Robotic Fabrication of Nail-Laminated Timber: A Case Study Exhibition

Daniel Ruan
Princeton University

Arash Adel
Princeton University

1   Bespoke nail-laminated timber construction.

Introduction

Previous research projects (Adel, Agustynowicz, and Wehrle 2021; Adel Ahmadian 2020; Craney and Adel 2020; Adel et al. 2018; Apolinarska et al. 2016; Helm et al. 2017; Willmann et al. 2015; Oesterle 2009) have explored the use of comprehensive digital design-to-fabrication workflows for the construction of nonstandard timber structures employing robotic assembly technologies. More recently, the Robotically Fabricated Structure (RFS), a bespoke outdoor timber pavilion, demonstrated the potential for highly articulated timber architecture using short timber elements and human-robot collaborative assembly (HRCA) (Adel 2022). In the developed HRCA process, a human operator and a human fabricator work alongside industrial robotic arms in a shared working environment, enabling collaborative fabrication approaches. Building upon this research, we present an exploration adapting HRCA to nail-laminated timber (NLT) fabrication, demonstrated through a case study exhibition (Figures 1 and 2).

The case study is a three-floor structure supported by two curved walls, exemplifying a nonstandard NLT multistory housing construction system that would be difficult to achieve using conventional methods. For the exhibition, we constructed a single story of this structure.
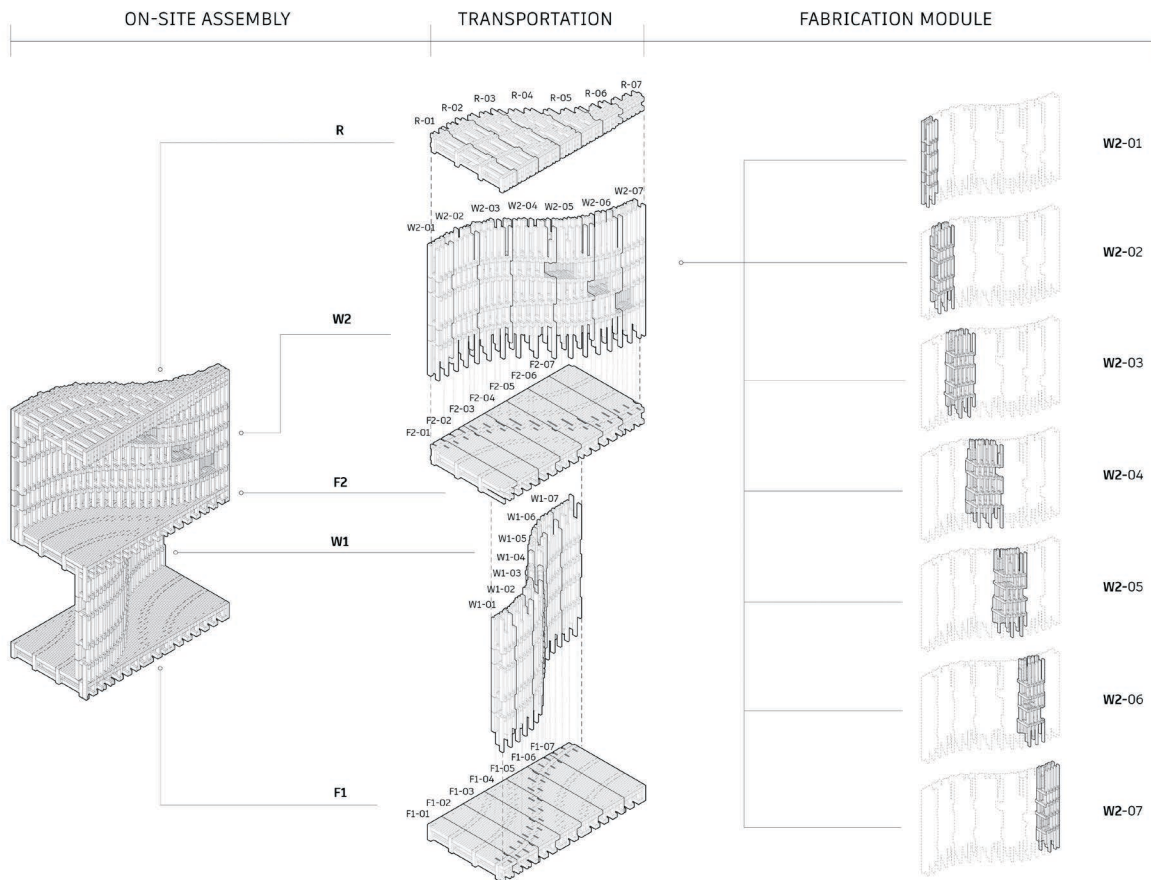
2   Multistory NLT constructive system and its components. For the exhibition, we constructed the second story.

Design

The case study structure was fabricated using a robotic workcell consisting of two six-axis industrial robotic arms, each with a payload of 60kg and a reach of 2m, mounted 2.7m apart. The two robotic arms employed custom pneumatic gripper end effectors and had separate pickup stations for dimensional 2x4 lumber. The workcell also included a shared table saw and assembly platform, with a combined working envelope approximately 1.6m wide, 4.6m long, and 2.0m high. The minimum element length that could be safely cut without colliding with the saw was 330mm, while the maximum element length was 880mm, to prevent collision with the robot during the cutting process. These parameters defined the fabrication constraints for the design.

The constructive system was informed by NLT design guidelines (Holt, Luthi, and Dickof 2017) and physical prototyping experimentation. The core of the constructive system was an underlying pattern that repeated every three laminations to create a double-layered structural component. One visual effect of this pattern was a series of seam lines between sections of the NLT, with the number of sections bounded by the element length constraint. For instance, in the case study, we divided the 3m-tall wall into five horizontal sections using four Bezier curves (Mortenson 1999), creating a visual perspectival scaling effect along the wall surface (Figure 6). We interrupted the pattern by algorithmically transforming elements to introduce functional openings such as embedded shelving.

A minimum overlap of 30mm from any timber element edge was required to ensure proper fastening between laminations. This allowed elements to be offset out of plane up to 59mm (the width of an element minus the overlap), allowing for curvature and textural effects in the NLT. The exhibition structure was situated within a 2m by 3.8m footprint and showcased an S-curved wall, simultaneously demonstrating the mass customization potential of the robotic fabrication process and being structurally self-supporting to leverage a cantilevering ceiling with a maximum 1.7m span and 2.32m interior height. This wall partitioned an interior and exterior space, and Perlin noise (Perlin 1985) was applied to the elements on the exterior face of the wall,
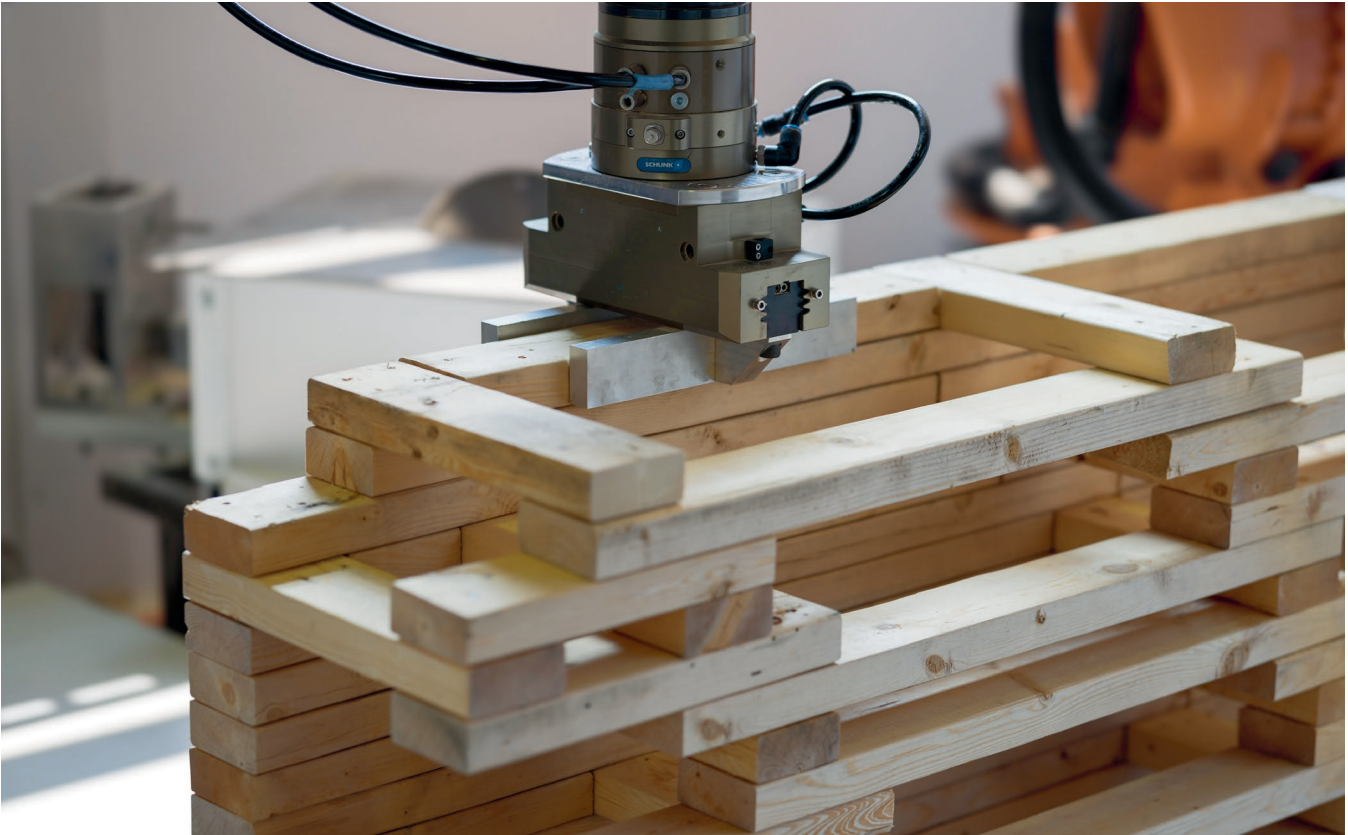
3   Robotically placing an element on the NLT fabrication module.

4   On-site tilt-up assembly process.

5   Fully assembled NLT structure, showing exterior wall and cantilever roof.

offsetting them to create an undulating texture that could be potentially tied to performance aspects such as acoustics or shading (Figure 1).

We utilized an iterative feedback loop to ensure that the design was fabricable at each step of the assembly process, performing automated validation to impose the fabrication constraints. The final design was then subdivided into fabrication modules with a maximum of 15 laminations each to fit within the workcell envelope and to maintain a weight that three human workers can comfortably carry.

Fabrication and On-Site Assembly
We have implemented a digital design-to-fabrication workflow, in which a valid assembly sequence and fabrication instructions are generated from the computational design model to pick, cut, and place each element (Adel 2022; Adel Ahmadian 2020). These instructions also tell the human operator what nominal length of timber stock to load into the pickup station, minimizing offcut waste. After placing,

the robot halts to allow the human operator access into the cell to fasten the element to the previous lamination using a nail gun, as well as perform a quality check of the module (Figure 3). This process repeats until the module is completed, after which it is tagged and prepared for transport for final assembly on site.

The fabrication modules were first combined using screws to form sub-assemblies, which were then braced temporarily, tilted up, and shifted into place (Figure 4). We used ratchet straps to temporarily bond each sub-assembly in place, while more screws were used to fasten them to the structure. This on-site assembly method was particularly suited for the exhibition structure due to its location indoors and, as such, avoided crane usage and weatherproofing. In the case of the envisioned multistory structure (Figure 2), the on-site assembly process will need to be adapted to accommodate lifting larger sub-assemblies into place, which is an area for further research.

6   Fully assembled NLT structure, showing interior wall.

Results

The developed robotic NLT fabrication workflow enabled the construction of the exhibition structure consisting of 1,814 short timber elements fastened with 7,166 nails. This case study demonstrates the potential for mass-customizable housing using automated NLT prefabrication through its high-resolution structure, curved surfaces, and differentiated texture to accommodate performance constraints and functional requirements.

ACKNOWLEDGMENTS

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IMAGE CREDITS

Daniel Ruan is a Ph.D. in Architecture student at Princeton
University's School of Architecture, and a research assistant at
ADR Laboratory. His research is focused on the real-time robotic
prefabrication of timber assemblies, adapting leading-edge
robotic technologies for use in architecture and construction.
Ruan received his Master of Science in Digital and Material
Technologies at the University of Michigan, and his Bachelor of
Architecture from Rensselaer Polytechnic Institute.

Arash Adel is an Assistant Professor at Princeton University's
School of Architecture and the director of ADR Laboratory. His
laboratory conducts interdisciplinary research at the inter-
section of design, computation, and robotics, contributing to
resilient, sustainable, and low-carbon construction outlooks
and achievements. At the core of his comprehensive research
is investigating human-machine collaborative processes, which
tackle fundamental questions related to the future of the design
and construction industries and their potential to have a broader
impact on inclusive and equitable building culture.

Before joining Princeton University, Adel was an Assistant
Professor of Architecture at the University of Michigan. He
received his Doctorate in Architecture from the Swiss Federal
Institute of Technology (ETH) and his Master's in Architecture from
Harvard University.