Robotic Timber Construction

A Case Study Structure

Arash Adel
University of Michigan

Edyta Augustynowicz
ERNE AG Holzbau

Thomas Wehrle
ERNE AG Holzbau

1 A bespoke timber sub-assembly

INTRODUCTION

Several research projects (Gramazio et al. 2014; Willmann et al. 2015; Helm et al. 2017; Adel et al. 2018; Adel Ahmadian 2020) have investigated the use of automated assembly technologies (e.g., industrial robotic arms) for the fabrication of nonstandard timber structures. Building on these projects, we present a novel and transferable process for the robotic fabrication of bespoke timber subassemblies made of off-the-shelf standard timber elements. A nonstandard timber structure (Figure 2), consisting of four bespoke subassemblies: three vertical supports and a Zollinger (Allen 1999) roof structure, acts as the case study for the research and validates the feasibility of the proposed process.

FABRICATION

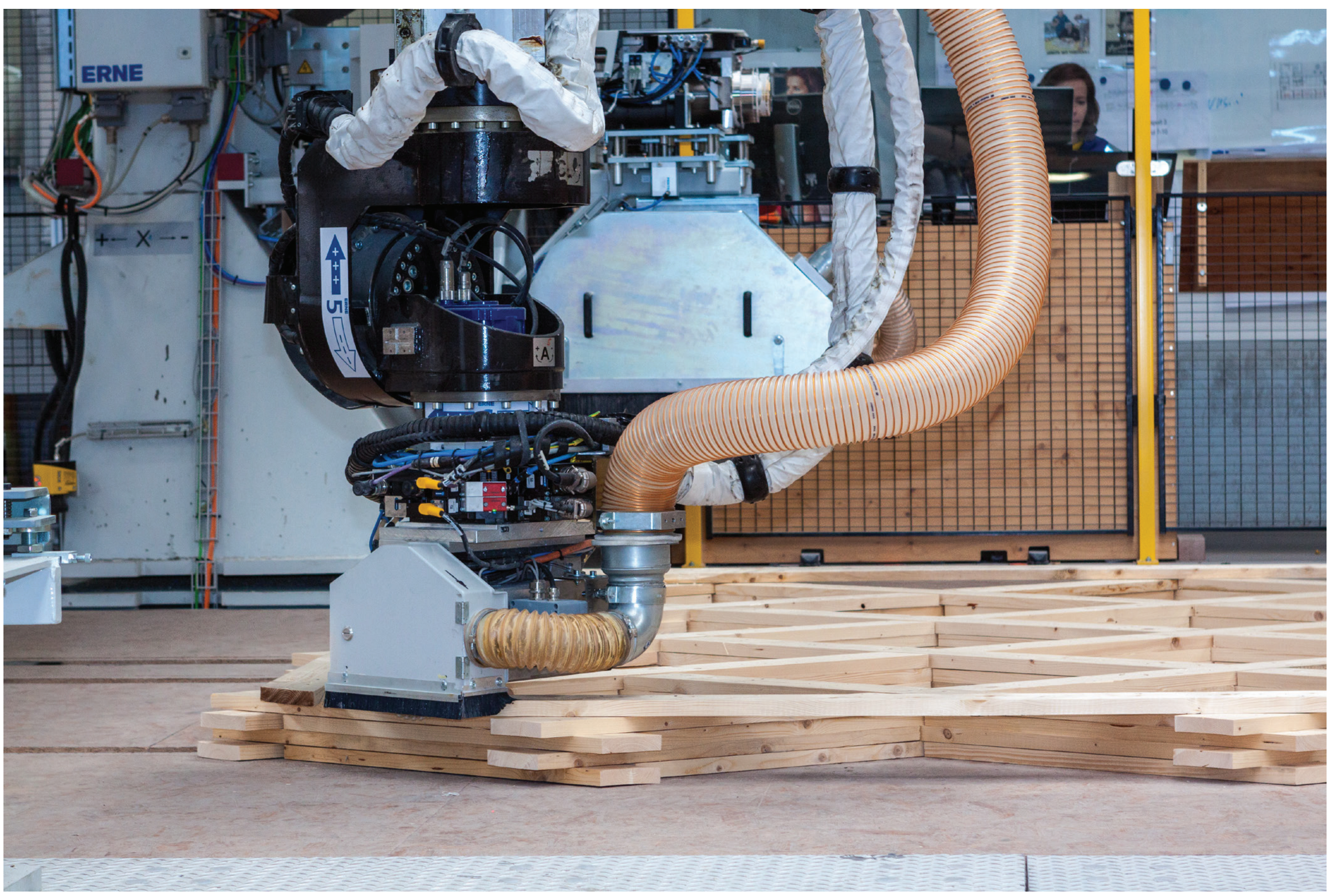
The fabrication setup of the project consisted of two distinct robotic cells (Figure 3) embedded in an industrial setting, each targeted at specific assembly routines (e.g., assembling a layer-based structure in a vertical direction). The first work cell is a 4-axis portal robot attached to a telescopic based mounted on a 2-axis gantry system (Figure 3a, with a total of 7-axis). The working envelope of this setup is 48m in length, 5.6m in width, and 1.4m in height. Besides the portal robot, this setup includes a picking station, an assembly platform, and an automatic tool-changing station enabling the portal robot to change its end-effector. Two custom end-effectors were employed for this project: a pneumatic gripper that includes an automatic nailing gun and a circular saw attached to a spindle for trimming timber elements. We also designed and built a custom picking

2 The case study structure

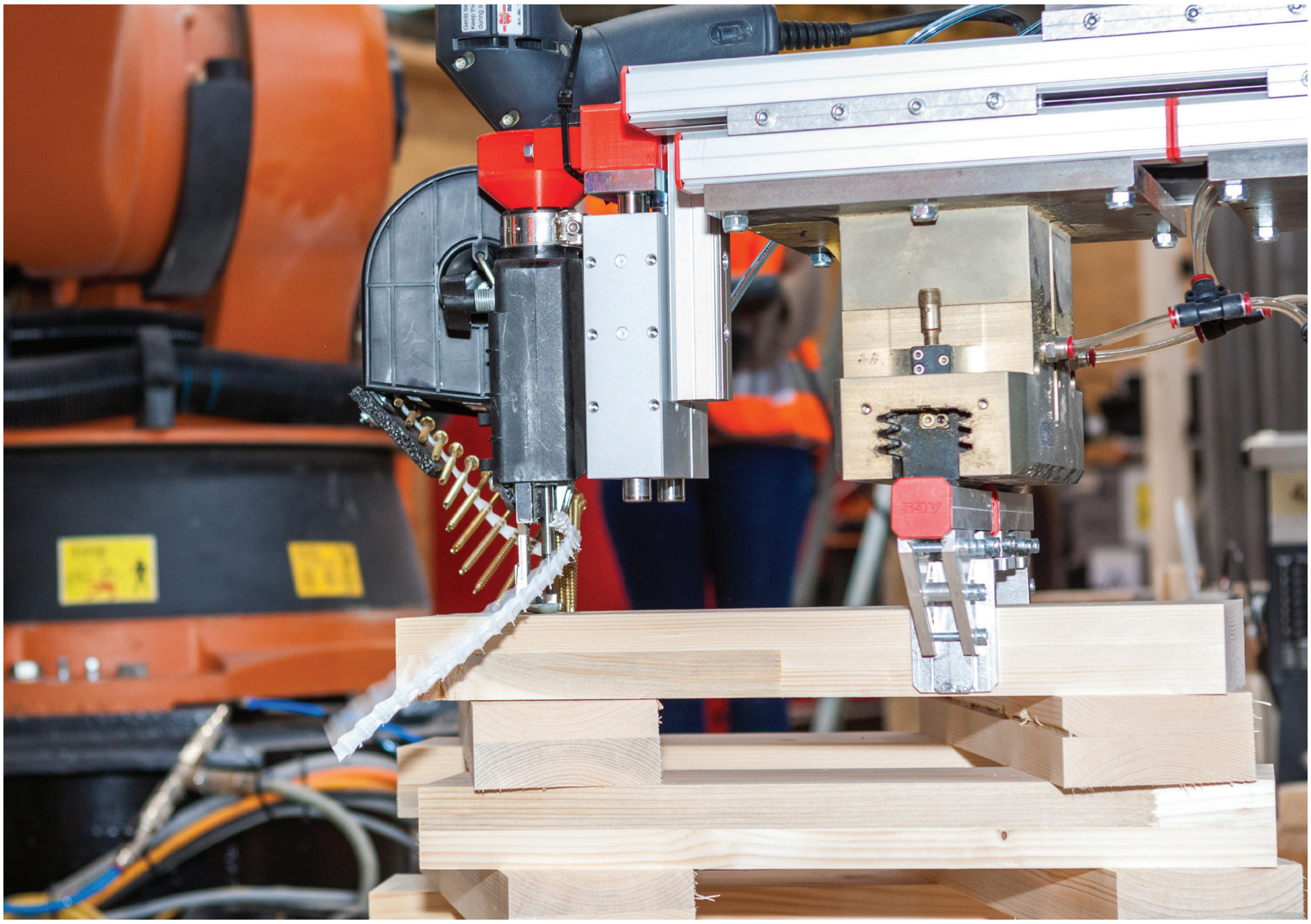
station that included nine slots for picking timber elements. The second work cell consists of a six-axis robotic arm[1] with a payload of 240kg and a reach of 2.9m, mounted on an external linear axis with a length of 4.5m (Figure 3b). The working envelope of this setup is 10.3m in length, 5.8m in width, and 2.9m in height. Besides the robotic arm, this setup includes a picking station, a table saw, and an assembly platform. The robotic arm is equipped with a custom-built pneumatic gripper that includes an automatic screwdriver for joining timber elements.

Each of these fabrication setups imposes specific constraints (e.g., the dimensional constraints of the working envelope) that must be incorporated into the design. The pavilion acts as the case study for the research and demonstrates the feasibility of the proposed approach for designing and assembling different building components that fit within the constraints and capabilities of each setup. The first fabrication cell was used for the assembly of the roof structure. For this case study, the timber elements of the roof structure were precut since the roof consists of 168 timber elements divide into only four standard size elements. The automated assembly process of the roof structure built upon the automated assembly of The Sequential Roof (Willmann et al. 2015) and consisted of the following main steps. The portal robot grips a timber element from one of the nine pickup stations (the elements were manually placed into the pickup points), carries it to the assembly platform, and places the element on the platform based on the element's predefined final position. Subsequently, the gripper shoots a nail at one end to attach the element to the timber layer underneath while holding it in place and then re-grips the element at its other end to correct the element's orientation and shoots nails based on the ordered list of the coordinates for placing nails. The nailing process starts from the other end of the element in respect to the first shot nail to minimize assembly tolerance due to the displacement of the timber element during the nailing process. After assembling all the timber elements of the grid shell (short elements), the portal robot attaches the long edge slats, nails them to the assembled structure,

3 Fabrication setups: a) work cell I; b) work cell II



4 Trimming the edge slats



5 Robotic placing of a timber slat and automatic insertion of screws

changes its end-effector to a circular saw attached to a spindle, and trims their corners in-place (Figure 4).

The industrial robotic arm was used for the assembly of the vertical supports. Due to the constraints of the working envelope of the robotic arm and its reach, we divided each vertical support into two halves, fabricated each half separately, and connected them to get the entire vertical support subassembly. In order to minimize fabrication tolerances at the interface of the vertical supports and the roof, we fabricated each half vertical support upside down. To fabricate each half, we developed a prototypical just-in-time robotic timber assembly process based on previous research results (Adel Ahmadian 2020; Craney and Adel 2021), which includes the following main steps. The industrial robotic arm grips a timber slat, carries it to the table saw, cuts the element in cooperation with the saw, places the slat on the assembly platform, and connect the element to the previously assembled timber layers with screws using the automatic screwdriver attached to its end effector (Figure 5). This process repeats until the half vertical support is fully assembled.

After the pre-assembly of the vertical supports and the roof structure, they are put together to form the overall structure (Figure 6) and then transported to the final position of the structure (Figure 7).

RESULTS

The developed process enabled the fabrication of a nonstandard timber structure, including three bespoke vertical supports and a novel roof structure (Figures 8, 9). These images also demonstrate the resulting expressive qualities and the intricate details of the structure.

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Taubman College of Architecture and Urban Planning, University of Michigan

Instructor and Project Lead: Arash Adel

6 Connecting the pre-assembled roof and vertical supports

Students: Ying Cai, Han-Yuan Chang, Ryan Craney, Carl Eppinger, Monik Gada, Chih Jou Lin, Feras Nour, Thea Thorrell, Christopher Voltl, Aaron Weaver, Chia Ching Yen

ERNE AG Holzbau
Project Lead: Thomas Wehrle, Edyta Augustynowicz
Team: Oliver Ackermann, Sascha Schade, Thomas Reiner

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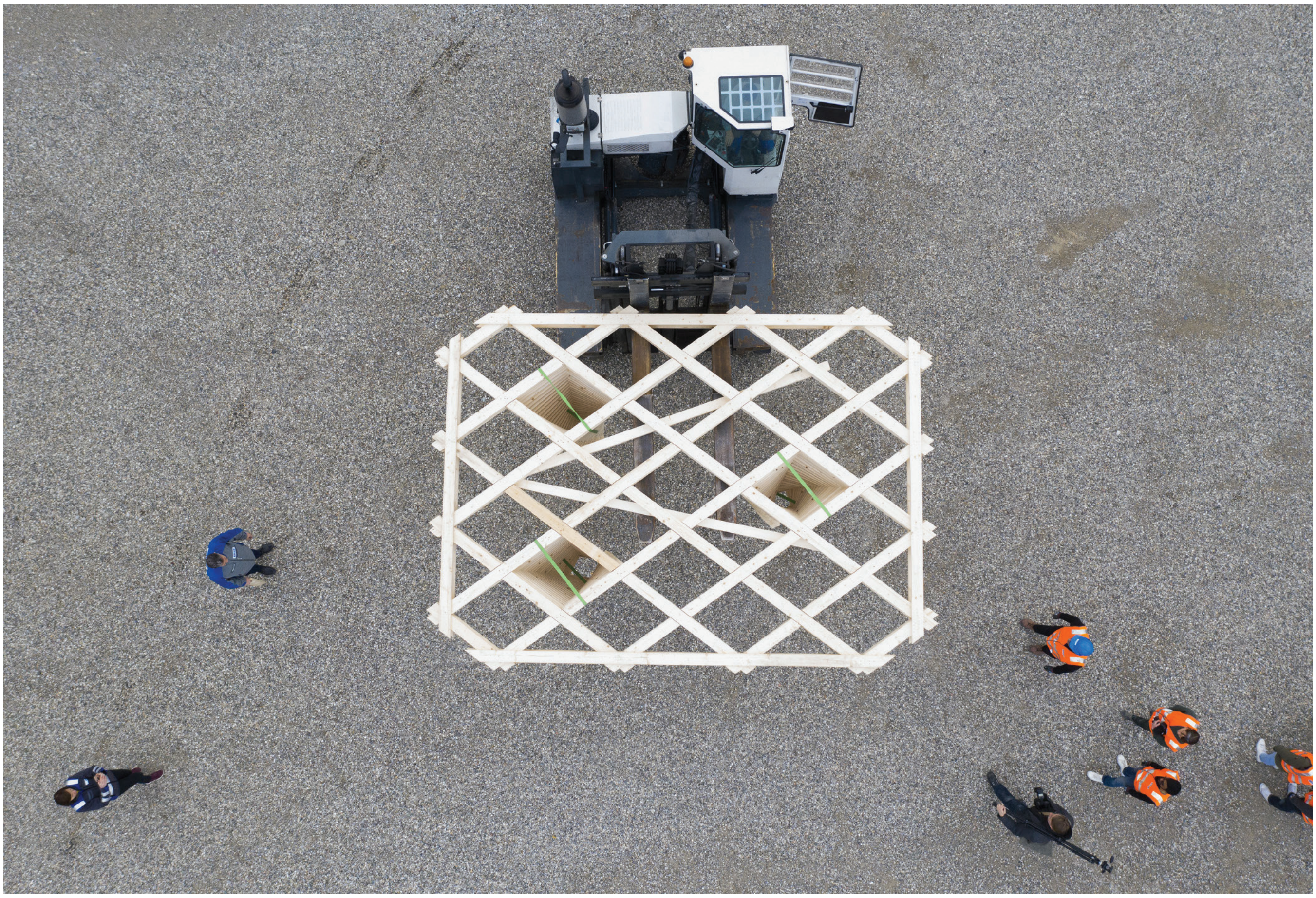

7 Onsite positioning of the pre-assembled structure

NOTES

1. KUKA KR240

IMAGE CREDITS

Figures 1, 3, 4, 5, 6, 8: Daniel Nikles, 2020
Figures 2, 9: Ryan Craney, 2020
Figure 7: Oliver Ackerman, 2020

Arash Adel is Assistant Professor of Architecture at the University of Michigan's Taubman College of Architecture and Urban Planning, where he directs the ADR Laboratory. Adel's interdisciplinary research is at the intersection of design, computation, engineering, and robotic construction. He is particularly known for his work with novel integrative computational design methods coupled with robotic assembly techniques for manufacturing nonstandard multi-story timber buildings. Adel received his Master in Architecture from Harvard University and his doctorate in architecture from the Swiss Federal Institute of Technology (ETH).

Edyta Augustynowicz is an architect, researcher, and computational designer specializing in complex timber structures. She is currently affiliated with ERNE AG Holzbau. She holds a Master in Architecture and Urban Design from the TU Poznan and a MAS degree in CAAD from the ETH Zurich. Her previous experience includes Digital Technology Group at Herzog & de Meuron, Block Research Group at ETH Zurich, and Institute Integrative Design, HGK, FHNW in Basel.

Thomas Wehrle is CTO at ERNE AG Holzbau. He is responsible for the development of digitalization and the introduction of robotic production at the company. For his achievements with the imple-men¬tation of robotics in collaboration with ETH Zurich, he was awarded in 2017 the European Innovation Award for the Forestry and Wood Industries. In parallel he is tutor and researcher at Hochschule Luzern, Berner Fachhochschule and ETH Zurich. He holds a Master's degree from ZHAW School of Engineering.

8 The fully-assembled timber structure