

Abstract (EN)

The construction industry, a major contributor to global carbon emissions and resource depletion, is increasingly exploring renewable materials and circular practices. Timber, a renewable resource that sequesters carbon, offers promise for sustainable construction, but its reuse potential is often limited by traditional assembly methods that damage components during disassembly. This research investigates how digital and robotic technologies can transform timber construction to support circular and sustainable building practices. The thesis responds to the growing need for environmentally responsible construction by presenting a digitally driven, data-informed framework for reconfigurable timber architecture, where timber components are designed for easy assembly, disassembly, and reuse, minimising environmental impact.

In reviewing existing literature and practices, the thesis identifies two primary gaps: the limited reuse potential in timber construction and a lack of integrated digital tools for tracking material data over a building's lifecycle. Traditional timber framing, though offering some flexibility, often lacks efficient data management and reuse planning. As a result, timber structures are not readily adaptable or sustainable in the long term, limiting their contribution to a circular economy. To address this, the research focuses on the application of Industry 4.0 technologies, such as cyber-physical systems (CPS) and robotic construction, combined with sustainable design principles like Design for Disassembly (DfD). This integrated approach enables timber structures to be more adaptable, allowing components to be repurposed in future projects.

The thesis applies a voxel-based computational design method, coupled with robotic and human-robot collaborative assembly techniques, to create modular timber structures with integrated data tracking. Voxel-based design enables the translation of structural, functional and spatial requirements into optimised timber components, through quick generative design algorithms. The use of cyber-physical systems facilitates real-time data management, providing continuous feedback during construction and supporting material traceability across different lifecycle stages. The integration of human-robot collaboration and augmented reality technologies further provides the possibility of construction adaptation to emerging challenges and informed decision-making in real-time.

The findings demonstrate that a voxel-based approach combined with digital data management can significantly improve timber structures' adaptability and lifespan. Timber components designed for modular assembly and disassembly can be repositioned and reused without material degradation, aligning with circularity principles. The research also finds that integrating cyber-physical systems with robotic assembly enhances construction efficiency and precision, essential for maintaining structural integrity during reuse. By fostering an integrated, data-informed approach, the study highlights the potential of digital technologies to revolutionise timber construction.

The research findings have been demonstrated over the design, fabrication and assembly of a real-scale architectural demonstrator which will be shortly installed at the campus of the University of Southern Denmark (SDU) in Odense. It will further provide insights into the structural behaviour and resistance of the modular construction components to external loading and weathering conditions, which will inform their future reuse scenarios. Future research will investigate the scalability and expansion of the developed methods to different building scales and applications, strengthening the role of timber as a sustainable resource in architecture.