INTEGRALLY-ATTACHED TIMBER PLATE STRUCTURES

From computational design...

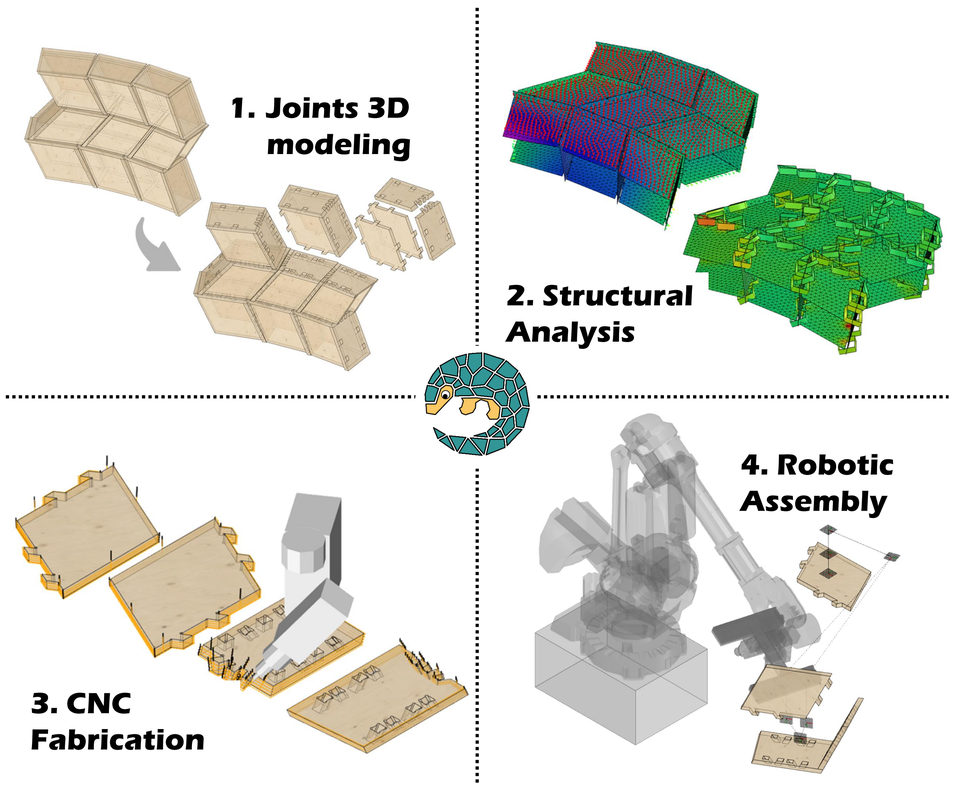

Figure 1 – The developed grasshopper plugin "Manis" allows the integration of design and fabrication constraints in a single interface.

This research focuses on the development of so-called *Integrally-Attached Timber Plate Structures (IATPS)*. This innovative construction system developed at the laboratory of timber constructions (IBOIS, EPFL) is inspired by ancient Japanese carpentry techniques. Timber panels are cut with a CNC router and connected by wooden joints to fabricate structures ranging from standard orthogonal slabs to doubly-curved vaults as featured in Annen's multi-purpose hall (see pictures below). Furthermore, in order to reach an even higher level of prefabrication, the feasibility of assembling the panels with an industrial robotic arm is currently being studied.

A recent achievement consisted in the release of *Manis*, an open source grasshopper plugin [1] that encompasses the 3D modeling of timber joints according to a specified assembly sequence, the generation of an associated finite element model for the structural analysis, as well as the generation and simulation of CNC toolpath and robotic trajectories for the fabrication and assembly of the panels respectively (Figure 1). The developed algorithm can be applied to any collection of timber plates, independently of the global geometry of the structure.

A major challenge lies in the calculation of compatible vectors of insertion for a given assembly sequence [2]. This is achieved by intersecting pieces of spheres representing the potential space of insertion associated to each timber joint (Figure 2, left). Furthermore, this method was extended to handle modular assembly sequences where groups of plates have to be inserted at once (Figure 2, right).

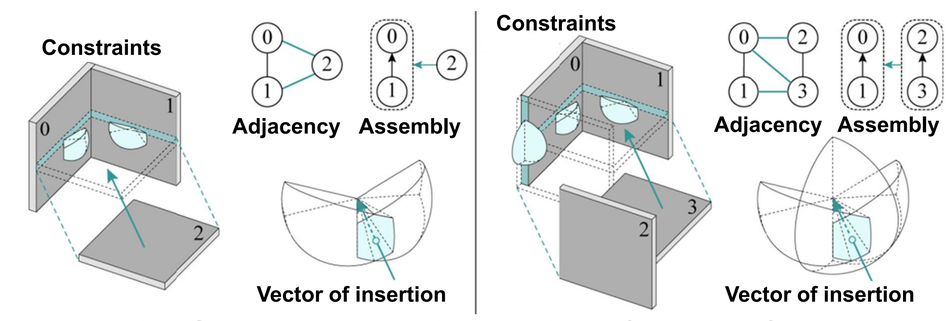

Figure 2 – Computing compatible vectors of insertion for a single plate (left) or a module (right) based on topological constraints.

...to robotic construction

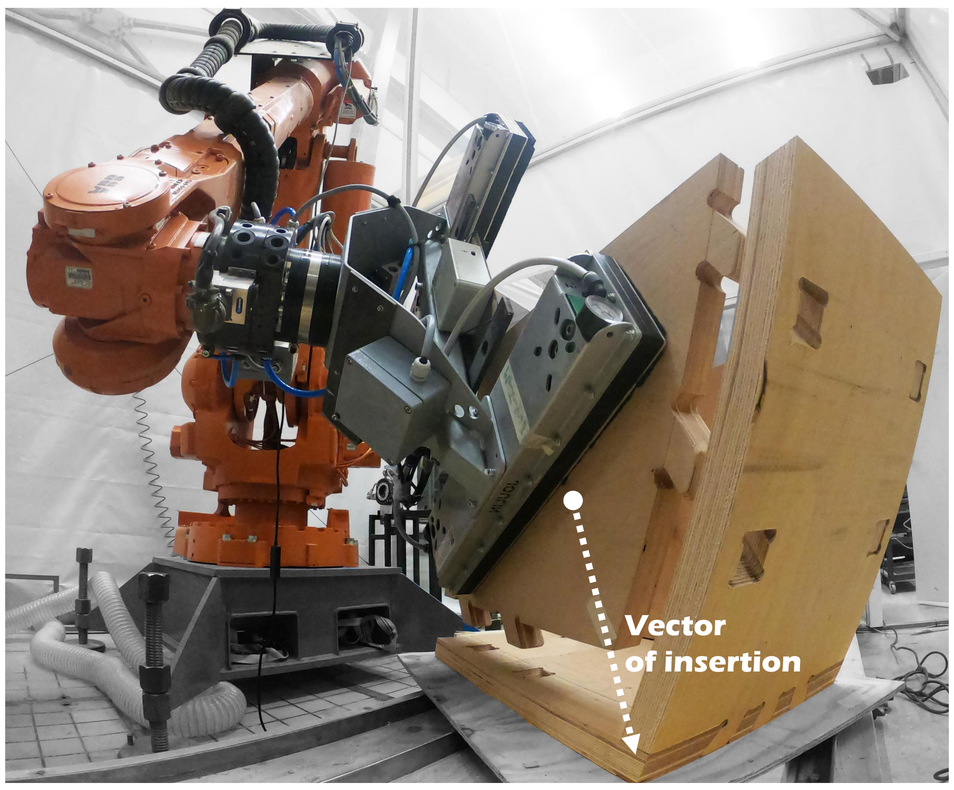

Figure 3 – For each plate, a vector of insertion compatible with the assembly sequence is computed to generate the robotic trajectory.

In addition to computational developments, experimental activities are being carried with a 6 axis robotic arm to assess the feasibility of automating the assembly process. A custom workflow has been implemented with our industrial partner (Imax Pro SA) to create a streamlined data exchange between the design interface and the robot controller. Robotic trajectories are generated within the design interface using the vectors of insertion associated to each plate (Figure 3). As further work on motion planning is necessary, collision detection is currently handled manually by adjusting the parameters of the trajectory according to the feedback given by the simulation.

Current investigations are focusing on determining the right amount of tolerance for the robotic insertion of timber joints. This is particularly challenging as too little tolerance prevents the joint from being assembled and too much tolerance compromises the rigidity of the structure. Therefore, the study consists in analyzing the evolution of friction forces during the insertion for different tolerances and shapes of joints. Forces are measured by a sensor equipped on the robot end effector and compared with the distances measured by two linear variable differential transformers fixed on the timber plates (Figure 4).

[1] N. Rogeau, A. Rezaei Rad, P. Vestartas, P. Latteur, Y. Weinand (2022), *A collaborative workflow to automate the design, analysis, and construction of Integrally-Attached Timber Plate Structures*, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, Sydney.
[2] N. Rogeau, P. Latteur, Y. Weinand (2021), *An integrated design tool for timber plate structures to generate joints geometry, fabrication toolpath, and robot trajectories,* Automation in Construction, Volume 130, October 2021, 103875.

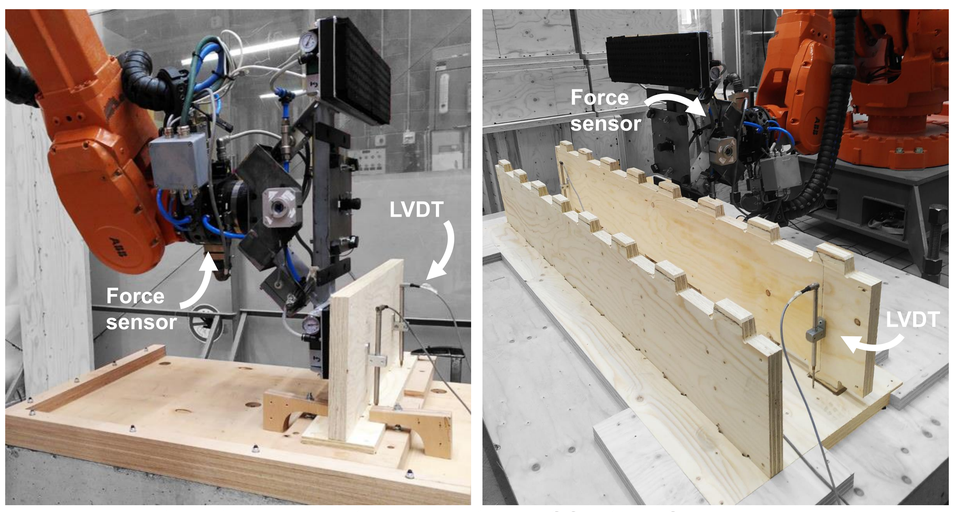

Figure 4 – Measuring the evolution of friction forces during the robotic insertion to deduce an optimal joint geometry.

The multipurpose hall of Annen, currently under construction in Manternach, Luxembourg (Architects: Valentiny hvp architects and Yves Weinand, Technology transfer: IBOIS)

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