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基于生物复合材料的双曲面分段式壳体展馆

Double Curved Segmented Shell Pavilion Made of Bio-composite Elements

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摘要：生物复合材料由于成本低、可再生和对环境友好的特性，在建筑中获得了新颖又广泛的应用。通过一对一的双曲面、参数化设计形成的分段式壳体，来展示生物材料在承重结构中的应用。这种结构由轻质的单向弯曲木和生物复合材料组成，其中，木质纤维基核心由长木纤维以单板形式加固。进一步探讨了高 3.6 m，面积 55 m^2 的展馆的建造技术以及生物复合材料应用的可能性。

关键词：生物复合材料；天然纤维复合材料；分段式壳体；多功能性；可持续性设计；木质纤维素复合材料；可持续性建筑

Abstract: Bio-based composite materials in architecture have gained various new applications due to their low cost, renewable and environment-friendly properties. This paper demonstrates the use of bio-based building materials for load bearing structures through a one to one double-curved, parametrically designed segmental shell. The Structure consists of light, single-curved wood and bio-composite elements where lignocellulosic-based core was reinforced by long wooden-fibres in the form of veneer. In this paper we furthermore discuss the fabrication technique of the 3.6 m height research pavilion covering 55 m^2 as well as possibilities of bio-composites.

Keywords: Bio-composites; natural fiber bio-composites; segmented shell; multi functionality; design for sustainability; lignocellulosic-based composites; sustainable architecture.

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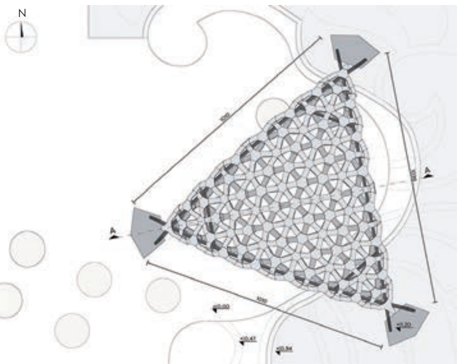
全球 35% 以上的能源以及近 45% 的资源应用于建筑行业中。如果人口持续增长，2030 年全球将需要比现在多 40% 的能源 [1]。为应对需求，我们需要为传统的不可再生资源寻找替代方案 [2]。现在大部分能源都被用于传统建筑材料如混凝土或钢铁的生产中。为满足可持续性建筑材料的要求，可以使用天然纤维生物复合材料来代替资源密集型材料（如钢、混凝土等）和其他合成纤维（如碳、玻璃等）。生物复合材料即天然纤维复合材料（NFRP），是由至少 2 种主要组分——纤维和基质（也称为黏合剂）制成的，其中至少有一种是基于生物的组分 [3]。天然纤维由于其可回收性和可重复使用性高，可以实现完整的生命周期，同时还具有现代性、几何灵活性和可持续性，这些特性在为实现更高的建设目标而寻求新的制造工艺时显得尤为突出。

生物复合材料展馆是一个高 3.6 m，跨度 9.5 m 的分段式壳体结构，通过真空辅助层压工艺将 121 个经过了参数优化的弯曲元件组合成型。每个元件的核心都以天然材料为基础，由单板形式的长木纤维加固，并涂有抗紫外线树脂以抵抗风化。

每个元件的核心都是通过压铸工艺制造



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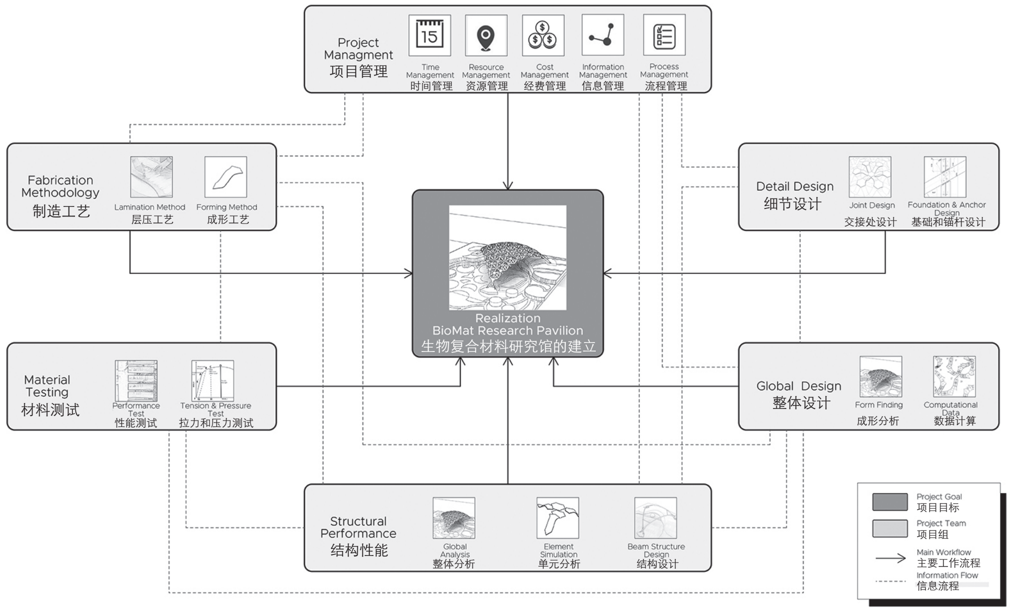

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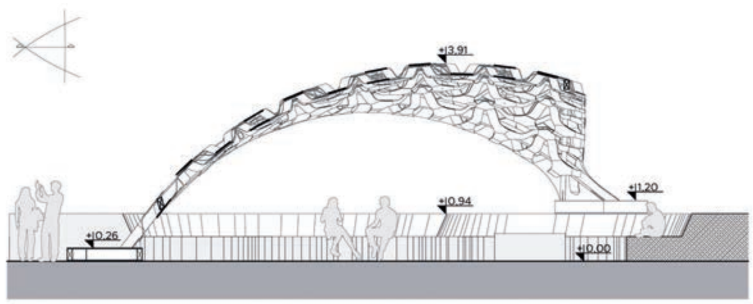

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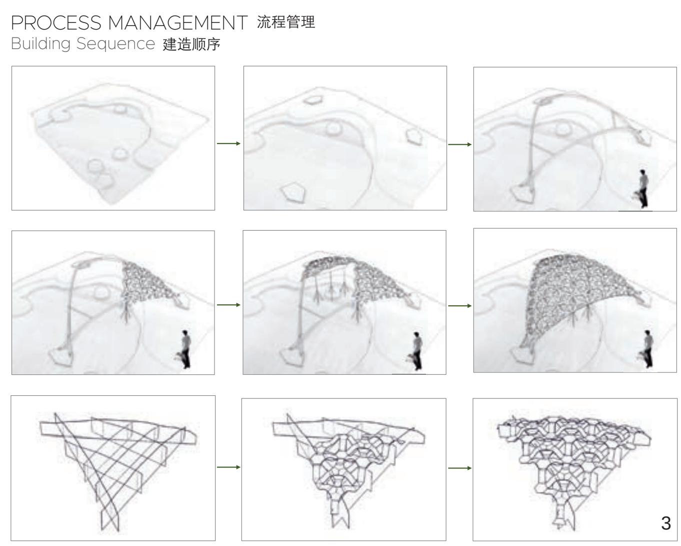

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1 用长纤维三维单板在通用模具上加固生物复合材料
Reinforcement of bio-composite by long fiber 3D veneer on universal mold

2 真空辅助层压工艺强化贴面
Vacuum-assisted veneer-reinforcement lamination process

3 流程管理
Process management

4 项目管理
Project management

而成的柔性板，其混合了生物塑料和天然纤维。天然纤维（例如稻草）这样的农业生产废料，在这里作为建筑材料获得了第二次生命。

与中密度纤维板（MDF）相比，柔性板的主要优点之一是优异的弹性，无须加热或水处理就能形成最典型的双曲面表皮。计算机数字控制机床（CNC）切割的纤维板，会被预切的三维层压板——一种可以同时向 2 个方向弯曲的层压板从两侧压成薄片。层压和成型的过程发生在真空压力袋内的模具中。层压技术不仅能将柔性平芯板转变为刚性三维的弯曲元件，还能形成具有比新材料本身更高机械性能的复合板。

例如，在弯曲实验中，样品弹性模量超过 5.5 GP，与 MDF 的弹性模量相同。同时，我们还开发了另一种类似木质复合板的变体，它把具有单向纤维的柔性木板作为板芯。这种变形实现了与第一种复合板相同的机械性能，由于组织方面的原因，最终在该展馆中使用了这种材料。

随后，所有的 121 个部件在现场用螺钉连接在一起，形成 4 个部分，并在交叉的木梁顶部拉动，实现连接。这种方法允许元件后续的分离和重新利用，以形成各种其他设计形式。

梁的基础位于不同的水平高度，能使结构形式适应当地景观的视觉和功能需求。在该结构内，元件彼此交织，形成一个类似于三维结构的分段式外壳，其中弯曲元件在空间的所有方向上都连接到公共节点上。

生物复合材料研究馆展示了由天然材料制成的新型建筑材料在建筑和结构上的潜力。生物材料项目组专注于研究其在建筑中不同方面的可持续性。这一建成项目是 10 个月高强度工作的成果，也是在生物材料应用领域中长期工作的一部分以及对可持续性建筑未来发展的探索。

5

6

7

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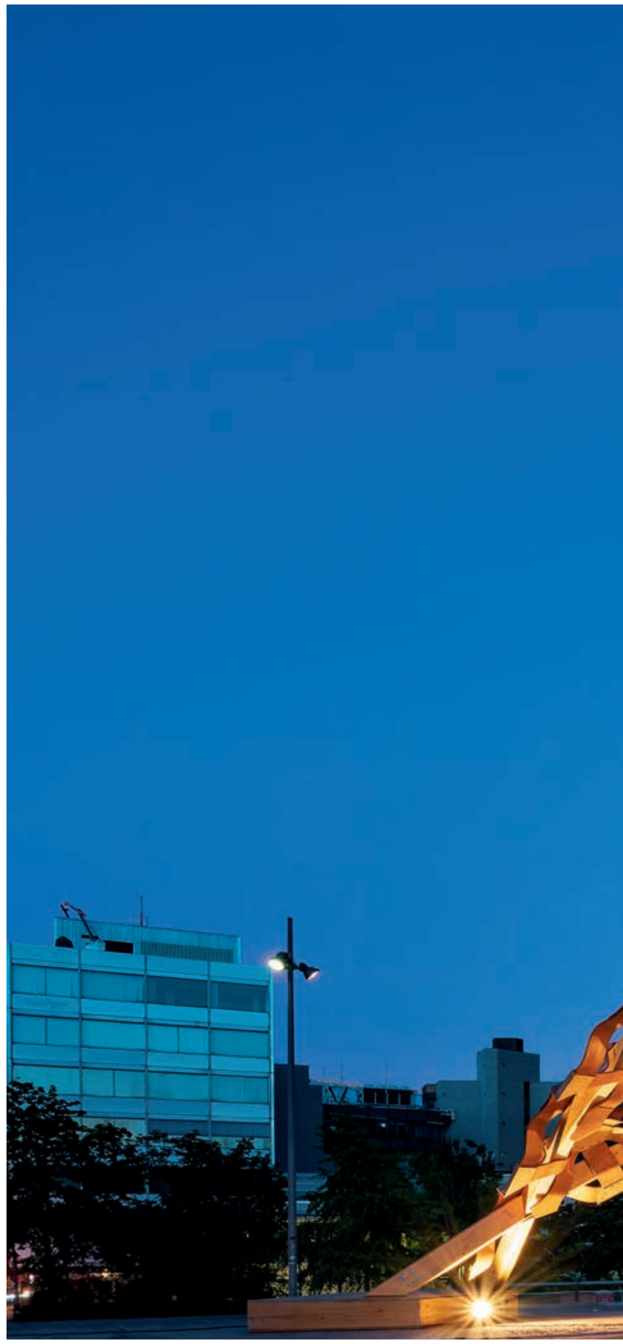
这项工作由经验丰富的建筑师和近 40 名建筑学专业的学生在两学期合作完成，得到了斯图加特大学（FKZ 22021516）、德国联邦食品和农业部下的可再生资源机构、巴登—符腾堡州基金会、弗劳恩霍夫研究所的支持，以及马蒂亚斯 · 斯坦奇和保利发有限责任公司研究项目中的经费支持。同时，这一项目还与多个当地和国际的研究所取得合作，包括荷兰埃因霍芬理工大学（TU/E）建筑环境系帕特里克 · 特乌菲尔教授、斯图加特大学建筑与结构设计研究所第二教研室土木与环境工程系的乌尔莱 · 库尔曼教授，以及工程大地测量第六研究所航空航天工程和大地测量系的沃克 · 施维格教授。木梁由布格巴赫尔 · 霍尔茨有限责任公司制造和提供，树脂由瀚森公司提供。



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（编辑 / 逵羽静）

项目名称：基于生物复合材料的双曲面分段式壳体展馆

项目完成时间：2018 年

面积：55 m^2

地点：德国斯图加特开普勒大街斯图加特大学

设计团队：建筑结构与结构设计学会生物材料与建筑材料循环研究小组

图片来源：斯图加特伊特克大学建筑结构与结构设计研究所生物基材料与建筑材料循环系

5 流程照片
Process photo

6 连接性增强的生物复合材料
Connected reinforced bio-composite elements

7 生物复合材料展馆（2017—2018 年）位于斯图加特大学，高 3.6 m、跨度 9.5 m，占地约 55 m^2，内部容积约 130 m^3
The BioMat Research Pavilion 2017—2018 covers an area of about 55 m^2 and an internal volume of approximately 130 m^3 with a span of 9.5 m and a height of 3.6 m

8 位于斯图加特市中心大学校园的生物复合材料研究馆（2017—2018 年）
The BioMat Research Pavilion 2017—2018 located at University Campus in Stuttgart city center

8

The building industry is responsible for more than 35% of global energy and almost 45% of global resource. If the population will continue the growing in 2030 the population will need 40% more of energy than today[1]. To meet this demand it is necessary to find alternative solutions to traditional non-renewable resources[2]. Traditional materials such as concrete or steel are responsible for most of the energy consumption. To meet the requirements for sustainable building materials the natural fiber bio-composites can be used instead of resource-intensive materials (steel, concrete etc.) or the other synthetic fibers (Carbon, Glass). Bio-composite materials, i.e. natural fibre reinforced polymeric composites (NFRP), are materials fabricated from at least two main components, a fibre and a matrix (also known as binder), where at least one of the two main components is biomass-based[3]. Thanks to high recyclability and reusability natural fibers can achieve a closed life cycle hand in hand with modernity, geometric flexibility and sustainability, especially when new manufacturing processes are used to achieve higher architectural goals.

The 3.6 m height, 9.5 m span research bio-composite pavilion is an interconnected segmented shell construction consisted of 121 parametrically optimized curved elements prepared by a vacuum-assisted veneer-reinforcement lamination process. Natural-based core of each element was reinforced by long wooden-fibres in the form of veneer, then coated with UV-resistant resin to resist against weathering conditions.

The core of the each element is a flexible board made from natural fibres mixed with bioplastic, manufactured by an extrusion process. The natural fibres, such as straw, are waste coming from agricultural production, which find its second life as material for architectural use.

One of the main advantages of this board in comparison to, for example, MDF, is exceptional elasticity which allows for forming even extremely double-curved surfaces, without heat or water treatment. The CNC cut fibre-board cores are later laminated from both sides with pre-cut 3D veneer sheets – a kind of veneer which can be bend in 2 directions at once. The processes of lamination and forming happen in a mold inside a vacuum press bag. Lamination not only allows to form a flexible flat core board into a stiff 3d bent element, but also allows to create a composite panel with mechanical properties higher than core material itself.

For example, during bending test specimens reached Elastic Modulus of over 5.5 GP which is equal to MDF. Simultaneously, another variation of a similar wooden composite plate was developed, in which a flexible wooden board with single direction fibres is used as a core. This variation achieved identical mechanical properties as the first one and finally, due to logistic reasons, was used in this pavilion.

All 121 components were later connected together on-site into 4 fragments, using screws, and pulled on top of the crossed wooden beams, where the final connections were realized. Such approach allows for elements to be separated later and reused to form various other designs and constellations.

Foundations of the beams are located at different height levels, allowing the structure form for visual and functional adaption to the local landscape. Within the structure, components interweave with each other, creating a segmented shell which resembles a 3D fabric in which the curved elements are connected to common nodes in all directions in space.

BioMat Research Pavilion demonstrates the architectural and structural potential of novel building materials made from natural material. BioMat department focuses on a mission of examining different sustainability aspects in architecture. This built work is the result of 10 months of intensive work, following many years of work in the field of applications of bio-based materials and diverse approaches towards future-oriented sustainable architecture.

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The work was the direct result of cooperation between experienced architects, around 40 architecture students over two semesters, with support from the University of Stuttgart, FKZ 22021516, the German Agency for Renewable Resources (FNR) in the Ministry of Food and Agriculture (BMEL), the Baden-Württemberg Foundation, Fraunhofer-Institut für Holzforschung (Fraunhofer WKI), and industrial funding from Mathias Stange ETS and profine GmbH in the framework of the Research Project (BioProfile), International and local collaboration has taken place, among others with the Technical University Eindhoven in the Netherlands (TU/e) - Department of Built Environment - Prof. Patrick Teuffel and various institutes of the University of Stuttgart, including the Institute of Construction and Structural Design (KE, Faculty 02: Civil and Environmental Engineering) - Prof. Urlike Kuhlmann and the Institute of Engineering Geodesy (IIGS, Faculty 06: Aerospace Engineering and Geodesy) - Prof. Volker Schwieger. Wooden beams were fabricated and supported by Burgbacher Holztechnologie GmbH, resin was provided by Hexion Inc.

(Editor / TI Yujing)

Project Name: Double Curved Segmented Shell Pavilion Made of Bio-composite Elements

Project Completion Time: 2018

Size: 55 m^2

Location: Universität Stuttgart Campus Stadtmitte, Keplerstraße, Stuttgart, Germany

Design Team: BioMat Group at ITKE

Sources of Figures: BioMat at ITKE University of Stuttgart

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