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ReSidence: Towards scalable and circular multi-storey natural hybrid material buildings

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1. Research context

In the context of climate change and the current housing crisis, a rapid transformation towards a systemic circular design and construction practice is needed to provide sustainable, affordable living space. Fostering a cross-sectoral rural-urban industrial symbiosis that utilises rapidly renewable wetland materials for scalable and sustainable building solutions can contribute to the formation of a circular local bio-economy. This case-study explores the upscaling potential, digital prefabrication methods and circularity of horizontally spanning willow reinforced earth components, with the aim to create economically and ecologically affordable housing. The use of willow, earth, jute, flax, and timber strengthens supply chain resilience by expanding material diversity, thus promoting biodiversity, and circular practices. This enhances structural performance while reducing dependencies on finite resources. This paper first presents the developed building system then the testing of the earth-willow-timber ceiling components.

2. Research and Development

This circular multi-storey building system synergistically combines timber, willow, and earth into willow-reinforced earth components and was rapidly developed at a 1:1 scale while building on previous research on earth-willow hybrid structures[1]. Designed for reconfigurability, reusability, and modularity, it is enabled by digital prefabrication technologies which are tailored for low-energy processing, reduced skill barriers, and minimal investment costs[2]. The approach was successfully tested in the form of the two-storey research demonstrator 'ReSidence' at the Landesgartenschau in Wangen, Germany, in 2024. The building system contains three major elements: Its primary glulam structure uses simple geometries, connections and bracings that enable modularity and reuse. The flax fiber facade elements aim to further diversify the biogenic material used in the construction system. These load-bearing bio-composite elements, measuring 4.9 m x 0.9 m, were robotically prefabricated to provide the structural interface for the point supported transparent facade sheets to the primary timber structure. Finally, the earth-willow-timber ceiling components are based on the reinterpretation of vernacular half-timbered construction and historical cap ceilings. The ceiling components (1.2 m x 3.6 m) integrate willow, earth, and timber into a load-bearing system. Digitally prefabricated willow baskets made from spliced willow, bound with jute yarn, and woven around wooden poles serve as reinforcement within the load-bearing earth, which is supported and framed by cross-laminated timber beams. The automated process of the willow weaving ensures uniform output quality, improves scalability and minimises skill barriers.

Figure 1. Demonstrator pavilion 'ReSidence' (2024, Wangen im Allgäu)

To establish the earth-willow-timber ceiling components as viable alternatives to standardised materials within the highly regulated building industry, the components underwent interdisciplinary performance studies aligned with applicable building certifications: The short-term load carrying capacity was determined in one 1:1 test on a full component, supported as a single-span hybrid beam. The test was carried out in the VAKA lab of KIT Timber Structures. The total failure load of 120.6 kN at a mid-span deformation of 17.4 mm is equivalent to a distributed load of approx. 27 kN/m^2. In a preliminary test on a similar component, a total failure load of 141.7 kN at a mid-span deformation of 21.5 mm and failure of the LVL-panel in bending could be reached. To receive information on the long-term deformation behaviour, one long-term load test on a full component was realized in the DDF lab. The initial mid-span deformation under a distributed load of about 10 kN/m^2 was 8.5 mm (=L/425). After 4 weeks under load, the deformation of the component had increased to 17.5 mm (=L/205). Two adjacent components of an improved second design iteration were measured in a test rig in accordance with DIN EN ISO 10140-2. Regarding the sound reduction index (49.3 dB) and the standardised impact sound level (70.8 dB), the test components form a slim ceiling structure that operates without screed and performs comparable to a reinforced concrete ceiling of the same mass. The same two components were used for the fire test that was carried out at MFPA Leipzig GmbH, Germany, with a duration of 134 minutes according to the uniform-temperature-time-curve of DIN EN 1363-1 in conjunction with DIN EN 1365-2. After approx. 35 minutes, significant spalling of the clay was observed on the fire-exposed underside of the ceiling components. Nevertheless, all the requirements (load-bearing capacity/ résistance (R), enclosure/ étanchéité (E), heat insulation/ isolation (I)) for the components were fulfilled. The adjacent components can be classified according to the fire resistance class REI 120. Lastly, the thermal properties of the ceiling regarding overheating in summer were simulated using the software WUFI. The properties lay between those of a typical reinforced concrete ceiling and a heavy solid timber ceiling.

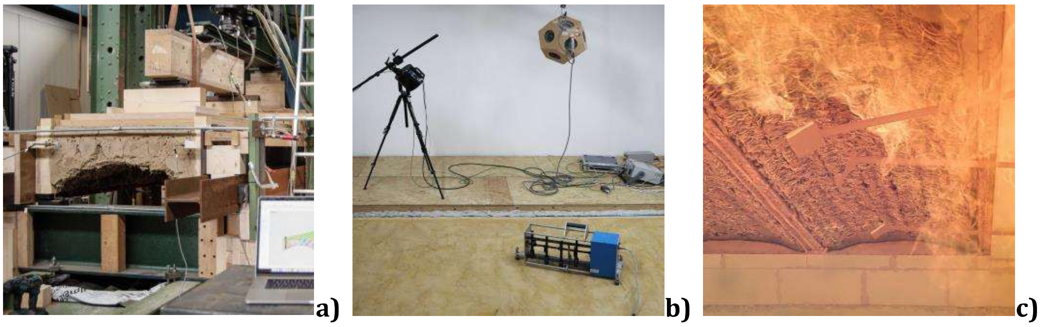

Figure 2. a) Load-bearing test, b) sound test, and c) fire test of the hybrid component ceiling slabs

3. Circularity

The rapid growth and high sequestration potential of willow cultivation via the continuous rewetting of drained wetlands and establishment of paludicultures offers a dual benefit. These systems enhance long-term carbon sequestration in soil and provide a diverse array of rapidly regrowing biomass, such as willow[3]. The research project investigates multiple circularity loops, modular reuse of all elements of the building system, remanufacturing of the earth-willow-timber components and fully circular end of life scenarios. The natural hybrid components are not chemically stabilised makes for an easy mechanical separation of the earth matrix and the willow rebar. While the recovered earth can be reused for new components, the spliced willow cannot be rewoven and will thus be reintegrated into the biological cycle at the end of its lifespan resulting in zero disposal waste[4].

4. Outlook

Preliminary cost estimations for scaled-up production indicate that, aside from the investment primarily driven by the formwork for the drying process, there is significant potential for cost reduction through full automation. Regardless, the upscaled production is projected to yield a ceiling system sales price within the upper range of comparable solid timber ceilings. In the next phase, the system will be developed into flat ceiling slabs to enhance standardisation and streamline fabrication. Given its high load-bearing potential and strong sound and fire performance, a next iteration will be evaluated in permanent multi-story housing as part of the *Internationale Bauausstellung 2027 (IBA27)* in Stuttgart, in collaboration with industry partners.

For further information and full project credits see: www.ddf.ieb.kit.edu

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