AR Glulam: Accurate Augmented Reality Using Multiple Fiducial Markers in Glulam Fabrication

Alexander Htet Kyaw
MIT

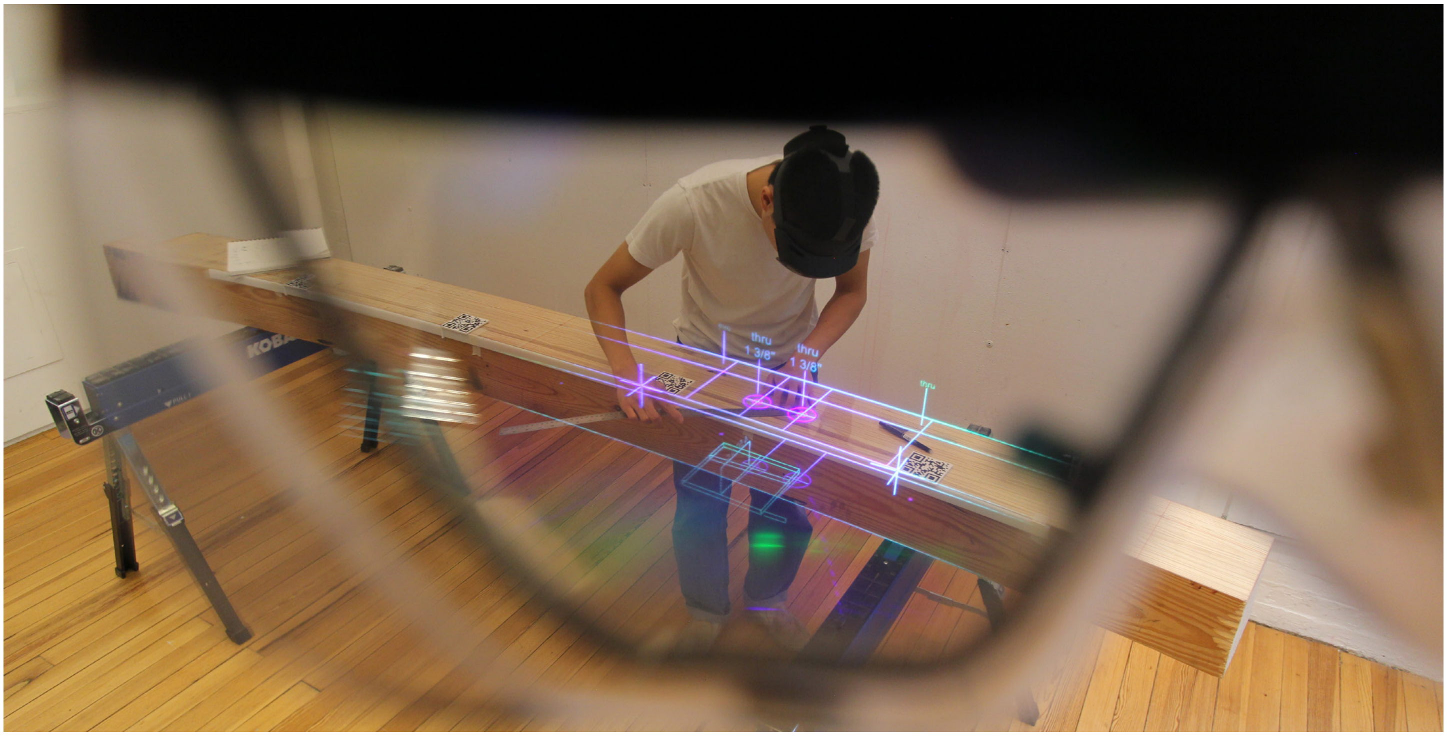
Arvin Xu
Cornell University

Sasa Zivkovic
Cornell University

Gwyllim Jahn
Fologram

Cameron Newnham
Fologram

Nick van den Berg
Fologram



1 Multiple Fiducial Markers for High Precision AR in a Lab Environment.

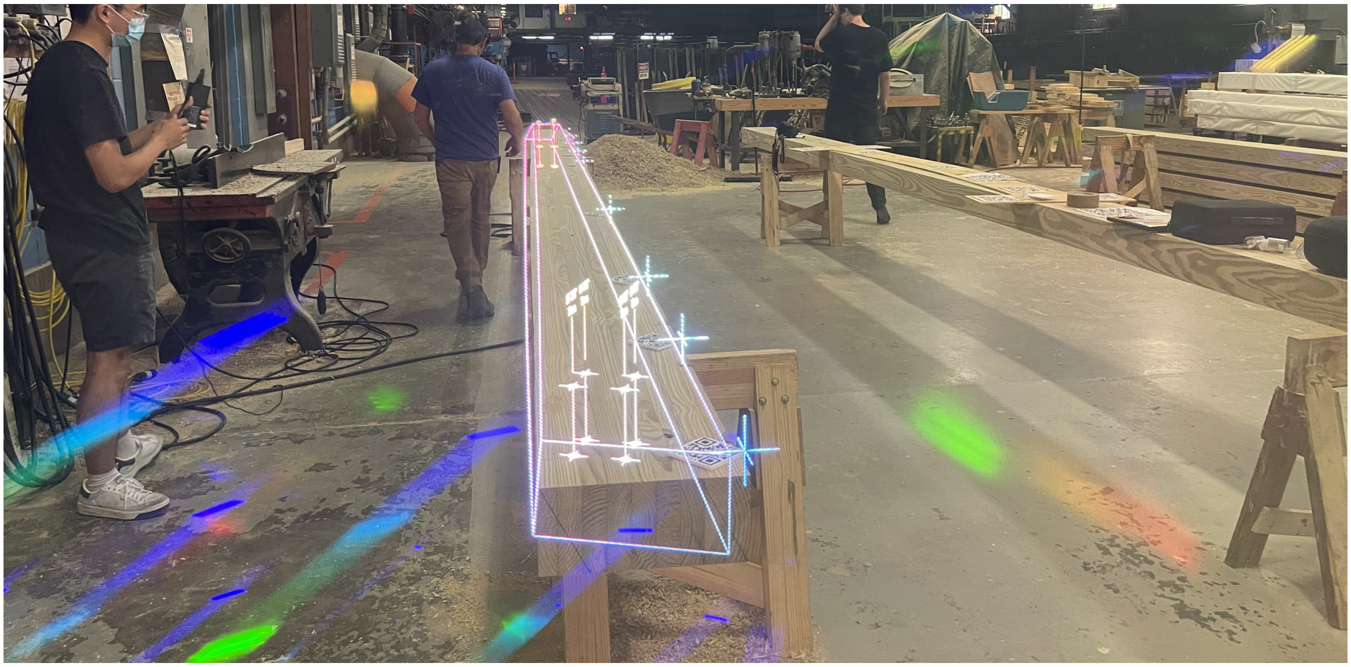
Introduction

Recent advancements in augmented reality (AR) have demonstrated applications in architecture design fabrication (Song, Koeck, and Luo 2021). Compared to conventional 2D construction drawings, AR can be used to superimpose contextual instructions, display 3D spatial information and enable on-site engagement. Despite the potential of AR, the widespread adoption of the technology in the industry is limited by its lack of precision (Chi, Kang, and Wang 2013).

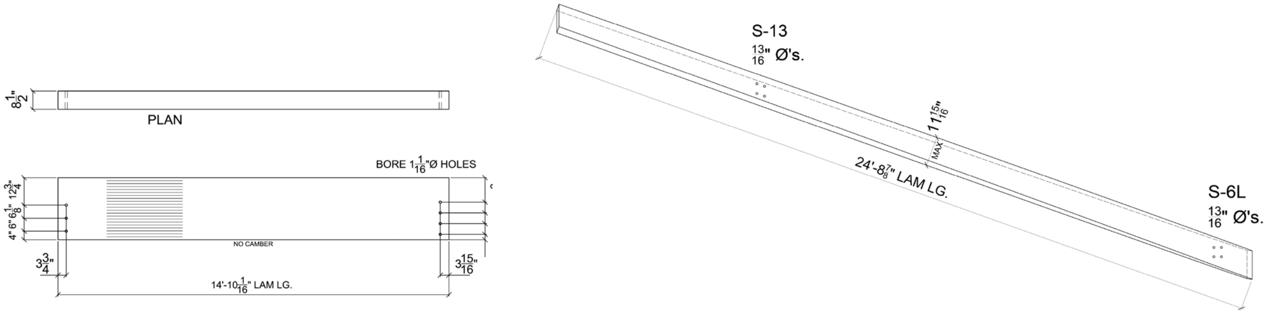
Precision is important for projects requiring strict construction tolerances, design fidelity and fabrication feedback. For example, the manufacturing of glulam beams requires tolerances of less than 2mm (Jones and Brischke 2017). The goal of this project is to explore the industrial application of using multiple fiducial markers for high-precision AR fabrication (Figure 1). While the method has been validated in lab settings with a precision of 0.97 mm (Figure 2), this paper focuses on fabricating glulam beams in a factory setting with an industry manufacturer, *Unalam Factory* (Kyaw et al. 2023).

PRODUCTION NOTES

Client:	Unalam Factory
Status:	Completed
Location:	United States of America (Connecticut, Pennsylvania, and New Hampshire)
Date:	2023

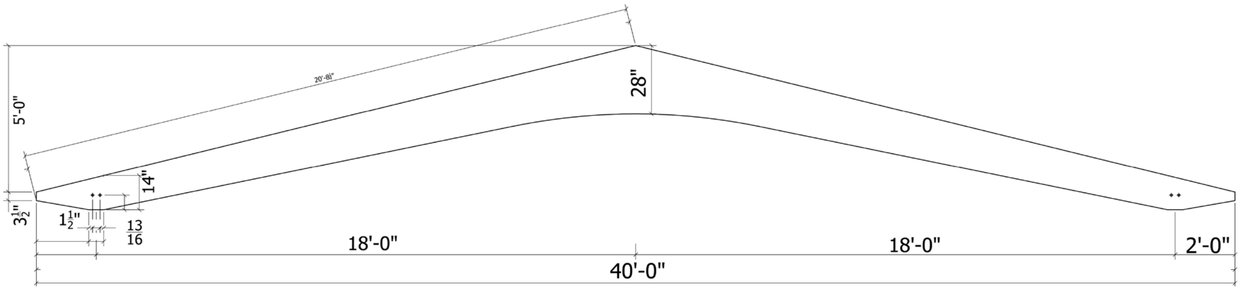


2 Multiple Fiducial Markers for High Precision AR in a Factory Environment.



14 ft Straight Beam

24 ft Twisted Beam



40 ft Chamfered Beam

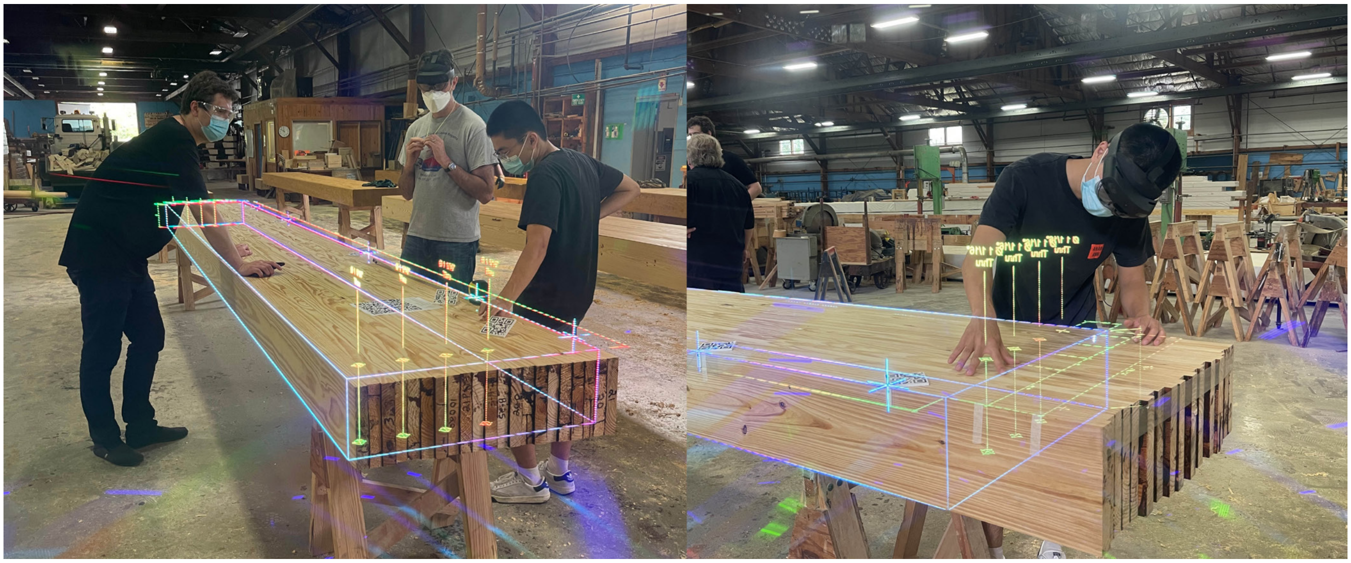
3 Three Different Types of Beams with Varying Shapes, and Dimensions. Fabrication Patterns.

Augmented Reality Software and Equipment

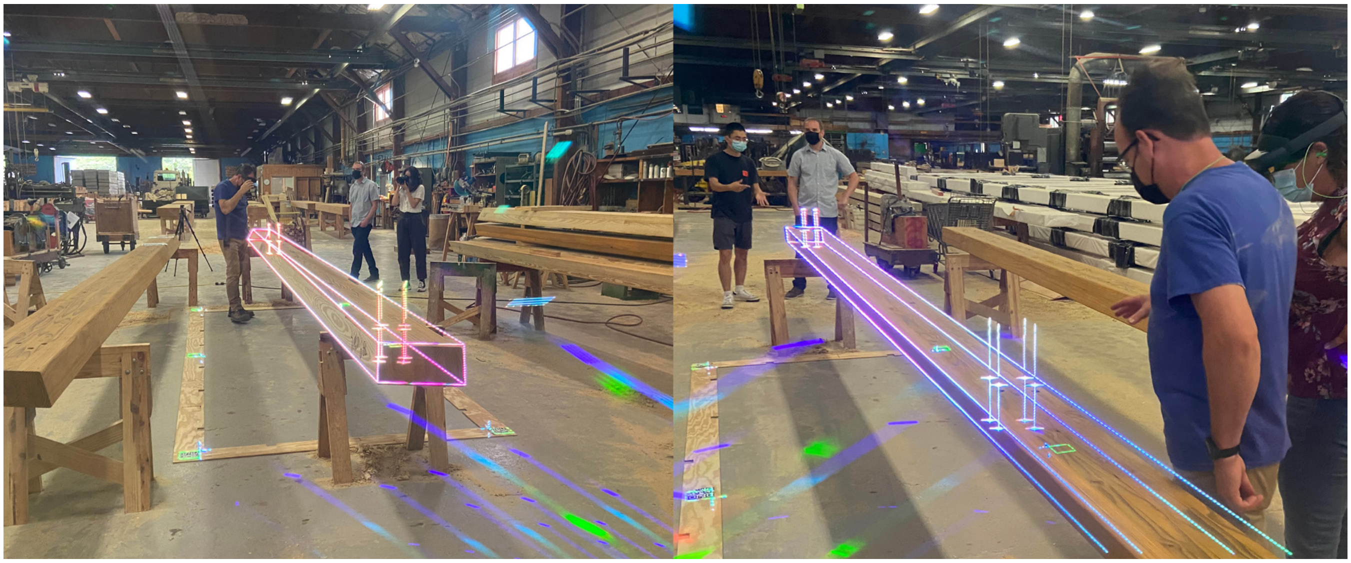
This project utilizes the *Twinbuild* software to recognize multiple quick response (QR) fiducial markers for correcting drift errors in AR. Each QR marker is linked to know points in the physical environment or on the beam. These points are interpolated and serve as reference points to maintain alignment accuracy using the HoloLens2 AR headset.

Experiment Setup

Three types of beams were fabricated: a 14-foot straight beam for the Upper Merion Area High School in Pennsylvania, a 24-foot twisted beam for the Milford band shed in New Hampshire, and a 40-foot cable roof beam for the Winding Trails Pavilion in Connecticut (Figure 3). The 14-foot beam has five markers at 2.5-foot intervals along the beam edge (Figure 4). The 24-foot twisted beam has 6 markers around



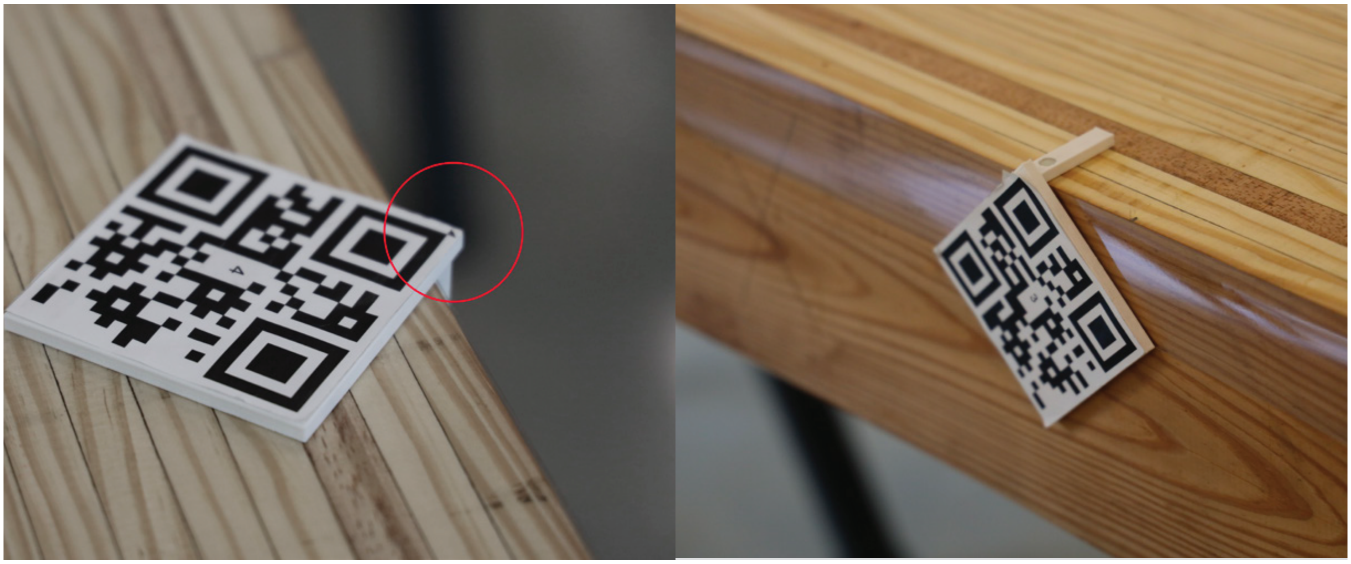
4 Fourteen Feet Long Twisted Beam for the Upper Merion Area High School in Pennsylvania.



5 Twenty-Four Feet Long Twisted Beam for the Milford Band Shed in New Hampshire.

6 Forty Feet Long Chamfered Beam for the Winding Trails Pavilion in Connecticut.

7 Clear Strip with Magnets Used as Guide for Markers.



8 Vertical and Horizontal Placement of Markers.

the beam at 6-foot intervals (Figure 5). Since the edge of the twisted beam is not flat, the markers are placed around the beam. The 40-foot beam has 10 markers at 4-foot intervals along the beam edge to reduce the number of markers (Figure 6). The markers' arrangements are varied depending on the usage and the type of beam.

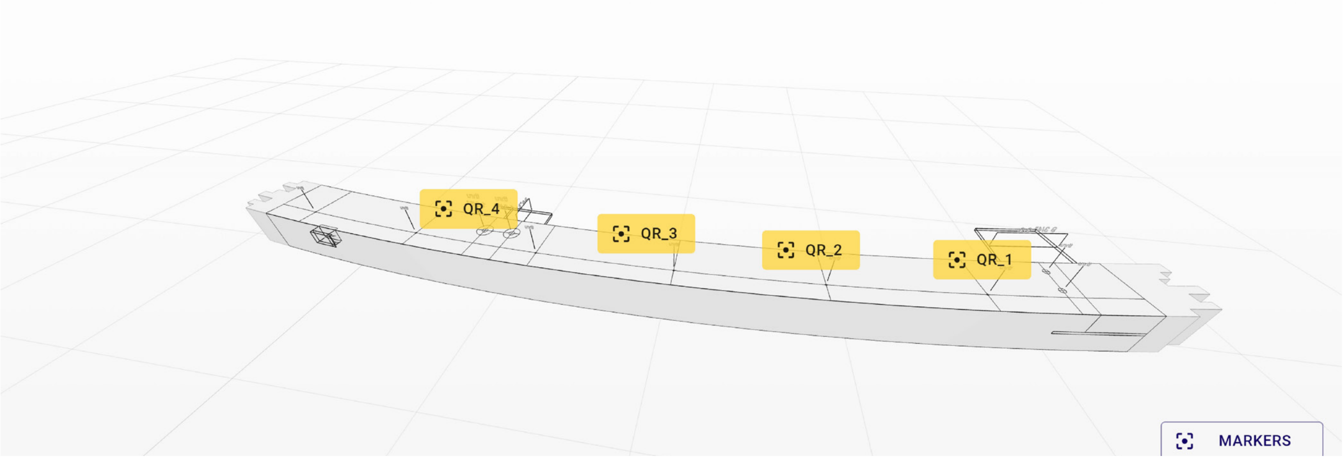
Process and Web User Interface

The procedure involves using a clear strip with magnets spaced at 2.5-foot intervals and 4-foot intervals for easy attachment of markers (Figure 7). This strip is attached to the edge of the beam. Markers are printed on a 3D-printed magnetic holder that can be snapped onto this strip. The markers can be positioned either horizontally on the top-facing edge of the beam or vertically on the side-facing edge (Figure 8).

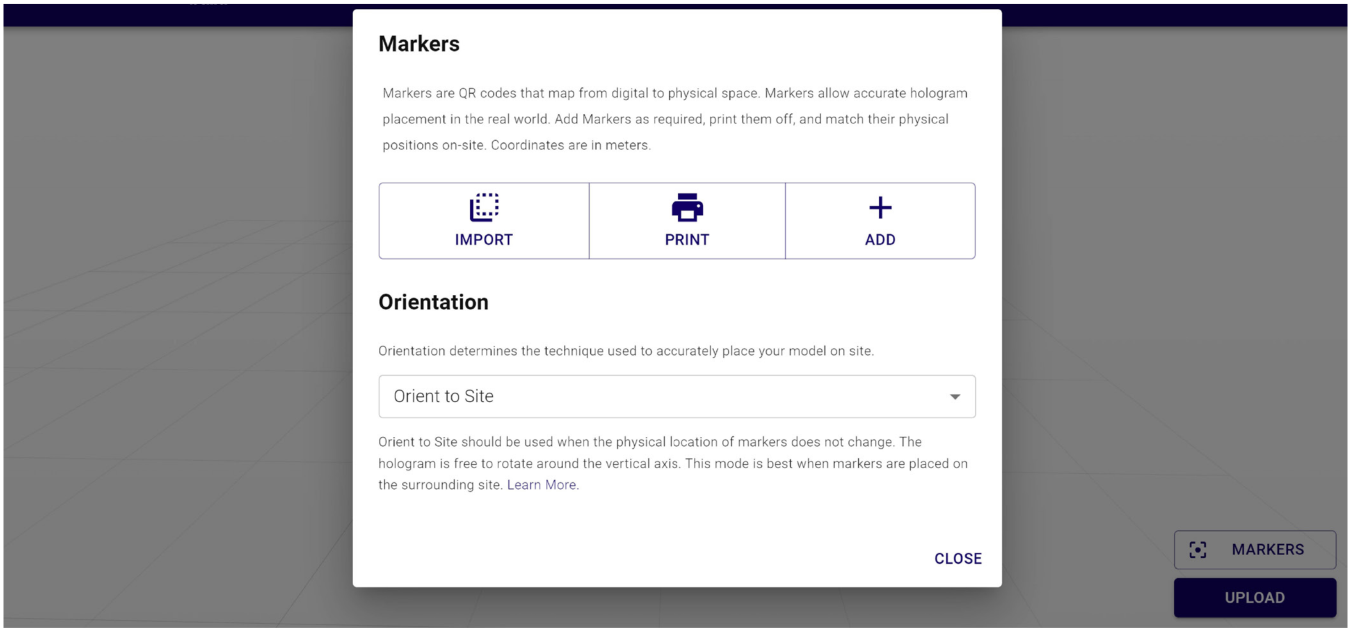
Each beam is assigned a unique QR code that references its digital model. These models are stored on a server, allowing users to upload them via a web interface (Figure 9a). This eliminates the need for the headset to be connected to a computer for streaming AR instructions. By scanning the QR code, the headset can access and display the corresponding beam model directly from the server. Additionally, the markers can also be printed from the web interface, enabling easy access (Figure 9b).

Precision in the Factory

Factory measurements indicate that the 14-foot straight beam, with markers positioned every 2.5 ft, has an average deviation of 1.2 mm. The 40-foot beam with markers positioned at every 4 ft, has an average deviation of 1.7 mm. Both are within the 2 mm tolerance standard required for glulam beam fabrication. The 24-foot beam, with markers positioned



9a Web Interface for Uploading Fabrication Model.



Markers

Markers are QR codes that map from digital to physical space. Markers allow accurate hologram placement in the real world. Add Markers as required, print them off, and match their physical positions on-site. Coordinates are in meters.

Orientation

Orientation determines the technique used to accurately place your model on site.

Orient to Site

Orient to Site should be used when the physical location of markers does not change. The hologram is free to rotate around the vertical axis. This mode is best when markers are placed on the surrounding site. Learn More.

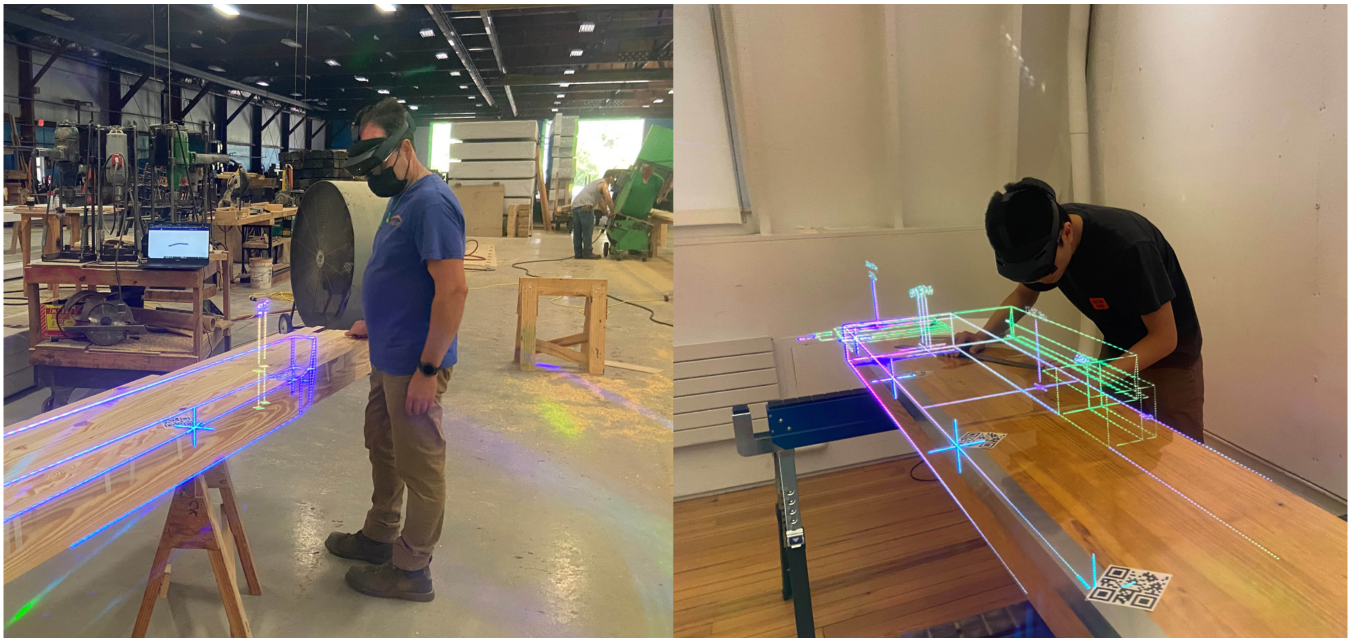
9a Web Interface for Printing QR Markers.

around the beam every 6 ft, has an average deviation of 2.3 mm. Placing markers further apart results in lower accuracy. However, it provides a simpler setup that can still be effectively used for other processes such as quality control.

Compared to results in the laboratory, the accuracy in a factory setting is slightly lower. This discrepancy is likely due to variations in lighting conditions and moving objects within the factory (Figure 10). Further studies in an industrial setting are necessary to investigate these factors using the multiple marker method. Lastly, while markers can be positioned both horizontally and vertically, users prefer to place markers in the same orientation as the fabrication instructions since it is easier to scan.

Conclusion

The paper demonstrates the industrial application of multiple fiducial markers for high precision augmented reality fabrication of glulam beams in a scalable manner (Figure 10). Future studies can use this work to extend its application to larger construction projects. This project challenges the idea that AR is only suitable for low-precision projects, by demonstrating its potential for high-precision applications. With enhanced precision in AR, there are new opportunities for applications where accuracy is important such as feedback-based fabrication (Kyaw et al. 2024), human-robot interaction (Kyaw et al. 2024), and on-site design fabrication (Kyaw, Otto and Lok 2023).



10 Comparison between Factory Environment and Lab Environment.

ACKNOWLEDGMENTS

This work was supported by Unalam (Craig Van Cott, Leif Van Cott, Rik Vandermeulen), Fologram Pty Ltd, and the College of Architecture, Art, and Planning (AAP) at Cornell University. The authors of this paper would like to thank the Robotic Construction Laboratory (RCL) project team (Lawson Spencer, Chi Zhang, and Lauren Franco) for their valuable feedback and assistance with the experiments.

REFERENCES

Chi, Hung-Lin, Shih-Chung Kang, and Xiangyu Wang. 2013. "Research Trends and Opportunities of Augmented Reality Applications in Architecture, Engineering, and Construction." Automation in Construction 33 (August):116–22. https://doi.org/10.1016/j.autcon.2012.12.017.

Jones, Dennis, and Christian Brischke, eds. 2017. "Wood as Bio-Based Building Material." In Performance of Bio-Based Building Materials, 21–96. Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100982-6.00002-1.

Kyaw, Alexander Htet, Jack Otto, and Leslie Lok. 2023. "Active Bending in Physics-Based Mixed Reality: The Design and Fabrication of a Reconfigurable Modular Bamboo System." In Dokonal, W, Hirschberg, U and Wurzer, G (Eds.), Digital Design Reconsidered - Proceedings of the 41st Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2023) - Volume 1, Graz, 20-22 September 2023, Pp. 169–178. CUMINCAD. https://doi.org/10.52842/conf.ecaade.2023.1.169.

Kyaw, Alexander Htet, Lawson Spencer, and Leslie Lok. 2024. "Human–Machine Collaboration Using Gesture Recognition in Mixed Reality and Robotic Fabrication." Architectural Intelligence 3 (1): 11. https://doi.org/10.1007/s44223-024-00053-4.

Kyaw, Alexander Htet, Lawson Spencer, Sasa Zivkovic, and Leslie Lok. 2024. "Gesture Recognition for Feedback Based Mixed Reality and Robotic Fabrication: A Case Study of the UnLog Tower." In Phygital Intelligence, edited by Chao Yan, Hua Chai, Tongyue Sun, and Philip F. Yuan, 331–45. Singapore: Springer Nature. https://doi.org/10.1007/978-981-99-8405-3_28.

Kyaw, Alexander Htet, Arvin Xu, Gwyllim Jahn, Nick Berg, Cameron Newnham, and Sasa Zivkovic. 2023. "Augmented Reality for High Precision Fabrication of Glued Laminated Timber Beams." Automation in Construction 152 (May). https://doi.org/10.1016/j.autcon.2023.104912.

Song, Yang, Richard Koeck, and Shan Luo. 2021. "Review and Analysis of Augmented Reality (AR) Literature for Digital Fabrication in Architecture" Automation in Construction 128 (August). https://doi.org/10.1016/j.autcon.2021.103762.

IMAGE CREDITS

All drawings and images are done by the authors.

Alexander Htet Kyaw is a researcher developing new tools and workflows for human-machine-material collaboration through computational design and fabrication. His work integrates multidisciplinary topics such as augmented reality, digital fabrication, robotics, biomaterials, deployable structures, simulation, computer vision, and machine learning. He is a dual degree candidate at Massachusetts Institute of Technology (MIT), working towards a Master of Science in Architectural Studies in Computation along with a Master of Science in Electrical Engineering and Computer Science. At MIT, Alexander works with the Digital Structures Lab, Media Lab, and Computer Science and Artificial Intelligence Lab.

Arvin Xu was a research associate at the Cornell Robotic Construction Laboratory (RCL) at Cornell College of Architecture, Art, and Planning. He graduated with a Bachelor of Architecture from Cornell University's Department of Architecture.

Sasa Zivkovic is an Assistant Professor at Cornell University AAP, the Director of the RCL at Cornell AAP, and a Co-Principal at HANNAH. Zivkovic's research focuses on the development of sustainable robotic construction technologies, material systems, and fabrication processes .

Gwyllim Jahn is a co-founder of Fologram and a Lecturer in Architecture at RMIT University in Melbourne. His work focuses on designing for mixed reality fabrication, most notably in the design and construction of the 2019 Tallinn Architecture Biennale Pavilion. Gwyllim's research has been published in leading computational design conferences and journals including IJAC, ACADIA and RobArch and he has given talks, presentations and workshops at international institutions including MIT, Stuttgart ICD, UCL, SciArc, Tongji and Tsinghua University.

Cameron Newnham is the co-founder and CTO of Fologram where he leads the technical development of mixed reality software for the design and construction industry. His experience lies in the creation of novel tools for designing and fabricating complex geometric systems, ranging from code libraries to mixed reality interfaces and extending to machine design and robotic fabrication. Cameron has experience as a computational designer in internationally renowned architectural practices, and academic experience as an Associate Lecturer – Industry Fellow at RMIT University. Cameron has led numerous international design and build workshops in Shanghai, New York, Paris, Boston, Sydney, and Melbourne.

Nick van den Berg is the co-founder and CEO of Fologram, a design research practice and technology startup building a platform for designing and making in mixed reality. Fologram's platform is being used by world-leading architecture practices, product design houses, manufacturers and design schools internationally. Nick is especially interested in building solutions that are utilised by a large user base around the world and has assisted with workshops focusing on utilising augmented and mixed reality as a design and fabrication tool at DMS, CAADRIA, Cooper Union, McNeel Europe, UDK & TU Berlin.