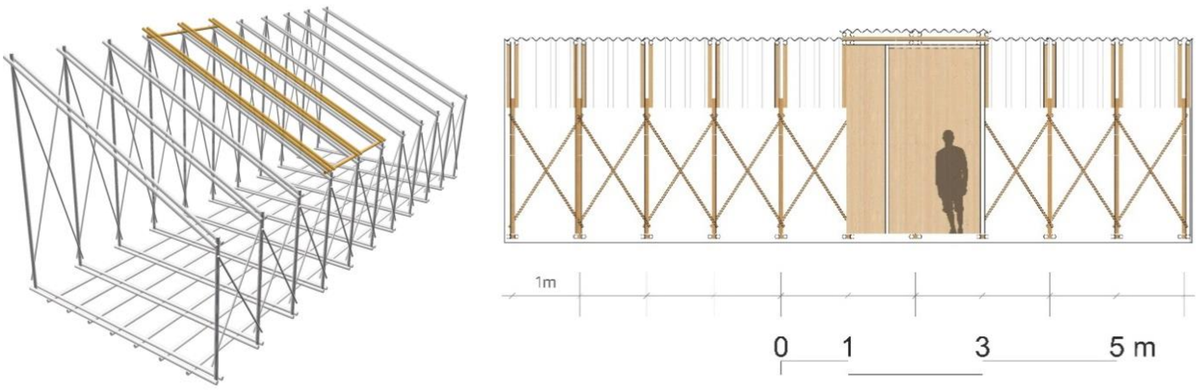

Figure 6: Left: Bamboo structure of the SUU, with the movable roofing highlighted in yellow. Right: Longitudinal Section of the SUU. Source: Rodrigues, B.

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.

5 DISCUSSION AND CONCLUSIONS

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. Aspects such as the water collecting system or the creation of more openings should be changed if the SUU is to be applied, more suited to the specific location. Other aspects like the specific agglomeration option of the unit or the position of the public/private/technical should also be more carefully studied in collaboration with the community where the SUU is to be applied.

The SUU is an initial 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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