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The Z Free Home – inspired by vernacular architecture

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Abstract

The Z Free Home is an eco-cycle home that is meant to represent a return to natural design solutions inspired by the passive and low environmental impact principles found in vernacular architecture. Throughout the centuries, vernacular building has exemplified climate resilience, resource efficiency and circular economic principles. The house will thus use these principles as design guidelines. It will be designed to offset all of its carbon emissions and aim to reach a negative carbon footprint. The Z Free Home will be built using bio-based fibres that can be repurposed from agriculture waste, meaning that when it is time to demolish the building, all its main components can be re-used again as building materials, food for animals, or biofuel. Even if an uninhabited Z Free Home is not demolished, most components will eventually rot and return to nature as compost. Building materials from the kitchen and toilet should however be recycled and reused so as to maintain the standard of zero waste. The house will be designed so as to construct in only 7 days with the help of 7 volunteers through a 'do-it-yourself' methodology and using only screwdrivers. All of these factors - zero energy, zero waste, zero carbon, zero labour cost (if you build it yourself), zero impact on the environment when the building is demolished – make the Z Free Home a unique challenge to design and build. This paper will discuss the methodological approach and show some preliminary results from the proposed low impact building envelope using natural materials (clay and plant-based materials like straw, reeds, wood, kenaf and jute) together with the passive and eco-cycle systems. As the project is still underway, this paper will describe outcomes to date and ending with a discussion on the next steps.

Keywords: *negative carbon building material; bio-based building envelope; natural fibre reinforced composites (NFRCs); biodegradable building material.*

1. Introduction

1.1 Study background

Limited global resources and the mounting climate crisis are among the greatest challenges faced by mankind today. There is a growing recognition that there is no planet B and that addressing climate change, biodiversity loss, mass extinction and environmental damage and pollution may be the principal challenges of our time (Hes & Du Plessis, 2015). Building and construction account for more than 36% of global energy use and 39% of energy-related carbon dioxide (CO_2) emissions (IEA, 2019). Moreover, over four million deaths each year are attributable to illness from household air pollution (IPCC, 2018). In recent years, the building sector has moved towards energy and resource efficiency, yet still not enough has been done to offset the rising energy demands from the building construction industry. Over the next 40 years, it is expected that 230 billion square metres in new construction will be built worldwide, the equivalent of adding a city the size of Paris to the planet every single week (REN21, 2018).

In conventional mass building, using industrial materials is the quickest and easiest solution. Environmental impact is not considered a high priority. Fortunately, many opportunities exist to deploy energy-efficient and low-carbon, passive and eco-cycle solutions for buildings and construction (Dabaieh, 2016; Dabaieh & Serageldin, 2020). While such ideas are not yet mainstream in the building market, especially within the residential sector, the Sustainable Development Goals are giving new purpose to businesses, their buildings, and how they are designed, constructed and used (French & Kotzé, 2018). Ambitious action is needed without delay to avoid locking in long-lived, inefficient buildings assets for decades to come.

1.3 The Z Free Home idea

The 'Z Free Home' aims to have a net zero environmental footprint using a return-to-nature design for a residential unit. Short construction time, low building costs and zero environmental impact are the main outcomes that this project strives to accomplish. The final project aims to exemplify how a 25 m^2 eco-cycle home prototype can reach nine 'Z' targets – zero emissions, zero energy, zero heating, zero cooling, zero waste, zero life cycle costs, zero labour cost, zero indoor air pollutants and zero impact on the environment after the building is demolished. The house's main components, roof, walls, and floors, together with interior furniture, are to be built out of plant-based materials. The house will be equipped with passive and eco-cycle systems aimed at closing the loop so the building will be self-sufficient with no pollution, waste, or harmful impacts on the environment or occupants. The house's innovative design intends to eliminate the energy demands for heating, cooling and power needed for water heating and cooking by using natural energy from the sun and wind together with household bio-waste. It is expected that these innovative passive and eco-cycle architectural design solutions will perform better than current energy efficient buildings and should save up to 60 % of household energy consumption compared to the current international and Swedish standards for energy efficient housing. As an energy self-sufficient house that uses renewable energy sources, the goal will be for the house to produce more energy than it consumes so that excess energy can be put back into the grid for later use or in case there is a deficiency in energy production. The idea behind the passive eco-cycle systems is that they should be low-tech and easy to install as plug and play systems for flexible use by the residents. They should also be easy to operate and maintain throughout the lifetime of the building. The house prototype will be built and tested in a cold climate urban living lab. The architectural design is shown in figures 1,2 and 3.

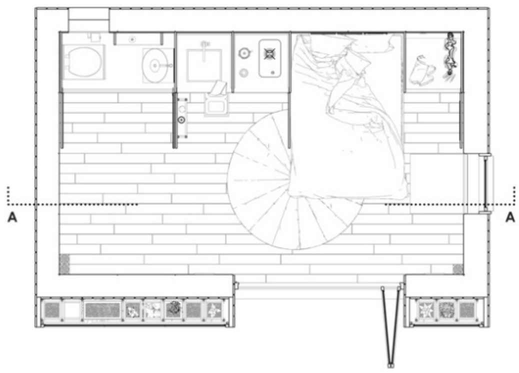

Fig. 1. A plan of the Z Free Home, showing interior amenities for eco-cycle compact living.

Fig. 2. Section AA showing the detailed design for all eco-cycle details in the bathroom and kitchen integrated with furniture.

Fig. 3. The house south façade showing the integrated design of the hybrid Trombe wall and the green wall as passive systems.

The aim of this paper is to document the preliminary investigative process of designing a carbon negative building material for the roof, walls, floor and furniture of a Z Free Home inspired by vernacular and traditional building construction materials in Sweden. The idea is to form a bio composite material consisting of natural fibre from agricultural waste as a reinforcing agent and filler for binding the building skin. The composite material will be used to form the Z Free Home's building envelope in order to reach carbon negative emissions during the building's lifetime.

1.4 Literature overview on bio composites & natural fibres (NFs)

Bio composites have been investigated by researchers and industries as a means of developing sustainable and biodegradable products. They come at various scales through using natural fibres as reinforcement as they are biocompatible, biodegradable, created from renewable resources and have superior physicochemical and mechanical properties (AL-Oqla et al., 2017). Due to their superior physio-chemical and mechanical qualities, natural fibres play a vital role in the composite industry. As a result, they are widely employed in many applications to replace expensive and non-renewable synthetic fibres such as glass fibre, carbon fibre, and aramid fibre (Syduzzaman et al., 2020).

Previous research on natural fibres in composites concentrated mostly on thermal, mechanical, and structural aspects. According to reports, the usage of natural fibres has various benefits owing to their inherent features, such as their light-weight, low density, renewable, and environmentally friendly structural composition. Despite these advantages, natural fibres have certain disadvantages, such as their hydrophilic nature and excessive moisture absorption. These disadvantages could be overcome by applying various surface treatments to the fibres and through using coupling agents (Jamaluddin et al., 2020). Natural fibres are classified as vegetable, animal, or mineral fibres. All vegetable fibres (e.g., cotton, flax, hemp, jute, etc.) are composed of cellulose, while animal fibres are composed of proteins (e.g., hair, silk, wool). Natural fibres can be utilized directly or in the form of chopped fibrous strands, non-woven matting, or fabric (Nickel & Riedel, 2003; Saba et al., 2014). The reinforcing fibres in bio composites must have high tensile strength and stiffness. The reinforced fivers act as embedded matrix gives the composite structure its shape, transmits shear forces between the fibres, and protects them from radiation and harsh conditions. The stiffness and tensile strength of a composite is the main factor for selecting the suitable fibres. Other factors to consider when selecting the reinforcing fibres include elongation at failure, thermal stability, fibre-matrix adhesion, dynamic and long-term behaviour, price, and processing expenses (Nickel & Riedel, 2003).

It has been shown that natural fibres can be utilized in a wide range of applications outside textiles, including composite materials, construction materials, heat and sound insulation materials, among others. Composite materials may be made with almost the same qualities using these components as a replacement for glass fibres. For example, they could replace glass fibres in composite materials, as they have virtually the same material qualities as those of glass fibres.

In recent years, lignocellulosic fibre reinforced composites (such as hemp, flax, and jute) have been employed effectively for light-weight applications, particularly in the automotive and construction industries. This is important in order to reduce the estimated 75% of energy used by automobiles, which is mostly due to vehicle weight. However, significant limits on the structural applications of these composites remain (Dhakal et al., 2018). The cultivation of fibre plants like hemp and flax has become more common in European agriculture over the last two decades.

The conventional construction industry plays a large role in environmental pollution and the scarcity of natural resources as it is heavily reliant on the extraction of fossil fuels and raw materials. Building industries all around the world are researching alternative sources of lignocellulose fibre due to a lack of wood, forestry laws, and the presumed lower cost of non-wood products (Halvarsson et al., 2009). Cereal straw (wheat and rice), flax, cotton, corn stalks, rapeseed stalks, bagasse, reed, and other non-wood plants are gaining attention as a possible cellulosic fibre source (Cheşcă et al., 2018). Several studies have discussed a possible solution in biologically enhanced materials, which are manufactured by cultivating mycelium-forming fungal microbes on natural fibres and organic waste rich in cellulose, hemicellulose, and lignin. Organic waste streams, such as agricultural waste, can be valorised by using natural binders like mycelium that produce a biodegradable substance at the end of their life cycle, which is compatible with the circular economy.

3. Methodology

The study followed an investigative explorative approach, which included a literature review, field visits and interviews. Initially, the literature search allowed for an introductory mapping of existing sources on natural materials. The focus was mainly on bio-based materials and materials that have the potential to be used in a composite to enhance building envelop properties. Sources include mainly handbooks, encyclopaedias, and journal articles. The search also extended to published experimental research lab reports together with video documentation on experimental work for bio-based materials testing. The literature helped to set a foundation and knowledge base for bio-based material availability, properties, uses, and cost efficiency.

After the literature review, structured interviews were carried out with 5 researchers, 4 craftsmen and 3 factory owners who have experience in using bio-based materials. The researchers are experts in using natural materials in building construction. One is specialized in using bio-based materials for temporary structures and for furniture, one in substrates, one in composites and the other two in using natural fibres from agriculture waste as construction materials. The interviews with the expert researchers were important for understanding the latest advances in bio-based materials and their use in industrial products.

The interviews with the craftsmen were important for understanding traditional as well as contemporary techniques in building with bio-based materials. about the craftsmen shared particularly useful information on the durability of natural materials and specific building techniques that are employed when working with natural materials today.

The investigative approach extended to exploring which materials are available around farmlands in southern Sweden (Scania region). Several field investigations were carried out to explore available biomaterials along with their cost and the implications of transporting them for the experimental use of the project. The local materials that were selected to be tested as a filler or substrate for mycelium in the material composite. The information gathered from the literature and interviews were helpful in putting together an inventory of available materials that could be used in the project.

Material selection started with mapping potential natural materials. These materials were then filtered to ensure they met the following requirements:

- Biodegradable and bio-based
- Ability to be utilized in low-tech construction methods
- Thermal and acoustic qualities
- Breathability
- Carbon sequestration
- Water and fire resistance in a composite material

Some materials were replaced with others due to local or regional availability. Then the materials were classified as natural fibres and filler/substrate according to their mechanical and physical properties and their role in the material composite for the building envelope. The outcome of the literature review will be the focus of this paper's results and discussion section.

4. Results and discussion

4.1 The selected natural fibres for the experimental study

The outcome of the literature study and the investigative field visits resulted in choosing flax and hemp as the two fibre sources and reinforcing agents to the composite. The main reasons for selecting the two materials are their availability regionally and their physiochemical and mechanical properties. However, the research also revealed the need to explore the limitations and possibilities of flax and hemp as structural components in natural fibre composites. As for the filler and substrate, reeds, hemp hurd (shives), wheat straw, rapeseed straw, corn stalks and seaweed were selected. While for the binding technique, which also relies on bio-based and natural bonding materials, the choice was between two approaches. The first option was to employ Mycelium, which is mainly found in the vegetative part of mushrooms and can be used to create a foam like, lightweight, biodegradable composite material that acts as a natural binder. The second option was to use bio-based adhesives. These can be found as raw material in renewable and organic resources. Fig. 4. shows the classification of the selected materials for reinforcement, filler and the binding technique.

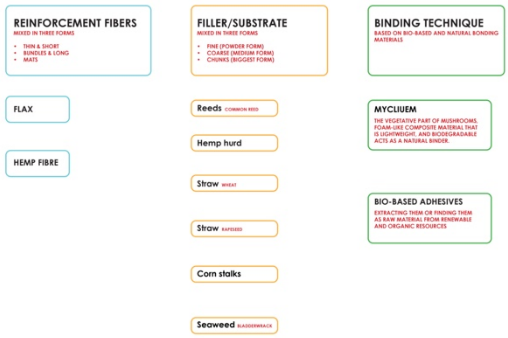

Fig. 4. The classification of the selected materials (natural fibres and fillers/substrates) and the targeted binding techniques.

4.2 The building envelop proposal

The outcome of the interviews with expert researchers and craftsmen together with the literature search informed three experimental trials with the selected materials. The outcomes of these trials should help inform the construction of the Z Free Home's building envelope.

The first trial will involve a one-layer composite. This method will be used as an introduction to using the selected bio-based materials. All materials will be combined with one another in different combinations and then tested for their binding properties.

The second trial will test sandwich composites consisting of two stiff exterior layers and one softer interior layer. The composite will contain two primary components: a multi-layered skin from fibre-rich woven textile and a loose core material combined with mycelium. The outer layers should be hard and filled with a mixture utilizing the selected binding approach (in the case of mycelium, the previously colonized substrate will regrow and integrate into the outer layers).

The third trial will test a multilayer composite inspired by the papyrus making process. Layers of various materials will be layered one on top of another to create a strong and rigid composite. Each layer has a certain function that must be defined before the start of the test. For example, one martials is for compressive strength, one for water resistivity and so on, to specify the materials used in this approach, more data from the previous two composites methods (one layer composite and sandwich composite) is required. When all layers are interlocked, the composition should exhibit a rigid structure that may be employed as a building unit to create a hard surface that is water and fireproof. Mycelium will play a main role which is to bind all the layers together for the final product before pressing or final heating. The layers could be added together before killing mycelium activity in the first stage, or after killing mycelium activity and then drying and pressing the layers to create inner parts that are more rigid and dry.

5. Conclusion

The Z Free Home project is an eco-cycle home that targets 9 different zero (9 Z's) in its design. To achieve this goal, the careful selection of building materials is essential. This study focused on the process of choosing natural materials to use in the building's envelope. The study took cues from vernacular building materials and methods. For example, using natural materials available in the surrounding area. The Z Free Home aims to revitalize vernacular principles through the use of natural and bio-based materials in a contemporary context. This paper reviews the outcome of one main method used in collecting data on the use of natural materials. Material selection was discussed in view of required properties and potential uses. This paper lays the foundation for next steps, which include testing the materials in a lab and then building a full-scale prototype. We hope that this pilot project will provide a proof of concept for the use of traditional natural materials that meet modern standards and demands. The benefits of using natural materials are numerous; however there are still challenges (e.g., building codes) that hinder the wider use of natural materials in buildings.

The author of this paper hope that future projects like the Z Free Home will soon bring credibility to natural material in mainstream building, at least in the residential sector.

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