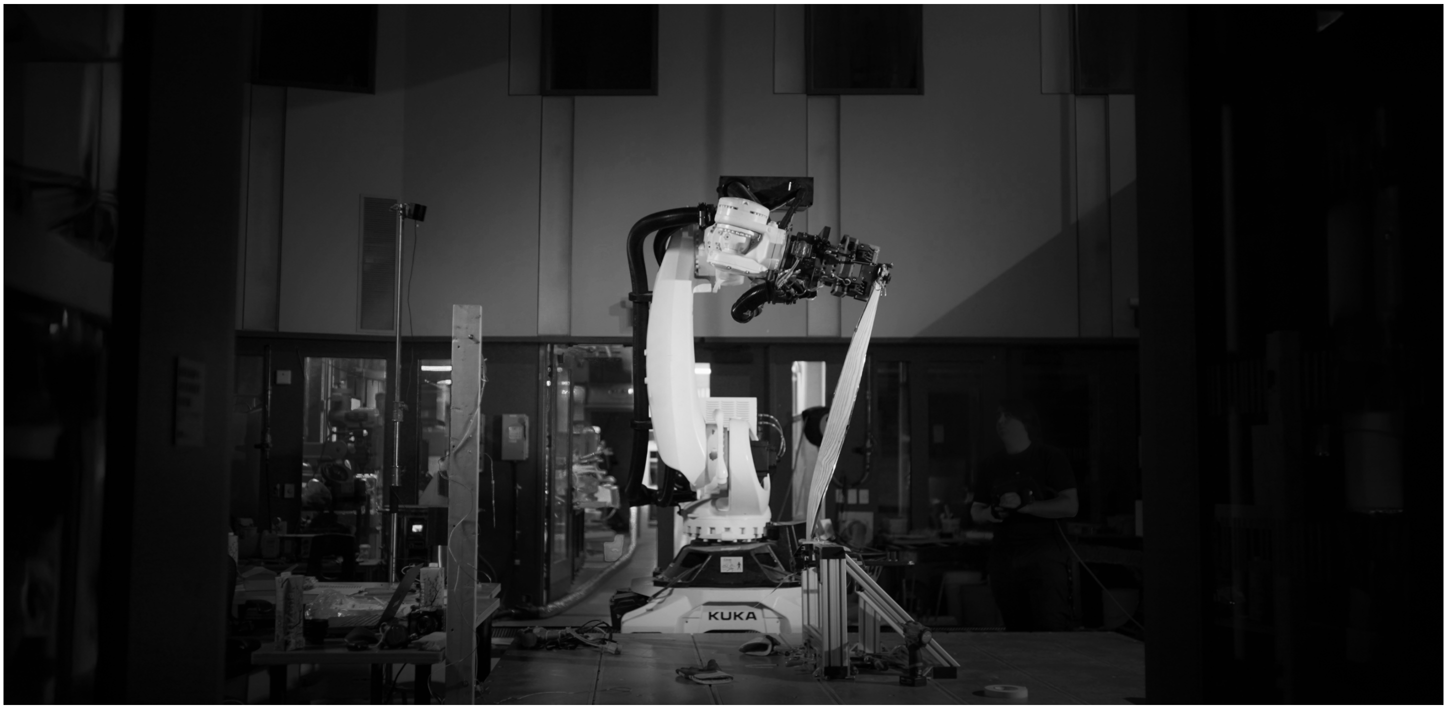


Photograph of our formwork-free robotic steam-bending system that enables controlled curvature of steamed wood strips. Photograph by Liam Cassano.

Material Feedback in Robotic Steam Bending: *A Quantitative Approach to Wood Forming*

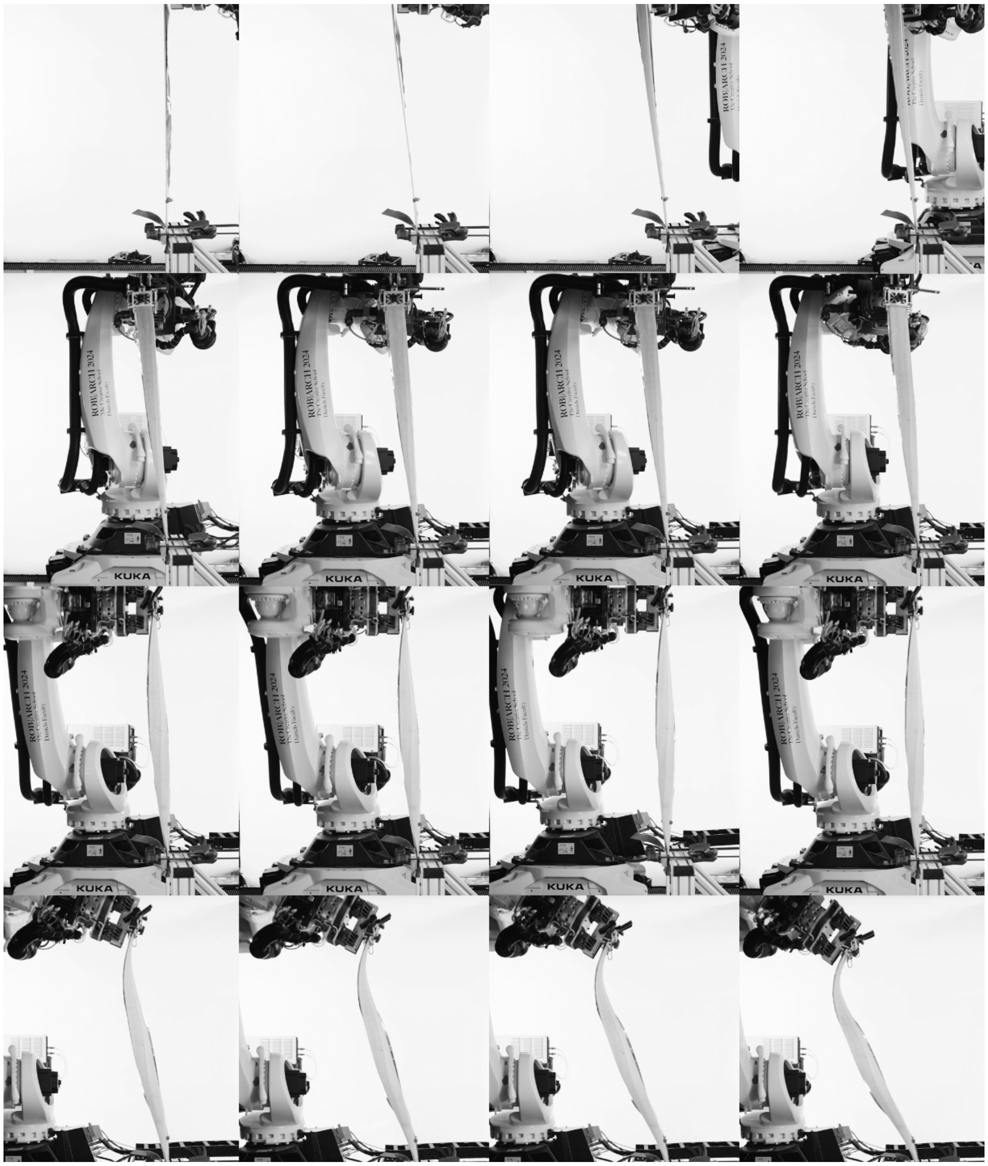
Liam Cassano
Olivia Carson
Karina Craig
Micha Fairfax-Angod

Supervised by
Maria Yablonina
& Nicholas Hoban

Robotic system design, engineering, and assembling by Liam Cassano; VR scanning system design and data interpretation by Olivia Carson; contextual research and scanning system management by Karina Craig; wood milling, assembling, and light scanning by Micha Fairfax-Angod.

This research develops a low-waste fabrication workflow that integrates robotic control, computational path planning, and empirical sensing to advance wood steam bending without formwork. By eliminating single-use jigs and enabling material-responsive design, the project bridges traditional craft and digital fabrication while minimizing resource use, establishing a method for predicting, executing, and evaluating wood deformation during and after robotic bending.

A catalogue of bend geometries, deviations, and springback behaviors was produced through a series of controlled tests, linking material response to computational input. The results demonstrate high geometric accuracy (average 1.15% deviation from target curves) and repeatability (99% geometric consistency), while quantifying springback as a predictable, material-specific behavior. The workflow contributes a scalable methodology for generating empirical material data, enabling responsive fabrication and reducing reliance on rigid tooling. **This research proposes a shift from eliminating variation toward designing with material intelligence, advancing a fabrication logic grounded in adaptability, low waste, and circular material feedback loops.**



Photographic sequence of robotic wood bending action. Photographs by Liam Cassano.

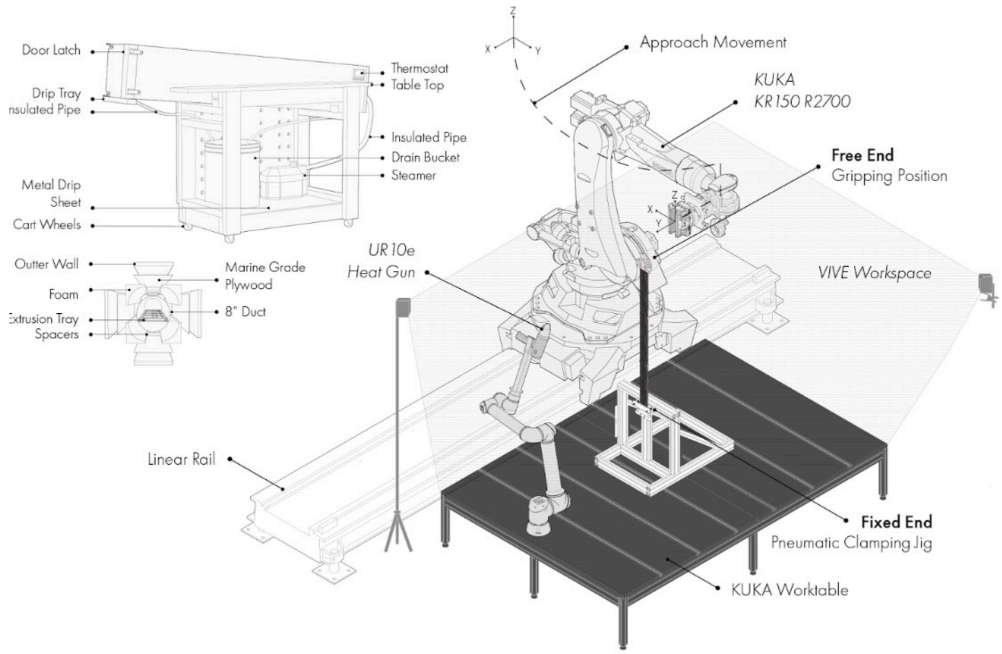
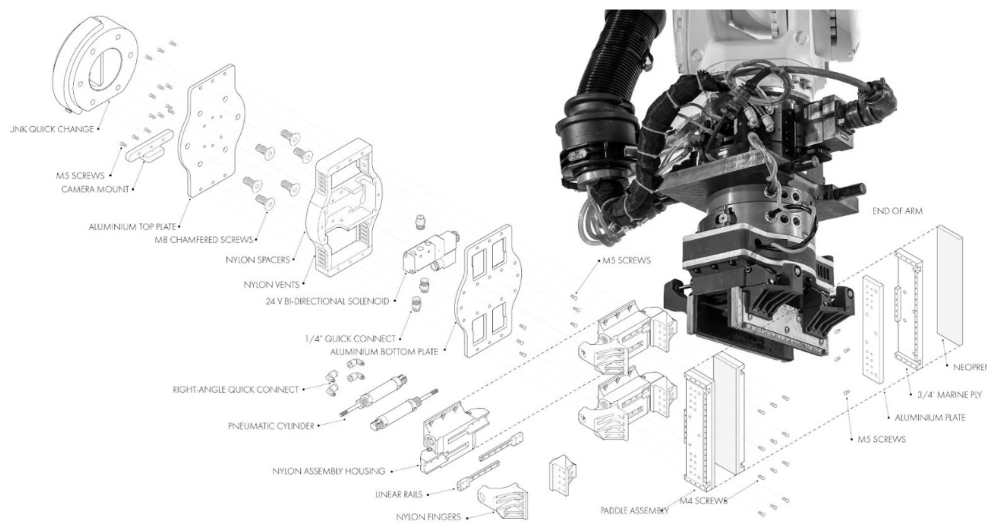


Diagram of the robotic bending and scanning environment. Steam chamber designed by Liam Cassano and Micha Fairfax-Angod; system engineered by Liam Cassano; drawing by Karina Craig.

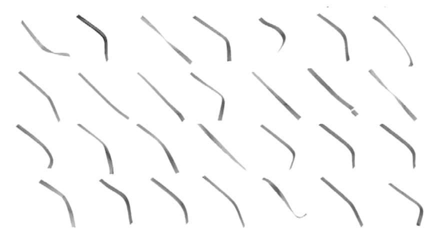


Exploded axonometric of the custom robotic end-effector, shown mounted on the KUKA KR150 R2700. System engineered by Liam Cassnano; photo by Liam Cassano; drawing by Karina Craig and Liam Cassano.

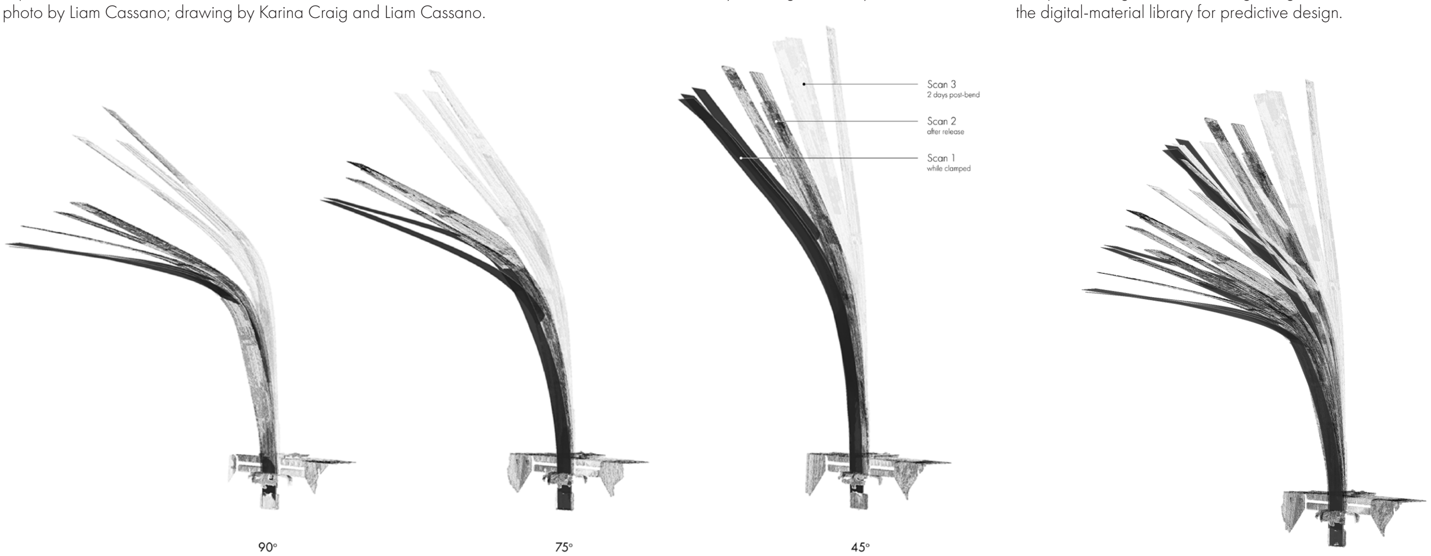
At this stage, our work contributes a successful methodology for a fabrication system that leverages the combination of computational simulation, sensing methods, and material intelligence. The robotic bending motion was programmed using a custom computational tool built in the Grasshopper environment, and using the KUKA|prc (Robots in Architecture, KUKA|prc) plugin to output robotic commands. The sequence of displacement operations in our formwork-free method greatly impacts the final geometry of the bent piece, implying that the path we take to the final position can result in different material reactions in the strip.

To re-digitize the physical bends, two sensing systems were used: a marker-based tracking system (HTC VIVE) for quick gathering of overall geometric information before drying (Scan 1), and a structured light scanner for gathering high-resolution scans after the drying process (Scans 1 and 2). Collected sensor data was used to benchmark the robotic bending outcome against the simulated curve geometry.

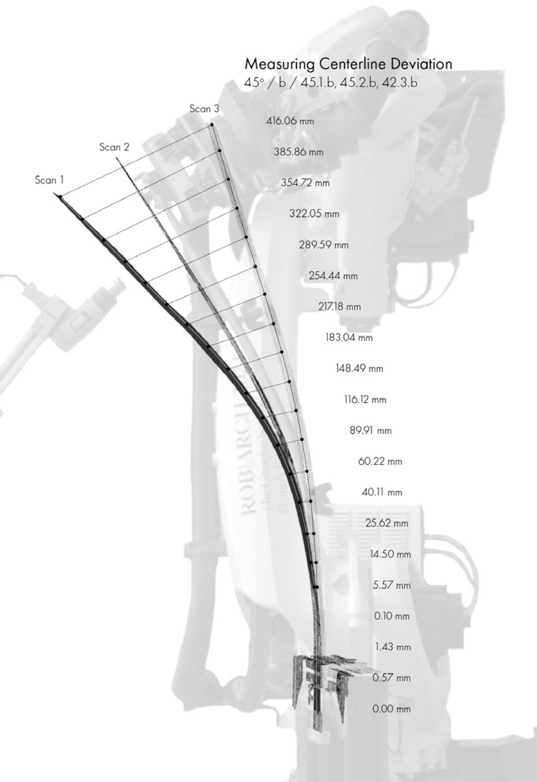
In contrast to traditional hand-bending, where formwork is required to maintain repeatable curvature, the robotic bending system achieves over 99% geometric consistency without reliance on formwork or jigs. (see graphs on next page) This has significant implications for precision fabrication, as it enables curvature variation with minimal setup and reduced formwork waste. This system thus offers an alternative to conventional methods, merging material responsiveness with computationally controlled repeatability, while advancing a circular fabrication model that prioritizes resource efficiency, adaptability, and long-term environmental benefit.

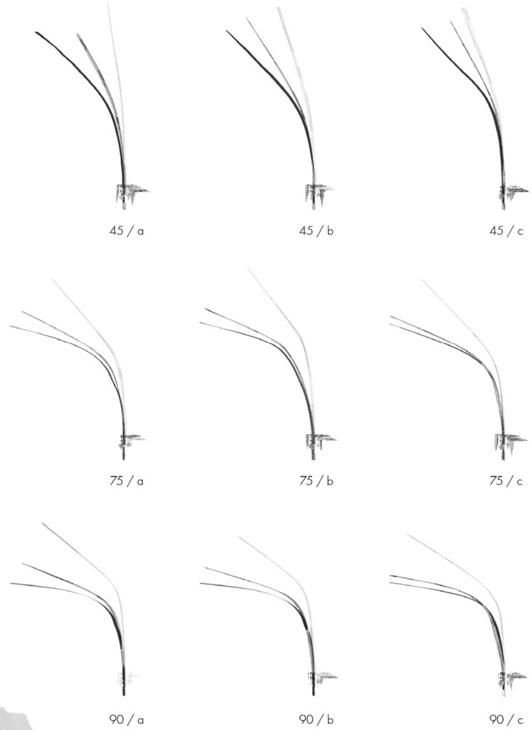


Sample catalogue demonstrating the geometric variation of the digital-material library for predictive design.

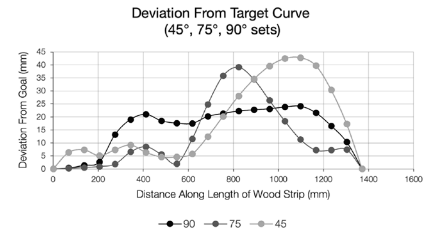


Comparing structured light scans of 2-Day post and initial springback with in-robot tracker-based scans across 45°, 75°, and 90° bends to determine accuracy and springback. To evaluate the material outcomes of each bend, a multi-modal sensing system (VIVE) was implemented in three stages: immediately after bending (Scan 1), after flash-drying (Scan 2), and two days after release (Scan 3). VIVE scanning system designed by Olivia Carson; VIVE system operated and managed by Olivia Carson, Karina Craig, and Micha Fairfax-Angod; light scans by Micha Fairfax-Angod; geometry refinement by Olivia Carson and Maria Yablonina; drawing by Olivia Carson.

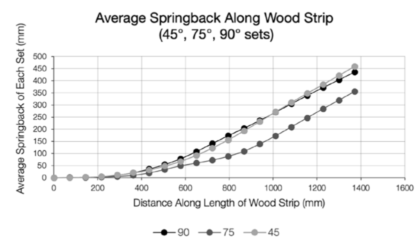




Measuring centerline deviation: each scan was labelled according to its base curvature (45°, 75°, or 90°), its position in the process (scan 1, scan 2, scan 3), and the test iteration, a, b, c. Scans by Micha Fairfax-Angod; geometry refinement and data interpretation by Olivia Carson.



Quantifying the accuracy of bent wood before robotic release: deviation from target curve. Each scan was labelled according to its base curvature (45°, 75°, or 90°), its position in the process (scan 1, scan 2, scan 3), and the test iteration, a, b, c.
These results demonstrate that the robotically bent wood strips achieved a high degree of accuracy relative to the simulated target curves, suggesting confidence in the predictive capacity of the system despite the inherent variability of the wood as a material. Data interpretation and graph by Olivia Carson.



Observing springback two days post-bending: Average springback along wood strip. Data interpretation and graph by Olivia Carson.

Physical demonstrator of a robotic steambent wood assembly, showcasing repeatable bending variation and modular potential for formwork-less construction. Final design by Liam Cassano, Olivia Carson, Karina Craig, and Micha Fairfax-Angod; wood milled by Micha Fairfax-Angod; robotic bending operations excuted by Liam Cassano and Micha Fairfax-Angod; wood finishing by Micha Fairfax-Angod.