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Sustainable construction

Digital manufacturing processes enable buildings to be constructed with flax and willow

A switch to sustainable and circular construction concepts is needed to significantly reduce greenhouse gas emissions in the construction sector. At the German National Garden Show (Bundesgartenschau, BUGA) in Mannheim, Kernen-based FibR GmbH, together with researchers from the Karlsruhe Institute of Technology, will be showcasing two innovative buildings made from flax and willow, renewable raw materials that exemplify possible building concepts of the future.

According to estimates from the World Green Building Council (WorldGBC; the international umbrella organisation of national GBCs working on accelerating sustainability in the built environment), around 40 percent of global CO_2 emissions come from the construction and operation of buildings.[1)] 11 percent of these are so-called grey emissions, i.e. emissions released during material extraction and production, transport, construction itself and end-of-life demolition. Heat and electricity consumption during building operation currently account for 28 percent of CO_2 emissions. Thanks to renewable energies, this percentage is set to fall in the decades to come. Based on construction methods remaining the same, it is estimated that grey emissions will account for more than half of a new building's CO_2 footprint by around 2050. Moreover, the construction sector is the largest consumer in Europe of primary raw materials such as sand, limestone and iron, and generates almost a third of waste due to poor recycling rates.[2)]

Flax and willow as the basis for sustainable construction

Architect Moritz Dörstelmann, tenure-track professor for digital design and fabrication at KIT and founder of FibR GmbH, uses robot-assisted fabrication technologies in building processes involving flax and willow.
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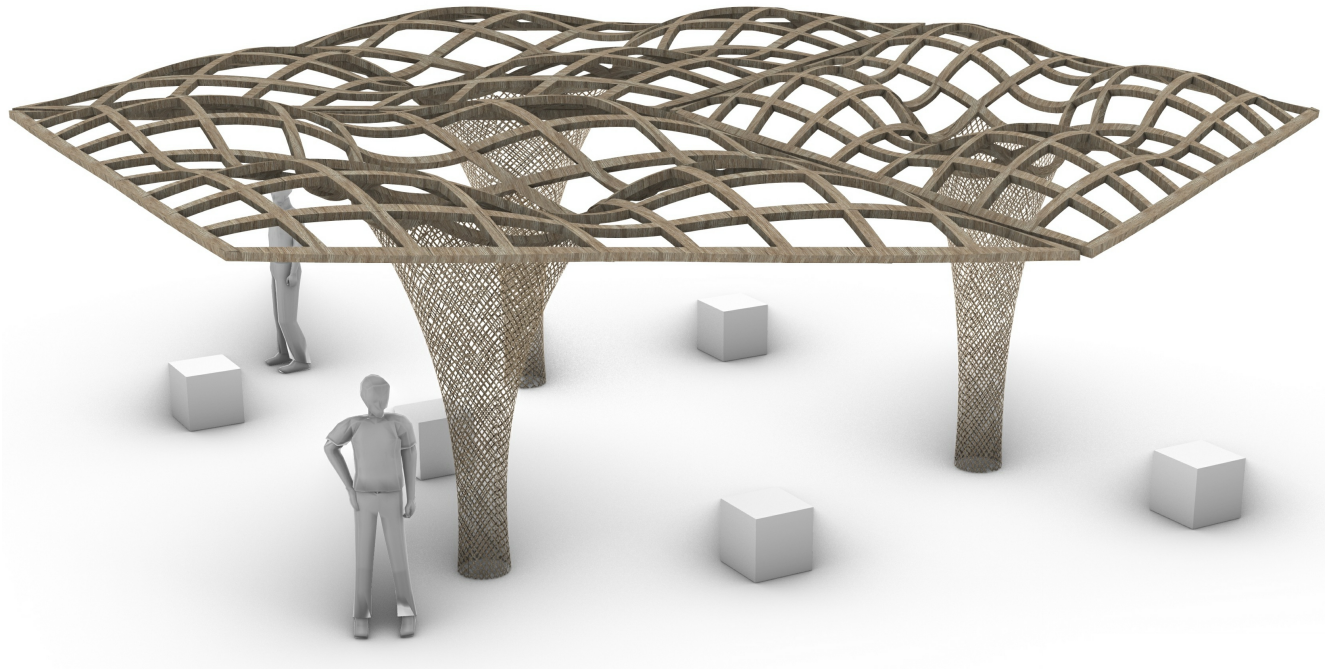
The new Digital Design and Fabrication (DDF) professorship at the Institute for Building Design and Technology at the Karlsruhe Institute of Technology (KIT) was created in 2021 to advance the development of novel concepts in the construction sector. "We want to use computer-based design methods and digital manufacturing processes to enable more circular and sustainable construction concepts," explains tenure-track professor Moritz Dörstelmann. "The basic approach is to find ways to consistently avoid extracting primary resources." That is why the architect's research is focused on processing renewable raw materials such as flax or willow. [3)] Unlike wood, which has growth cycles of 15 to 30 years and cannot easily meet demand, flax and willow can be harvested annually.

Dörstelmann can look back on many years of experience in this field at various research institutions and was involved, among other things, in the development of a robotic filament winding technique that can be used to produce lightweight structures, including those made of flax. [4)]

The short flax fibres are first joined together to form a roving. After this roving is passed through a bath of bioresin, it is placed on a shaping frame with the help of a winding robot to achieve optimal load transfer. After drying, the filigree construction elements then have a high load-bearing capacity.

Dörstelmann founded FibR GmbH together with a partner in 2017 so that he could use the process on an industrial scale. The



Design of the demonstration building with supporting pillars made of flax fibres and a roof construction made of wood for the BUGA 2023 in Mannheim.

company, based in Kernen im Remstal, has so far used flax fibres to build the livMatS pavilion at the Botanical Garden in Freiburg (2021) and the Smart Circular Bridge at the Floriade international horticultural exhibition in the Dutch city of Almere (2022).

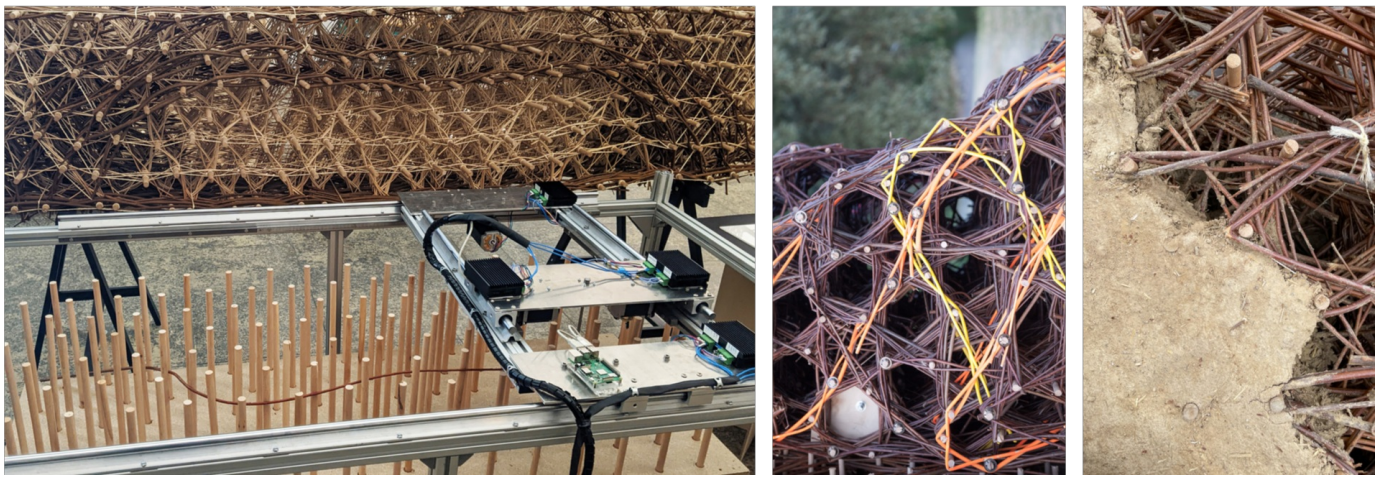
Since March 2022, FibR GmbH, together with five KIT professorships, has received funding from the Baden-Württemberg Ministry of Food, Rural Areas and Consumer Protection as part of Baden-Württemberg's sustainable bioeconomy strategy. The ReGrow project aims to open up new applications for flax and willow, both fast-growing raw materials that can be locally produced. Initial results will be presented in the form of two demonstration buildings at the German National Garden Show (BUGA) in Mannheim from April to October 2023. FibR GmbH is constructing a pavilion made of flax, the KIT professorships are developing a demonstration building made of willow.

Historical building material reinterpreted

"The use of willow as a building material is a research topic with a promising future that will be demonstrated on a large scale at BUGA," Dörstelmann says. "To produce a stable, load-bearing structural component from flexible, thin rods, we rely on a strategy similar to what nature does with wood." Wood is a natural composite material, consisting of the solid biopolymer lignin and cellulose fibres. "We combine the willow with clay and reinterpret this historic building material using digital design and manufacturing technologies." Scalable building elements are created after precise analysis of how the directional properties along the fibre can be used in combination with other materials.

The willow used for ReGrow grows near Karlsruhe on flood plains along the Rhine. This means it does not compete with food crops or forestry. The architect explains: "Such areas contribute to biodiversity, as they are only harvested once a year and are otherwise available as habitats." Unlike construction timber, which is dried in kilns in an energy-intensive process before it is processed, cut willow shoots are first stored in the air for a few months, a process that is environmentally friendly as it does not consume energy. As the willow shoots dry, their cross-section shrinks by about 40 percent. After around six months, the willow shoots (2 to 2.5 m long) are watered again and spliced together into a continuous strand of overlapping willow elements, a process similar to that used in textile manufacturing. The machine to do this was developed at KIT. "Using digital manufacturing methods makes it possible to create the desired products from renewable raw materials of uneven shapes and lengths. So we can process the willow directly from the field."

In the subsequent step, a robot weaves the willow strand into a basket-like construction that serves as formwork. The gaps are filled with clay, which gives the construction a stability comparable to wooden elements. In the willow-clay composites, the willow absorbs the tensile forces and the clay the pressure. "A large part of the ReGrow investigations consist of testing the construction's load-bearing capacity," Dörstelmann emphasises. This is done in a holistic and interdisciplinary way in close cooperation with Prof. Dr. Riccardo La Magna from the Professorship 'Design of Structures' at the KIT's Faculty of Architecture and also involves experts from the fields of architecture, civil engineering and materials science as well as electrical and production engineering. The researchers have access to a 500m^2 hall that is generously equipped with all they need, enabling them to quickly transfer small prototypes into large-scale models.



The robot developed at KIT (left) splices the willow rods together into a continuous strand and creates a component with a basket structure (centre). To increase stability, the spaces in between are filled with clay (right).

Versatile elements made of willow-clay composite

The components, which are made from renewable raw materials and require little energy for their manufacture, have additional advantages: they are modular and reusable. Thanks to a reversible joining technique, they can be detached from each other after assembly, transported easily and used elsewhere, creating a fully recyclable structure. In addition, the clay can be washed out and reused without losing its properties.

The willow-loam composite building made in Mannheim will grow until BUGA closes in autumn 2023 and gradually integrate new thematic aspects. Local energy production, for example. The architect explains: "When developing new building technologies, it is important to think about potential interfaces with other building materials and components right from the start. When planning and manufacturing our willow structures, we took into account interfaces to photovoltaic systems as well as the load-bearing capacity required. This involved working with a research group led by tenure-track professor Dr. Ulrich Paetzold from the KIT's Light Technology Institute." Another research theme addresses the microclimate in the outdoor area of the research buildings. A cool, green canyon will be created between two parallel walls using plants and special humidification. For this purpose, researchers from the Professorship 'Building Physics & Technical Building Services', headed up by Prof. Dr. Andreas Wagner, transferred simulation methods that already existed for indoor areas to the outdoor area and developed structural conditions for implementation as well as a suitable sensor technology.

From a bioeconomic point of view, the lightweight structures made of flax and the more solid components made of willow-clay composites complement conventional timber construction well. Once local value chains are established, the innovative robot-assisted manufacturing processes have the potential to become not only a more sensible, but also a cheaper construction method in the future.

Design of the demonstration building made of willow-clay composite with integrated solar panels (green) that will be displayed at BUGA 2023 in Mannheim.
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Cooperation partners at the Karlsruhe Institute of Technology (KIT):

- KIT Professorship 'Digital Design and Fabrication' (Tenure-track Prof. Moritz Dörstelmann)
- KIT Professorship 'Design of Structures' (Prof. Dr. Riccardo la Magna)
- KIT Professorship 'Building Physics and Technical Building Services' (Prof. Dr. Andreas Wagner)
- KIT Light Technology Institute (Tenure-track Prof. Dr. Ulrich Paetzold)
- KIT Institute for Industrial Production (Dr. Ing. Rebekka Volk)
- Industry partner: FibR GmbH Kernen

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Article

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- FibR GmbH
- KIT | Project InterTwig

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