

Nemagari Crafting – Utilizing Bent-root Timber with Mixed-Reality Fabrication

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This paper discusses the intentions and results of a collaborative workshop aimed at bridging manual and digital epistemologies with new mixed reality (MR) visualizations and fabrication workflows. The use of MR is rapidly gaining momentum in both academic and professional settings, for use in architectural design research and construction on and off site. MR is an extension of digital and computational modeling proficiency that has significantly reshaped the AEC industry, and MR presents a new educational paradigm as this area of expertise becomes more widespread and in demand. By engaging with a historically significant context, the workshop proposes a reconsideration of how digital technologies can interface with manual crafting and tacit knowledge. The workshop acknowledges a definition of culture as a set of communicative acts, and that technology consists not only of the machines, devices and software, but more importantly the relationships between instruments, people, and fields of knowledge. Four MR-guided fabrication workflows were developed, each recognizing that informal technological knowledge has distinct epistemological characteristics that may be productively impacted by holographic intervention.

INTRODUCTION

Following the second World War, Japan's Ministry of Agriculture and Forestry began an aggressive planting campaign to address the country's reconstruction. To enhance the productivity of national forests, huge amounts of cedars were planted due to their quick and resilient growth, replacing the native broad-leaf species in many areas. Simultaneously, Japan's cultural connection to cedar as a building material waned as the country continued to westernize, and eased regulations on imported lumber reduced the country's self-sufficiency rate of timber use to 18% by the turn of the century.¹

Over time, vast amounts of abandoned tree plantations have grown too dense, blocking sunlight for smaller plants that contribute to healthy biodiversity. This has resulted in an increased risk of landslides, increased pollen, and changes to

the ecosystem as excessive nitrogen in the soil due to human activity washes into rivers and ponds causing algal blooms as the smaller plants are not present to absorb it.² The forests surrounding Hida, a town in Gifu, Japan known historically as an epicenter of traditional carpentry, joinery and craft, are facing these challenges. When rice was the tax, and since Hida is too mountainous to grow enough to contribute, local carpenters were instead commissioned to build temples and shrines throughout Japan. These mountains are also steep and receive heavy snow, often bending younger trees at their trunk under the load. The tree will continue to grow with a



Figure 1. 3D scan and photograph of *nemagari*. Hidakuma.

curve, making its lumber difficult to harvest and process within standard industrialized processes. Within this context, this paper presents recent collaborative efforts that help address these issues by developing new mixed-reality (MR) fabrication workflows with local craftspeople to utilize large-scale *nemagari* (bent-root) timber. *Nemagari* is typically avoided, but when harvested out of necessity, are reduced to chips or firewood due to their shape. The material remains underutilized as their natural geometry is considered a downgrade in standardized milling operations.³ Instead, the research discussed in this paper explores how MR can be leveraged to compliment the skill of the craftsman with real-time holographic guides. The holograms enable the efficient processing of large and unwieldy logs into precisely constructed architectural elements, making



Figure 2. wood cutting jig with sensor (2018 workshop), compressed timber weaving (2019 workshop), *Torinosu* fabrication (2020). Bruscia, Hidakuma.

use of their natural curvature that would otherwise be a hindrance to manual, CNC, and robotic fabrication techniques.

MONOZUKURI WORKSHOPS

The authors have led a series of workshops in Hida exploring a variety of topics that combine traditional practices, such as carpentry and basket weaving, with current computational techniques. The 2018 workshop was planned as a precursor to the workshop discussed in this paper, as it was prior to obtaining augmented reality headsets. While the technical focus was tangential to AR-guided fabrication, the workshop helped establish a working partnership with local carpenters and set in motion a line of inquiry aimed at developing a mode of communication between digitally designed objects and the tacit knowledge of the carpenter.

Using a 6 DoF sensor like those commonly used in smartphones, a custom wood cutting jig was prototyped and tested. The sensor feeds the orientation of a wooden block, relative to a bandsaw blade, to the parametric model in real time. The data is checked against the desired cut angle for each notch in the structure. When the physical angle matches the angle set in the model, visual feedback is provided, the jig is locked in position, the first two cuts that outline the notch are made, and the notch is chiseled manually by the carpenter. This process is akin to traditional wood marking techniques using ink pots, a critical step that precedes notch chiseling in *kumiki* fabrication.

The workshop held in 2019 was supported by local industries to experiment with a unique wood compression technology. Given the abundance of cedar in the area and the long history of furniture making known to the region, compression techniques have been used to transform cedar, a soft wood, into a harder material to better utilize the resource within the local industry. Compressing the material in the opposite direction has the inverse effect; harder timber of broad-leaf trees is made more malleable like a live branch. This allows hard woods to more easily succumb to steam bending for curved

elements in chairs and tables, and through a proprietary drying technique, the wood's original characteristics are restored post-bending. Inspired by the compression of hardwood for increased malleability, the workshop resulted in two lattice structures that were assembled from strips of the compressed timber using the *kagome* basket weaving pattern. The topologically induced bending guides the form naturally, and no steam was necessary to maneuver the material into doubly curved surfaces.

In 2020, the Japan-based authors collaborated with Eri Sumitomo Architects and Aki Hamada Architects on *Torinosu*, a sculptural public furniture piece consisting of nemagari logs that were chainsaw cut using holographic guides in a mixed-reality fabrication process.⁴ AR was used to both cut the individual logs and assemble them by guiding the chainsaw and drilling operations. This project was an important precursor to this research as an earlier implementation of a similar workflow. Additionally, this experience helped facilitate our work within a shorter timeframe since the craftspeople involved were already familiar with the AR headsets, holographic overlay, and the process of calibrating the hologram to physical objects.

Building on these efforts, the most recent workshop remotely connected faculty and students based in the USA with craftspeople and consultants that reside and work in Hida, Japan. Held within the context of a graduate architecture research studio, students were grouped into four project trajectories. Results of the workshop are presented here as a work in progress, as there are numerous ways to fine-tune the process and build on these MR crafting frameworks. The primary toolset consisted of digital modeling and simulation in Rhinoceros 7 and Grasshopper, holographic interaction and preparation using Fologram and MR visualization with Microsoft HoloLens 2.

Team efforts were divided into four trajectories, each with specific visualization and calibration criteria: structure, texture,

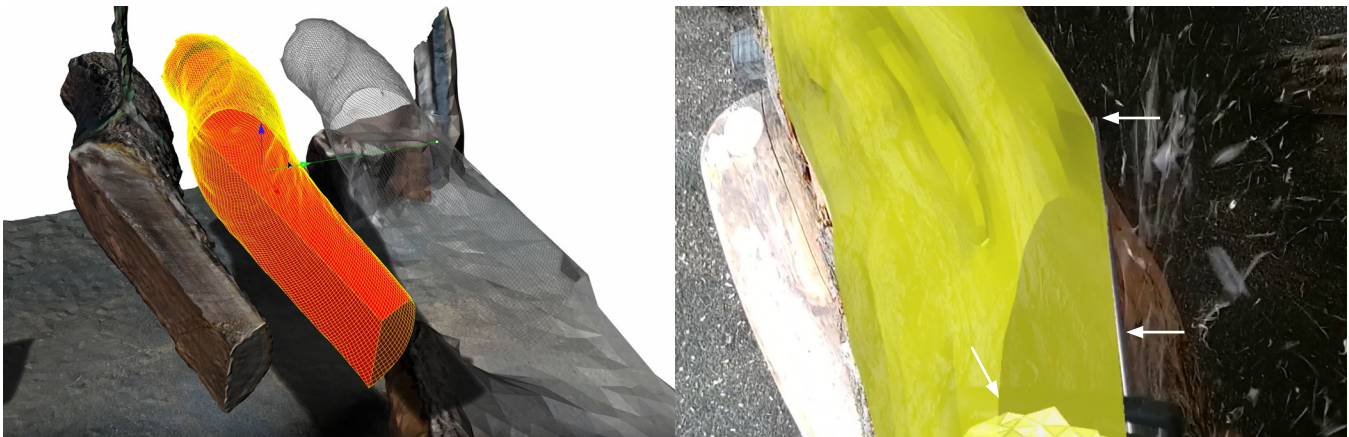


Figure 3. comparison of post-chainsaw cut 3D scan and initial digital model, chainsaw operator view through the Microsoft HoloLens 2. Kanaoka, Hidakuma.

weight, and assembly. Construction from an inventory where no two parts are exactly alike necessitates new tools for visualizing the design intent and for accurately cataloging the exact shape of the logs.⁵ LiDAR scanning, a crucial component to the discussed MR workflow, was used to verify the accuracy and fitment of each processed log, prior to and following each chainsaw cut, so that the holographic guides for subsequent parts may be quickly adjusted as necessary.

RELATED WORK

As extended reality tools continue to become more widespread in a variety of industrial and research contexts, particular areas of inquiry are being formed with like-minded contributions. Within the burgeoning area of MR fabrication, we find ourselves most closely aligned with recent efforts by the following authors due to the focus on irregular tree geometries and purely AR-guided assembly.

Timber De-Standardized and *Timber De-Standardized 2.0*⁶ provides a framework for how non-standard or waste materials can be salvaged and repurposed through an integrated process of 3D scanning, mixed reality, and computational analysis. A digital catalog of 3D scanned logs allows users to engage in an interactive MR environment to freely configure a wide variety of structures consisting of elements found in the archive. Alternatively, *Structural Upcycling*⁷ presents a design to fabrication workflow that incorporates the natural geometry of tree forks into a structure by matching them to nodes within a pre-designed structure. While the tree forks are modified for precise connections to more standardized elements, their natural formation and internal fiber directions are maintained. Like *Timber De-Standardized* by Lok et al., this approach also uses a digital library of tree forks and finds opportunity in the natural geometry of the material to match compatible design intentions, greatly reducing the need for complex machining operation.

Holographic Construction and Making in Mixed Reality by Jahn et al. demonstrates methods for generating holographic construction information from parametric models, replacing 2D drawings with “unambiguous, contextual, shared and interactive design information.”⁸ Their software platform, Fologram, allows users of a popular 3D modeling software (Rhinoceros 3D) to very quickly create customized holographic instructions that translate design models into immersive processes of fabrication and construction, bypassing the requirement of standard two-dimensional drawings.⁹ This work introduced in the following sections has made extensive use of Fologram as the primary software platform for facilitating similar exchanges.

MR TRAJECTORY 01 – CHAINSAW CUTTING

The “structure” project became the primary focus of the 3-day workshop that resulted in a branching assembly of large nemagari, each approximately 3m in length. The 3D scan for each log was combined and modified into a three-part assembly, requiring two long chainsaw cuts guided by intersecting holographic planes or a full holographic twin of the desired part calibrated to each log as per the chainsaw operator’s request. A new 3D scan of each cut log was compared to the digital model, and necessary adjustments were made to ensure fitment. This process was repeated after each cut to account for the margin of error inherent to both the calibration and cutting process. As the calibration of holograms to physical objects improves, the margin of error will likely decrease. For the time being, the holograms were calibrated to the logs by scanning printed QR codes that are placed in the workshop in a location that is dimensionally matches the location of the digital QR code and the digital twin of the log. Slight adjustments are made to obtain a tight calibration, including interactively moving the hologram using hand-gestures, moving the digital logs to better match the physical position and orientation of the physical log, and physically adjusting the position and orientation of the physical log itself. Oversized butterfly joints were intended to hold the logs together into a column-like assembly, the



Figure 4. assembled prototype at the Yanagi Mokuzai lumberyard and composite of 3D scanned logs. Chudy, Heiser, Nicpon and Hidakuma.

joinery of which would be done using hand tools also guided by calibrated holograms. Future work includes tool calibration to track the exact location of the chainsaw blade providing real-time feedback of the blade's position relative to a target cut surface or desired cut depth, and the implementation of MR chainsaw cutting and hand tooling in a completed structure.

MR TRAJECTORY 02 – VISUALIZING BALANCE

With an appreciation for the cultural importance of trees exemplified in various *matsuri* (civil or religious festivals), the “balance” project focused primarily on ways in which holographic visualizations could demonstrate how a large and heavy log could be carefully balanced from an off-center fulcrum point. The bulky log would appear light and subject to invisible forces as the balance subtly shifts when the log is wet. Holographic simulations attempted to describe the intended awe of a precariously balanced tree while the fabrication process was guided with similar techniques used in project trajectory 01. Future work includes testing a variety of visualization techniques that reveal invisible factors, i.e., log density and moisture content, and implying weight and balance within interactive holograms. This trajectory focuses more on data visualization and physical simulation than fabrication guiding but still requires accurate calibration and explicit overlay of holographic information. Qualitative notions of architectural representation will need to be tested against their ability to use abstract and symbolic graphic standards to convey intent and materiality.

MR TRAJECTORY 03 – COLLABORATIVE SCULPTING

Taking a more collaborative approach, the “texture” project drew inspiration from *naguri*; timber processing techniques that leave behind unique markings along the surface of the log. Mesh modeling and calibrated holographic visualizations were initially intended to guide the same traditional hand tools that are historically associated with *naguri* but are equally useful to carving processes using power tools. Color gradients applied to the 3D scan data converted into customized meshes dictate the intention to vary the depth of texture; a direct result of tool use that can only be translated by experienced hands. The speed, pressure, and strike angle of chisels, axes, and electric grinders alike are controlled by the interpretation and skill of the craftsman. Future work includes material prototyping, customizable holographic user interfaces, and collaborative hybrid sculpting. Further study of the AR overlay includes developing more specific graphical gradients based on structural analysis and a variety of aesthetic criteria.

MR TRAJECTORY 04 – GEOMETRY REFERENCING

Acknowledging calibration as an important part of MR fabrication as well as accurate physics-based simulation, the “weave/thatch” project investigates the combination of the two. The study here is multi-faceted; first, to calibrate a bending simulation to real-world material parameters by overlaying a hologram modeled in K2Engineering/Kangaroo2 over an actively bent wooden lath. When aligned, the numerical inputs are less arbitrary, and the simulation can more accurately reflect the bending of the material being used. Second, the project reveals the topological rules of kagome basket weaving

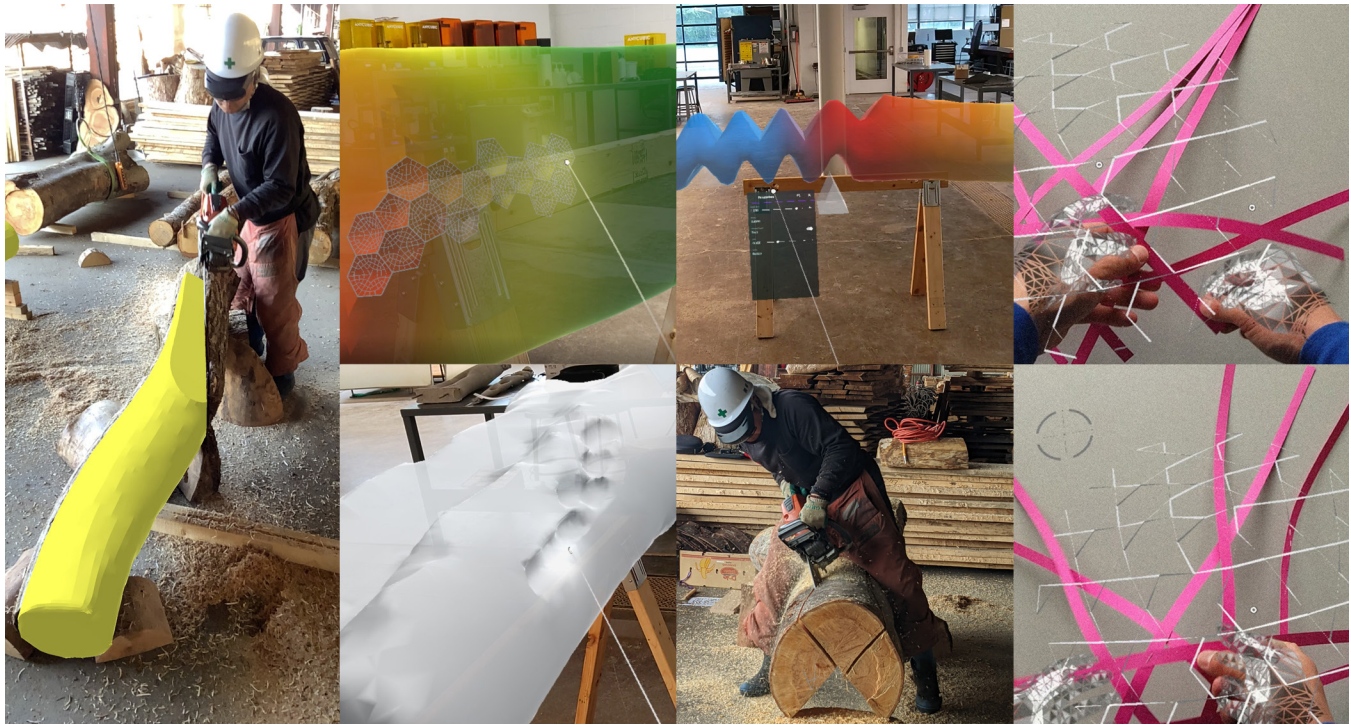


Figure 5. *MR chainsaw cutting, AR sculpting, interactive AR simulation and fabrication of a balancing log, AR guided paper weaving.* Hidakuma, Bruscia, Marsh, Mohammadyar, Clay, Cruz, Kaur, Vu.

by reducing the complexity to holographic nodes shown as points of specifically arranged triangles. By connecting the dots, a novice unaware of how the topology determines the form can learn about the mathematical concepts underlying traditional weaving techniques. Future work includes developing MR guided and novel thatching sequences for non-traditional structures.

CONCLUSION AND OUTLOOK

In summary, the work outlined in this paper formed at the intersection of teaching and research intends to contribute to the current discussion of the efficacy and effectiveness of MR when combined with experienced, tacit fabrication knowledge. The tangibility of a calibrated hologram allowed the multi-cultural collaborators to share a common language; the hologram, in a sense, speaks for itself and is free of technical jargon that is often hard to translate between languages and trades. Argued here as a resilient workflow, the holographic guides enabled us to communicate design ideas and potential fabrication sequences without language or geographic barriers preventing timely progress. Secondly, the unsustainable forestry practices during the post-war reconstruction period that the Hida timber industry is addressing in a variety of ways is a critical issue to the local economy. New technologies are playing a role in the rethinking of how this local resource may be efficiently utilized. Augmenting traditional crafting, fabrication, and construction techniques with computational tools brings newfound interest and attention to this history

and situating now ubiquitous computational tools within these contexts productively humbles their influence.

In recent years, much effort has been made to wield computational processes in a form-conversion process that produces extremely precise drawings and machine legible instructions to CNC controlled gantry machines and robot arms. The expectation is that the machines can reduce tolerance within the constraints of the material and scale of assembly while maintaining constructability. Our observation thus far, through our work and the preceding work of others, is that holographically guided fabrication techniques open new opportunities to engage with manual expertise without entirely forcing the hand. Constructability in this context is less a criterion to enforce dimensional accuracy, but more a give-and-take between the digital representation of the desired outcome with the interpretation and skill of the expert laborer. The workflow is perhaps more collaborative, calming the expectation that the construction matches the model with exactitude, to a more nuanced conversation over technique, feasibility, and unplanned variation.

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