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PERFORMATIVE PROPERTIES OF WOOD IN FREE-FORM LIGHTWEIGHT STRUCTURAL SYSTEMS

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INTRODUCTION

New design tools have expanded the possibilities of creating structural systems made of wood. Structural systems known from the pre-informatic era are currently undergoing revision. Particular attention is paid to the inalienable physical properties of wood, which determine the operation of this type of structural system in architectural buildings.

The publication will present the results of comparative analyses of structural systems made of wood in the pre-digital era and the digital era. These studies have shown that wood properties that were not considered before are gaining new importance. These are structural systems developed for freeform geometry based on topology (NURBS). These are usually free, asymmetric forms with complex geometry that are the result of parametric modeling based on control points for NURBS curves and surfaces [1].

CREATING CURVILINEAR FORMS IN THE PRE-DIGITAL AND DIGITAL ERA

In architecture and construction, traditional methods of designing and constructing objects imposed regular forms based on Euclidean geometry. Solids and shapes that could be reproduced according to the rules of classical geometry did not involve complicated construction or technological or material solutions. During the development of architectural theory, designers searched for ways to implement forms with a high degree of geometric complexity (curvilinearity, curvature of surfaces, a high number of elements with individual shapes) in wooden architecture. Tracing curved lines and defining curved surfaces has always been a challenge for designers. The problem of determining curvature has also occupied the minds of mathematicians for many generations. During the Baroque period, new design techniques and drafting tools emerged, making it easier to plot geometrically complex building and structural elements. However, further development in this direction was hindered by the lack of tools for their design and implementation. Architects and engineers struggled with the constant problem of performing arithmetic calculations, which forced numerous simplifications [2].

The lack of effective IT solutions supporting the design process resulted in limited possibilities of freely using variants and introducing changes at various stages of project development. The implementation of isolated experimental facilities (e.g. Multihalle in Mannheim) made it clear that designing this type of form involves difficulties in determining surface geometry and material organization [3]. Designers and contractors had to wait for technological support provided by IT design tools, which opened up new possibilities in the area of geometry modeling in the CAM/CAD relationship, which changed the paradigms of industrial production.

CURVILINEAR FORMS AND WOOD PROPERTIES

Curves and surfaces are built based on topology and control points, which are an integral part of their description, ensuring the possibility of their modification, which is an integral part of the form-shaping process. The feature of topology-based geometry is fluidity, providing the possibility of modification. Gridshell structures were the first active wooden structures in history to reveal other properties of wood than those used in post-and-beam structures, primarily elasticity. New solutions in the field of materials used and element connections made it possible to overcome the limitations resulting from the anisotropic macroscopic structure of wood [4]. The inherent material properties of wood allow the structure built from it to respond to changes in environmental conditions (temperature, humidity) and the related loads from wind, precipitation, and sunlight (Fig. 1).

Research on the use of wood properties in the implementation of free forms in architecture has demonstrated a change in the meaning (redefinition) of specific material features used in the digital era compared to the pre-digital era [5].

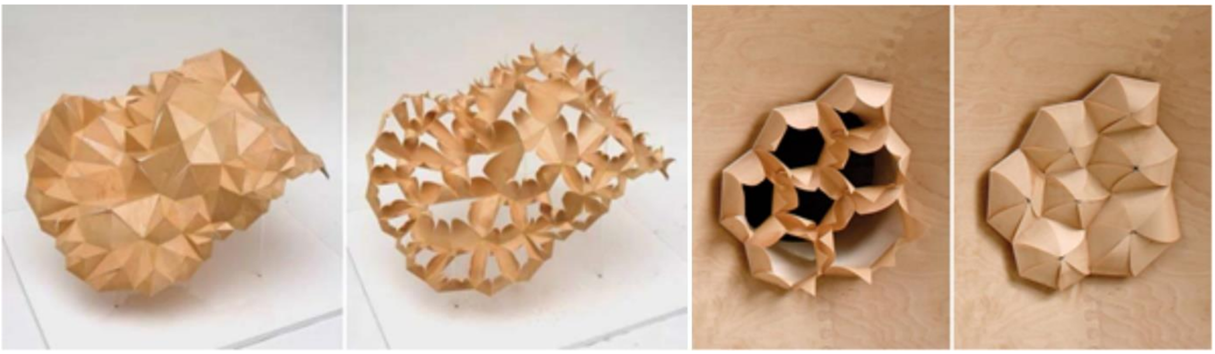

Fig. 1. Responsive wood-composite structures reacting to changes in ambient relative humidity
a-b) Responsive Surface Structure, Stuttgart, 2008 (Achim Menges, Steffen Reichert)
c-d) Hygroskin Pavilion, Stuttgart, 2013 (Achim Menges)
(source: elaborated by M. Golański based on [6])

This redefinition covers the following areas:

- new properties resulting from wood processing and processing methods,
- use of initial stresses,
- multidirectional material systems,
- use of wood behavior (performance).

Fig. 2. Bending-active plate structure, ICD/ITKE Research Pavillion, Stuttgart, 2010
(source: elaborated by M. Golański based on [6])

RESULTS

The conducted research showed that in the 21st century, a new approach to designing wooden architecture has emerged (Fig. 2). Architecture has reached an unprecedented stage of its development in which the design of structural free forms and the use of wood-based materials allow the implementation of structures that are effective in terms of structure and materials (Fig. 3). The transition from computer-aided design to parametric modeling and computational design resulted in a shift from form modeling using the form-making method to form-finding [6]. The designed free form is created as a result of simulated loads, phenomena, and processes that influence its shape. The resulting geometry of the form requires different structural solutions and connections of wooden structures.

Fig. 3. Surface-active structure made of single-curved CLT components, Urbach Tower ICD/ITKE Research Pavillion, Stuttgart, 2010
(source: elaborated by M. Golański based on [5])

The implementation of wood in the realization of free forms in architecture inevitably leads to a new understanding of the structure of the object and a departure from Semper's concept of tectonics. The introduction of the concept of digital tectonics in 2005 opened up a new understanding of the relationship between geometry, material, and fabrication. During the research, an analysis was carried out of objects with structural free forms characterized by structural and material efficiency. The basis for their design was a parametric model containing information about the geometry of the mold shape, structural elements, and properties of the material from which the mold will be built, as well as information about the limitations resulting from the processes of manufacturing and assembling the structure in situ. Digital tectonics allows you to integrate geometric, structural, material, and fabrication aspects in one digital model with coherent logic.

The adopted comparative analysis scheme made it possible to determine what changes have occurred in the approach to designing free forms made of wood. Moving away from straight-line construction solutions (such as columns and beams) implies the search for new solutions that will take into account not only geometric features but also the inherent properties of the material, which have not been used before. In addition, new means of production (CNC) provide the possibility of making structural elements and their connections that were not easily achievable before.

It has been proven from the examples of the analyzed objects that the implementation of free forms from wood with curvilinear geometry requires a new understanding of the characteristics of the material and the resulting possibilities of its formation. The objects selected for research are shell structures in which the structure elements create a spatial structural system with complex, curvilinear geometry. New construction systems such as flexible gridshells, diagrid systems, or segmented coatings require different types of connections of their elements.

The different nature of the structural coating's operation determines the departure from the post-and-beam structures typical of the pre-digital era. In the implementation of wood, other properties of this material are also used to create free forms than in the past. This is determined by the different forms of wood-based materials produced in the form of surface or volumetric elements that can be precisely shaped through CNC machining. Changing the internal structure of a building element, e.g. by cross-gluing layers of wood, increases the load-carrying capacity and increases the efficiency of the supporting structure. New types of structures also use previously unnoticed or undesirable properties, such as flexibility and wood shrinkage and swelling.

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