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TEMPORARY BUILDINGS IN REUSABLE LIGHTWEIGHT MATERIAL DESIGN

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ABSTRACT: There is a growing need and market for temporary buildings for various purposes, including large construction projects in the tourism and events sector or in civil protection. This paper gives an overview about the use of reusable lightweight materials in temporary buildings. Based on a project proposal submitted to the 7th framework, a new concept of temporary buildings is proposed. This concept combines the advantages of the premanufacturing of a small number of parts and wooden components and a flexible and modular erection of the temporary building. The focus is on fast establishment with a maximum of three persons. A flexible and modular extension is possible. Assembling and disassembling the individual components with novel connect systems, adapted from the furniture industry, is proposed. This project aims to bring these concepts into new temporary buildings with new, reusable, and flexible lightweight design.

KEYWORDS: Lightweight materials, Temporary housing, Automated production, Pre-manufacture, Connection, Form stability, Wood modification, Wood veneer

1. STATE OF THE ART

1.1 WOOD AND SANDWICH MATERIALS

Wood is an excellent natural renewable material for green buildings. Wood products have a number of environmental advantages over other building products: manufacturing wood products is a rather simple, clean, and low-energy process, and wood is a globally available raw material. Wood combines relatively high mechanical strength with low weight. This characteristic is based on the cellular structure of wood with specialized cells with an optimized arrangement of the cellulose fibrils in the S2-layer of the cell wall. The orthotropic structure of longitudinally oriented consolidating cells, which are arranged in mutually reinforcing growth rings, gives a good, light-weight material based on the weight.

The emergence of new lightweight construction and new materials such as plastic or aluminium timber has often been marginalized for structural and mechanical engineering applications. Moreover, wood is widely in walls, ceilings, floors, roofs, stairs, etc. Especially for lightweight construction, new lightweight materials have been developed. The classic sandwich structure consists of two thin and stiff face sheets and a thick, lightweight and stiff material in between. Light weight panels have long been used in the aircraft and space industry, where a low weight is needed in combination with high stiffness. To benefit from the properties of the outer layer and the core, both parts have to be glued to a rigid composite with a good shear stiffness and tensile strength. The typical load failure of the composite is due to delamination between the core and the top layer under shear load or tensile load. Therefore, the introduction of an intermediate layer between the outer skins and the core structure was discussed [1].

Lightweight materials have successfully been introduced to wood and furniture industries. The main benefits of the lightweight core panels for furniture applications are the high strength to density ratio, being lighter and easier for transporting and handling products, as well as having cheaper transportation costs [2].

When aiming to produce sandwich panels, the wood based panel industry faces two major challenges: reducing the density of a panel shall not cause deterioration of its mechanical properties, and products have to stay competitive despite increasing raw material and energy costs. Conversely, the customers and furniture producers demand weight-reduced solutions [3].

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1.2 USE OF WOOD IN TEMPORARY BUILDINGS

Beside the classical use of construction materials, the essential benefit and value of materials used for temporary buildings are constantly growing. While wood is well known for permanent structures, such as framing, beams, and flooring, it plays an equally important role for temporary structures and buildings. Two main classes of temporary buildings are known:

- modular buildings and
- prefabricated buildings and/or structures.

Wood’s favourable strength-to-weight ratio means that timber structures can often be erected without relying on support from other temporary structures. Concrete and masonry require support from timber falsework, which is one more advantage of timber structures.

There is a growing need and market for temporary buildings for various purposes, including large construction projects in the tourism and events sector, in civil protection, or for housing refugees. The term “temporary”, however, is used to describe a fairly long time period; often up to decades in many use situations. For example, the average time for a refugee to stay in a camp is 17 years [4]. For larger constructions, these buildings are often produced in the form of halls. The materials are not often reusable, which can be considered a great waste of our common natural resources. Tents are commonly used, especially for housing refugees. Being able to quickly build temporary buildings in a resource efficient manner that also meets the requirements of standards and reusability is highly desirable. Therefore, there is a great need for new, functional materials for building applications for these particular use scenarios.

Quarantelli (1995) defined four stages of housing in the recovery process related to natural disasters [5]:

1. immediate relief (within hours),
2. immediate shelter (within a day or two),
3. temporary housing (preferably within weeks), and
4. permanent housing reconstruction (probably within a few years).

Johnson et al. (2004) studied the housing development after two different disasters [6]. They confirm the development process described by Quarantelli (1995) but also notice that the process from disaster to new permanent housing constructions differ depending on factors such as organisation of help and political aspects [5].

Tents are often used for accommodation after natural disasters, as well as for refugees. Tents are easily and quickly mounted. Other systems, like tents for events (parties, rock music festivals, exhibitions, and fairs) have to be built quickly but will be used only for a few hours or days. For longer housing periods tents are not suitable. They are relatively uncertain, difficult to heat, and do not provide solid protection. There are problems with moisture condensation on the tarpaulin. People in crisis situations need a safe and solid refuge. And they need to personalize their house to fulfill their own demands.

There are examples of more permanent solutions aimed at refugee housing, such as the better shelter project that is utilized by e.g., UNHCR [7]. The better shelter concept is based on a light-weight stainless steel frame and covered with panels made of a plastic material delivered in flat packages. Its estimated lifespan is 3 years.

Other, more permanent materials are necessary for temporary buildings planned for a longer lifespan. In temporary buildings several, sometimes different, demands on material and construction properties exist.

A very recent development is the lightweight panel that combines lower weight with high strength and insulation properties. Skuratov (2010) described a panel having three layers with a core layer made of low-grade sawn timber that has a pattern of hollow cells that reduces its weight. The use of a core layer with cellular structure reduces the weight and wood consumption in the production of three-layer panels [8].

Obyn et al. (2015) investigated the thermal performance of emergency shelters. There it becomes possible to receive a realistic thermal model of lightweight structures. Here a special performance is required, because emergency shelters might be used in several regions of the world [9]. Naji et al. (2014) compared three different lightweight material structures – light wood frames, lightweight steel frames, and 3D sandwich panels - concerning their structure, energy, and cost efficiency. The result is that the combination of several materials in a 3D sandwich product results in best structural performance, best heat insulation performance in roof construction, and the lowest costs for production and maintenance [10]. Negro et al. (2011) reported about the development of a new wood-based lightweight material with good physical-mechanical to weight performance and good sound absorption properties. This new material, based on Okoume plywood skins bonded to a honeycomb core, are constituted by Okoume plywood cells. But the optimization of the sound absorption properties is still necessary [11].

A special combination of these different aspects provides a reliable basis to the project’s approach. The objective is the development of a novel, cost-effective, multifunctional, reusable lightweight sandwich material with high potential for energy savings for sustainable temporary use; e.g., in temporary buildings.

2. AIM OF A PROJECT PROPOSED TO FP7 IN 2012

Based on this, a project proposal called “Reusable lightweight sandwich materials for sustainable temporary use in building construction” was developed
during 2012 and sent to the seventh framework programme. The aim of the application was to develop a novel, cost-effective, multifunctional, reusable, lightweight sandwich material with high potential for energy savings for sustainable temporary use. This lightweight sandwich material is based on modified wooden top layers and improved by a coating based on nano technique approaches to improve its fire retardant and water repellent qualities. An evaluation will be made concerning the possibilities for shaping the insulation material or in what form the insulation material should be introduced, including foaming or moulding, in the sandwich material. The idea was that the material should be shaped during the production process and that the shape should be optimized by modelling to identify the expected movement of the material caused by, for example, spring-back and shrinking or swelling.

Demarcation of the material was made as follows: only materials from natural resources should be used to produce a high performance, shaped, lightweight substance for sustainable construction use. Higher performance would be provided by a combination of lightweight sandwich structures for heat insulation with densified surface layers made from wood for stability and wettability. All materials or parts of the materials should be improved for higher performance by a modification step using either a sustainable chemical or thermal modification. This modification step decreases spring-back, improves the dimensional stability, and increases the durability and wettability of the new sandwich material. The 3D shaping of the material allows the production of near-net-shaped products, which can be used in finalized construction without any major handling, aside from the assembly.

The goal was, first, to develop a thermal insulation composite system for exterior insulation with lightweight panels, and, second, to develop a shaped heat insulation composite system in lightweight construction. A modular system with a small number of parts is provided (Figure 1).

Figure 1: Approach of the project
Wood is preserved to be climate smart and has a number of advantages over other building materials. It combines relatively high mechanical strength with low weight, and is widely available as a raw material. It combines good mechanical properties with heat insulation and low weight. Wood can be described as an optimized three-dimensional biopolymer composite based on cellulose for tensile strain, lignin for compression strain, and hemicelluloses. The properties can be modified to make a biomaterial with designed properties and performance. The key question asks what properties and performance are desired. Properties that can be changed include the shape and thermal stability; resistance towards decay, ultraviolet degradation, and insects; water repellence; colour; texture; hardness; toughness; compatibility with other resources; and plasticity. In addition, wood-based materials can be readily recycled and reused.

Lightweight panels have long been used in the aircraft and space industry, where low weight, in combination with high stiffness, is necessary. This can serve as a good role model. The procedure, as shown in Figure 2, thus consists of the following steps to reach the aim of the lightweight material approach:

- **Nano level**: Nanomaterials for improved coatings with more functions, structure-property relationships, and material design on the nano level, surface and interface interactions and behaviour;
- **Micro level**: Chemical, physical, biological effects, material structure;
- **Macro level**: Materials and semi-finished development, transformation and shaping processes;
- **Construction level**: Functional integration, modular component design, and material reliability and quality assurance; and
- **Across all levels**: Modelling and Simulation as a Multiscale Approach.

The process to develop this sandwich material required research based on an innovative research validation approach, whereby new material modification and combination created multi-material composites with higher functionality. This new high-performance bio-product would be capable of a longer service life for reusable temporary buildings in severe moisture environments. Unfortunately, the application was unsuccessful, but the idea was kept alive because the partners wrote an application to the **Wood Modification Network in the Baltic Sea Region**. This network consisted of researchers from Latvia, Poland, Sweden, Germany, and Estonia. The partners joined forces in this network to develop multilateral education and R&D collaborations. They aim to work on current problems in combined modification and transformation processes; the procedural description and calculation and optimization of the processes; as well as on the development of the product design.

![Figure 2: Multi-scale approach to develop the sandwich material](image-url)
3. IDEAS FOR A NEW APPROACH

Based on this old application and later discussion within the Wood Modification Network in the Baltic Sea Region, a new approach was envisioned. Temporary buildings demand very special requirements compared to traditional building applications. Under temporary conditions, the assembly and disassembly properties are very important factors, and the handling of the building parts must be very easy. In civil protection, it is especially important that the systems handle extreme conditions. Construction elements thus need sustained exposure to extreme wetting, drying, cold, and heat. The material should be reusable in similar buildings with function, design, and structural requirements in the foreground. For this reason, a modular concept is desirable. Lightweight construction is currently considered the most intelligent solution available for the ecologically sustainable optimization of efficiency. Innovative lightweight construction for interior design and architecture has a need for new multifunctional, sustainable, and reusable materials. There are a wide range of applications for temporary buildings. In the future, not only will the individual temporary functions of the building be considered, but reusability will also be realized based on a simple, light, easily-built, modular, and highly functional design system.

To achieve this goal a new approach to automated wood house production is necessary because wood housing companies currently work in a very low automated and “low-tech” production mode. Some countries, like Austria, Germany, or (Northern) Italy, have wood housing companies with a very high level of premanufacturing. Here the time of construction on the work ground is very short, but it takes long time periods to premanufacture the wooden constructions. Then, high-weight-carry lorries are needed to transport the big components to the work ground. The production is less flexible. In contrast, the production of wooden houses can be more work-ground-oriented, like in the UK. Here, many production steps are directly done on the work ground with a very low level of premanufacturing. The level of flexibility is much higher, but much time is consumed in the work place. The buildings are not quickly built.

The proposed modular design implies new ways of thinking concerning the production system. The curved shapes and materials used are normally not used in house building today. Therefore, new thinking concerning production techniques is needed. The design of the elements is more related to furniture products than building products. Production techniques that we know from the furniture industry can be an interesting alternative to use. Such techniques can be transferred to the building industry and used for the preproduction of the elements. Each element may then be treated in the same way as a piece of furniture. This may secure quality minded thinking in the handling of the elements. The small amount of element types further creates a great potential of achieving effective flows, as well as simplifying automation of the production. The system should be self-adjusting with/without flooring. The same type of assembly system used between the wall/ceiling elements should work between the wall and floor. Connection to the ground could be secured by ground screws. With that kind of attachment the need for a building foundation disappears. “The terrain remains untouched, there is no soil sealing and the overall logistical effort is minimal. A big advantage, since the designs and the building process can be planned much more effectively and without loss of time” [16]. To be able to build the system autonomously, solutions such as solar-panels can be integrated to the system. Also,

To solve the problems of this approach, the temporary buildings idea, which was behind the aforementioned applications, is still current. The igloo concept is still envisaged. However, the construction still needs to be covered. There are examples of companies that provide such solutions, which means that a building can be covered with a prefabricated shell [12]. Traditional assemblies in buildings are not as flexible as assemblies of components with fittings for furniture assembly. Therefore, it would be advantageous to develop a new concept of connections – adapted from the furniture industry. The production system of the building components is planned to be highly automated. An ongoing project, Flexible automation in manufacturing of laminated veneer products, to study these possibilities has been in the works since January 1, 2016 in a traditional wood manufacturing industry, together with academia and a company that delivers fully integrated automation solutions. The project is linked to relationship material characteristics – robot automation, the ability to automate the furniture industry in Sweden and the related manufacturing costs – and investments in automation. The project is financed by The Knowledge Foundation [13] and the industry. There are already highly-mechanized production lines for beams made of laminated veneer [14]. These can serve as role models, as well as the production of high volume furniture with a high degree of automation. For example, a highly automated factory making 25 000 pieces per day of an IKEA Billy bookcase. The production runs 24 hours per day, 7 days per week. The staff of about 200 is mainly concerned with the handling of materials [15].
optically transparent wood [17] can hopefully be used to give natural light indoors in the future.

A solution that handles more than one of the four steps listed by Quarantelli (1995; in the State of the Art chapter) is desirable [5]. This could be installed by three people in an emergency situation. Extensions could be used for a longer time scale. The system could be based on a few recurring building elements. The elements should be self-supporting, with inclusive climate shield according to heat and cold. The igloo mind-set could be kept from the old approach and built on laminated parts. This concept is energy efficient and partly self-locking during assembly. Instead of a super material, it may instead be divided into a super construction and a super protective area. The protective area would be exchangeable and adaptable depending on the climate and the time frame of the solution. In its simplest form, the protection would serve as a coating or as a sock with fish scales. A submarine can serve as a role-model. This has a stable tube with an outer shell. The assembly should be manageable by two people handling the elements and a third person taking responsibility for assembling the elements through fittings inspired from the furniture assembly. Dismantling and reconstruction should be done without problems. As already in the design, all solutions must be recyclable. It should be easy to carry parts on existing transport solutions. All components must be removable by hand. The construction should provide protection for the climate and offer security and dignity for the people living or working there. It should be resistant to violence caused by hand. The solution should provide conditions to gradually enhance comfort and sanitation solutions in place. A basic model scalable in length with floors, walls, and ceilings (Figure 3 and 4) could be used in an emergency effort to later be supplemented with additional storeys and with a more permanent foundation. This means that the first part would be mounted on the latter. The basic model consists of three different building elements for walls and ceilings. The floor also consists of three different elements. This idea is realized in a project that will create a guideline of how effective flows with automated production for similar products can be created. Identified needs and requirements, as well as the project structure, are summarized in Figure 5.

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**Figure 3:** Basic solution scale able in length. Perspective view.
Figure 4: Basic solution scale able in length. Front view and section view.

Figure 5: Project concept.
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