THESES OF THE PH.D. DISSERTATION

Architectural Application of Biocomposites: Preparation of an Experimental Structure

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2021

Theses of the Ph.D. dissertation

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INTRODUCTION

In this research we studied the architectural role of composite materials and then we narrowed the circle to biocomposites. Widespread use of composites opened a new chapter in the history of architecture and allowing new forms as well. Application of modern composites begun with reinforced concrete. Besides, the lightweight construction appeared, which first used laminated timber more recently wood-based composites. Later, fiber reinforced polymers (FRP) spread. The advantages of natural fiber reinforced polymer (NFRP) composites are even less weight, and optimal heat and noise insulation. They are environmental friendly and more economical than other composites. Nowdays, there are opportunities to apply biobased and biodegradable polymer. Adding natural fiber reinforcement enables the construction of load bearing biocomposites. However, those are still in the experimental phase.

The development of biocomposites is inseparable from inorganic polymer composites, since they share physical characteristic and technologies. The chemically similar wood based composites spread in the field of construction and furniture industry mostly with plate products. In contrast, inorganic FRP is used by the vehicle industry which requires curved surfaces. Modern composites appeared at the same time as the development of minimal structures, and lightweight and ultra lightweight structures a mostly made of them. The development of lightweight shells has a significant impact on post-millennial architecture.

OBJECTIVES OF THE RESEARCH

The spread of biocomposites has effected packaging, the vehicle industry and medicine during the last two decades. Many believe that biocomposites are harbingers of a sustainable economy, since they are made of renewable materials which are made in underdeveloped, agricultural regions. At the end of their life cycle, they are biodegradable, which protects the environment. Energy efficiency and life cycle management motivate most of their applications. Those are mostly various structural parts with lower weight and lower cost. Architectural applications are emerging as well in lightweight construction. Besides, there are experimental constructions to study lightweight composites and to research the possibilities of future applications.

The aim of this research is to prepare for a lightweight shell structure. This requires a form-finding model which is ideal from the structural and technological point of view. During the last decades, great deal of architectural experiments was made, and many of them were inspired by the development of materials and technologies. They are used for technological development by testing editing principles and building methods. With other words, the aim is to develop new architectural forms. Reinforced concrete, laminated wood and glass, various lightweight materials played the most significant role in recent construction. However, the progress of artificial materials raises many questions since there is no long term experience with most of them. New materials and technologies have also spread to engineering, effecting health care, environmental protection and the economy. Therefore, studying this topic requires a holistic approach.

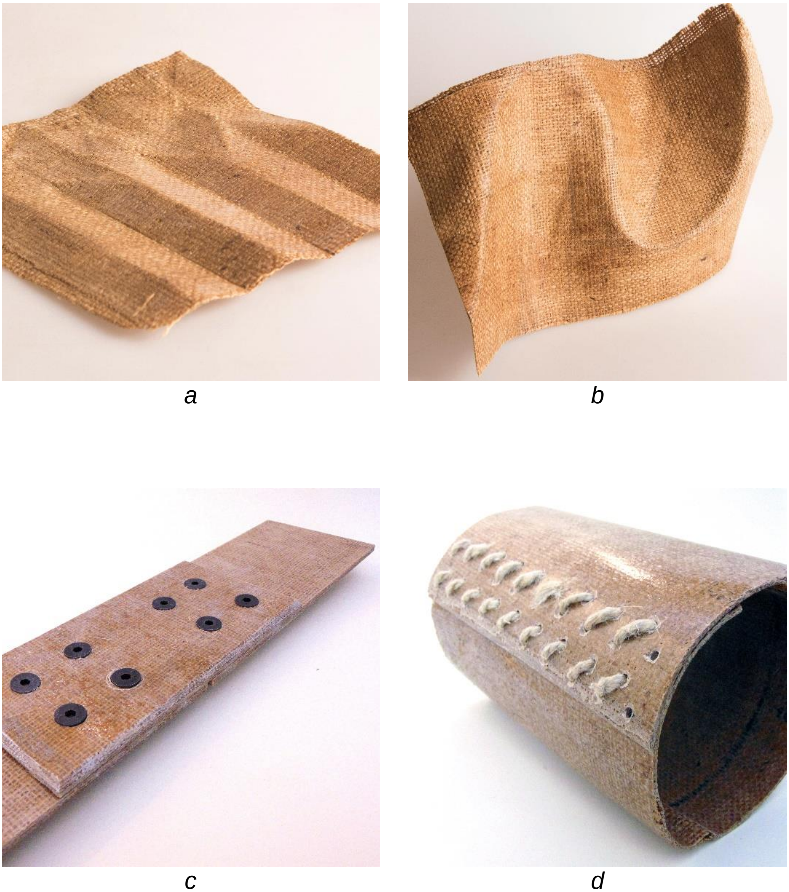

Figure 1. Experimental products out of biocomposite

METHODS OF THE RESEARCH

We began the research with a historical overview and with case studies. The studies cover several built examples from the last decades and experimental constructions. Later, a technological and conceptual overview follows. This is required because different resources have diverse definitions about biocomposites. Therefore one has to make his own definition for the actual project.

During the research, several experiments were performed to test the teoretical review of biocomposites. Experimental specimens were made out of polylactic acid (PLA) and hessian. Those were examined several ways to recongize their abilities. Advanced manufacturing technology was developped according to destructive tests and microscopic investigation. Utilizing the results, experimental products were manufactured out of our biocomposite (Figure 1).

Finally, according to case studies and own experimental results, a form-finding method was developed for a lightweight shell construction out of biocomposites. Naturally, the method is based on the abilities of the experimental products. First a physical model was developed for a forthcoming investigation which enables digital editing.

SUMMARY OF THE RESEARCH

Historical investigation showed that folding in architecture developed in parallel with the spread of composites. As a main feature, folded architecture applies structures which are submitted to complex stresses. Composites, made of materials with diverse mechanical properties, are highly appropriate for this. This opens up the possibility of a continuous building mass in which the traditional components of the building like slab, wall, column are able to organically blend to each other. A traditional building shape can built with more homogenous materials. Modern materials provide higher strength in thinner structures resulting in radical changes in the building proportions during the 20th century.

Sustainable development also motivates the spread of biocomposites. Biodegradability allows applications in the packaging industry. Manufacturing products out of PLA and other biopolymers reduces their environmental impact and reduces waste. The other main consumer is the vehicle industry, where it is replacing some of the ceramic composites to reduce vehicle weight, and fuel consumption. Although biocomposite parts have lower strength, they are lighter, cheaper and better heat insulators. They usually replace ceramic composite or plastic parts. Biocomposites, manufactured for the construction industry are mostly spin-off projects of such developments from the vehicle industry.

Various lightweight structures can be made out of biocomposites. Several experimental constructions were erected made out of polymer-ceramic and wood based composites to advance lightweight shell construction. Those projects share the method of designing an ideal structural shape. Ultralightweight structures usually have an even load distribution. They often employ unorthodox editing methods. One of them is based on paper folding and is suitable to design plate constructions. The other is the tape shell, which is appropriate to design laminated timber structures and their is the tensegrity, which is optimal for a metal grid (Figure 2).

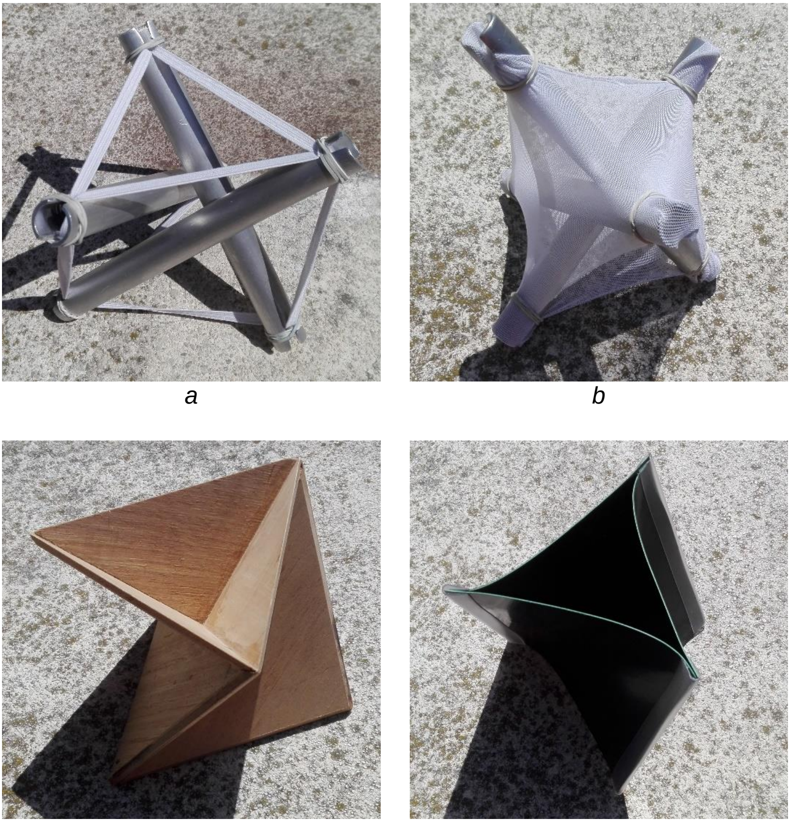

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Figure 2. Form-finding models

Our biocomposite experimental products show good mechanical properties for packaging, furniture and the construction industry. Properties and composition of a composites depend on the details of manufacturing technology. Since the mechanical tests showed significantly higher results against tensile stress, it is beneficial to design a structure which is submitted to the most tension.

Between form-finding methods we studied, tensegrity submits materials to the greatest tension. However, tensegrity structures consist of bars and strings, covering the grids to create a surface structure. By using the proper canopy, one can replace the strings as well. With this knowledge, we built a model with fixing bars on a flexible sheet. The position of the bars follows an unfolding of a similar tensegrity structure. The folding of the sheet, mounted with bars, creates a vault. The surface of the vault can cover congruent surfaces, and the bars can be made of appropriate metal, wood or even composite products (Figure 3).

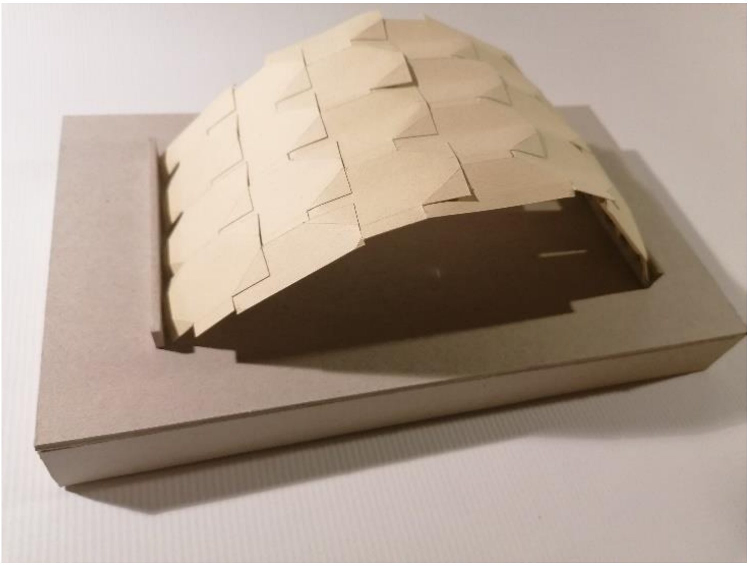

Figure 3. Model of a lightweight shell

THESES

1. Periods of architecture according to material use

The history of architecture is divided into three periods according to material use. These three periods separated by two great transformations of human life. The first is the Neolithic Revolution (or the First Agricultural Revolution) and the other is the Industrial Revolution. Since primitive architecture is dominated by compression, the architecture of settled people utilises the pressure strength of building materials. In turn, with the industrial revolution the combined structures spread and use of reinforced concrete began which was followed by further composites. As a result, the architecture evolved to a new period, dominated by composite materials which can resist complex stresses.

2. Impact of composite materials on architectural form

Since diverse composites, from the 20th century are highly resistant to complex stresses, covering large spans became possible with even thinner structures. As a result, the ancient proportional system of architecture reached a new stage. The development of shell structures soon beain which led to the appearance of new, formerly unknown froms in architecture. Next, the fuent architectural appears, which can fold form a wall to a roof, slab column or pillar. This phenomenon is the folded architecture which requires the versatile composite materials.

3. Experimental manufacturing of biocomposite and mechanical examinations

heat compression of multilayer PLA and jute textile produces a structural composite which is appropriate for packaging, furniture and architectural building. Destructive mechanical tests showed that chemical composition, methods of manufacturing determine the properties of the composite. Fiber orientation is essential for its mechanical strength. It has significantly higher resistance against tensile force, which makes it useful in a structure which subjected mainly to tensile force..

4. Lightweight shell structure design out of a biocomposite

One can build a lightweight thin shell structure out of pressed biocomposite plates with bars or diaphragm reinforcement. A hybrid solution was used to develop the optimal shell form, combining the tensegrity model of discontinuous pressure with an origami model. Since fiber reinforced composites have a significantly higher resistance to tensile forces, it is practical to build a model with continuous tension and discontinuous pressure to utilize material properties as much as it is possible. In the second step, one can cover the model to achieve a surface structure. To achieve high compression strength, it is beneficial to keep the bars in place, but the wires of the model can be replaced with the covering surface. However, bars can be replaced with stiffening plates. The direction of the original cable system points in the direction of the tensile force. Therefore it is practical to orient the fiber direction of the base material parallel to the cables.

PUBLICATIONS FROM THE TOPIC OF THE DISSERTATION

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