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Abstract. Timber De-Standardized 2.0 is a mixed reality (MR) user interface (UI) that utilizes timber waste produced by manufacturing dimensional lumber, suggesting an expanded notion for “material usability” in timber construction. The expanded notion of designing with discarded logs not only requires new tools and technologies for cataloguing, structuring, and fabricating. It also relies on new methods and platforms for the visualization and design of these structures. As a MR UI, Timber De-Standardized enables professionals and non-professionals alike to seamlessly design with irregular logs and to create viable structural systems using an intuitive MR environment. In order to develop a MR environment with this level of competency, the research aims to finesse the visualization techniques in the immersive full-scale 3D environment and to minimize the use of alternative 2D UI(s). The research methodology focuses on (1) cataloguing and extracting basic properties of various tree logs, (2) refining mesh visualization for better user interaction, and (3) developing the MR UI to increase user design agency with custom menu lists and operations. This methodology will extend the usability of MR UI protocols to a broader audience while democratizing design and enabling the user as co-creator.

Keywords. Irregular Tree Logs; Wood Construction; Augmented and Mixed Realities; Mixed Reality User Interface; Digital Representation and Visualization; SDG 9; SDG 12; SDG 13.

1. Introduction

Timber can be considered as one of the most common and most sustainable construction materials. However, it requires socio-economic responsibility of industries, ethical forest management, and sustainable harvesting practices to further reduce its carbon footprint and energy use. Without sustainable practices, the manufacturing process of timber products produces carbon emissions and affects the surrounding environment (Adhikari and Ozarska, 2018). Dimensional lumber products
are widely used in building construction in the US. Specifically, 87.6 million m³ of softwood lumber are annually used for residential building construction in the US (Spelter et al., 2007). Therefore, timber production entails significant energy consumption and carbon emissions in auxiliary manufacturing, including sawing, gluing, planing, and the transportation process (Bergman and Bowe, 2010).

Additionally, many countries do not have access to source local materials used for dimensional lumber and are reliant on imports for timber construction. According to the US Department of Agriculture (USDA), US import of softwood and plywood has increased 346% between 2010 and 2019, related to the growth of housing construction markets and increased lumber prices during 2017 (Howard and Liang, 2019). Furthermore, the shortage of domestic access to specific types of wood can be another factor that accelerates the lumber trade and potentially affects the environment. Thus, to combat these issues and further utilize timber as a localized resource, there must be an expanded notion of usable timber for structural and architectural applications.

This expanded notion of designing with unused logs requires new tools and technologies for cataloguing, structuring, and fabricating. It also relies on new methods and platforms for the visualization and design of these new structures. The Timber De-standardized research project leverages mixed reality technology to utilize regular and irregular logs, minimizing waste and unnecessary energy use during auxiliary manufacturing. As an MR user interface (UI), Timber De-Standardized 2.0 allows professionals and non-professionals to experience seamless design workflows using tree logs. This paper presents the following methodologies: (1) Mesh visualization studies, (2) cataloguing and extracting the basic properties of sourced tree logs, (3) refining the MR environment with menu lists and operations to visualize a manipulated geometry next to the original element. The live feedback from the MR environment and ability to work at a 1:1 scale provides the user with an informed, intuitive, and educational platform that is non-deterministic. A series of visualization strategies were developed to test the applicability of the MR UI features mentioned above. Timber De-Standardized is a design tool and an educational device using localized timber logs.

2. State of the Art

2.1. IRREGULAR LOGS IN DIGITAL FABRICATION

Recent academic research, including Wood Chip Barn (2016), Limb (2018), and Digital Workflows for Natural Wood in Constructions (2020), demonstrate the potentiality of discarded logs as a usable construction material. Wood Chip Barn at the Architectural Association utilizes inherent characteristics of non-linear logs like forks to construct a truss structure. It demonstrates a research pipeline from extracting basic information of irregular logs such as geometry centerlines and cross-sections to manage the harvested materials for construction (Devadass et al., 2016). Limb uses discarded tree forks that are not harvested due to their low economic value to build a full-scale reticulated shell by replacing mortise and tenon joinery methods (Von Buelow et al. 2018). Digital Workflows for Natural Wood in Constructions transforms irregular natural logs into digital information to rationalize the geometry and to inform the fabrication process using an advanced laser scanner and bespoke algorithm (Larsen et al., 2020). These projects enable the possible implementation of irregular tree logs...
as an added resource for building construction. However, there are limitations to the direct user engagement with material information such as geometric properties or structural analysis feedback.

2.2. IMPLEMENTATION OF MIXED REALITY IN CONSTRUCTIONS

During the 2018 CAADRIA conference, the workshop Making in Mixed Reality, introduced Fologram, a software platform that enables designers to generate an interactive holographic instruction within a MR environment (Jahn et al., 2018). During the workshop, a pavilion made of bent steel tubes was constructed by leveraging this MR platform which assisted and guided fabrication, and assembly. In a prior investigation by this research team, Timber De-standardized 1.0 is a framework that salvages irregular and regular logs by utilizing a MR interface for the design, fabrication, and assembly of a structurally viable tree log assembly (Figure 1). The process engages users through a direct, hands-on design approach with an embedded structural analysis feedback loop to modify and design irregular geometry at full scale within an immersive MR environment without altering the original material (Lok et al., forthcoming). Although both projects focused on a MR workflow design practice, advanced skills for multiple 2D & 3D computational UI platforms are still required. Moreover, the projects revealed the necessity for more intuitive UI for users.

![Figure 1. Physical Components, Composite of Mixed Reality, and Structural Analysis](image)

3.3. Methodology

3.1. MIXED REALITY WORKFLOW

The research in this paper is built upon the above-mentioned prior investigation. A digital archive of 3D scanned logs constitute the building elements from which users, designing in the MR environment, can digitally harvest log parts (through slicing) and place the elements into a digitally constructed whole. The constructed whole is structurally analysed and optimized through recursive feedback loops to preserve the user’s predetermined design. This iterative toggling between the physical and virtual emancipates the use of irregular tree log structures while informing and prioritizing the user’s design intent. To test this approach, a scaled prototype was developed and fabricated in MR. The interactive workflow provides greater design agency to users as
co-creators in processing material parts. However, the process has an entry barrier due to the requirement of advanced expertise in different computational software. Hence, the main goal of this current research is to embed the entire processing of and designing with irregular log members in an immersive MR environment.

This paper improves upon previous research with an MR design workflow without using supplementary 2D UI platforms. The UI is improved by providing users with specific visualization of the log parameters and design operation menu in a full-scale 3D workspace. The refinements enable users to seamlessly design iterations of wood components or structural systems with one single MR protocol menu (Figure 2).

The UI menu is developed in the following phases. (1) Users can select and isolate a certain log geometry among the digital log library in the full-scale 3D environment. (2) The visualization categories allow users to choose the mesh option and toggle the geometric information such as centerline, cross-section, and diameter. (3) Users can slice geometries by moving and rotating slicing planes to generate wood components. The index will be automatically created for material cataloguing. (4) Users can bake the timber components by tapping the original geometries (Figure 3).
3.2. DIGITAL TREE LIBRARY

The workflow begins with collecting logs and converting the physical elements into digital data. For the digital tree library, irregular logs were sourced from a local groundskeeping entity, catalogued and indexed using a 3D scanner. Then, the digital logs were used as ‘building blocks’ for design iterations (Figure 4). In the MR space, users can see this digital log library on a 1:1 scale. The virtual catalogue menu allows users to browse and to select proper forms and scales for further operations. The visualization of the selected log geometry is differentiated from the other log elements. The user can turn off the rest of the logs by tapping the isolate menu (Figure 5).

[Figure 4. Digital Log Library, Figure 5. Log Library Visualized in an MR environment]

3.3. VISUALIZATION

3.3.1. Mesh Visualization Studies

Mesh, the geometric discretization of surfaces, plays a significant role in various fields of computation. For example, establishing high-quality mesh data is considered a success factor in determining computing performance (Baker, 2005). In computational fluid dynamics (CFD) for instance, mesh quality significantly affects the convergence and accuracy of CFD solutions (Katz and Sankaran, 2011). In the case of additive manufacturing, the optimization of mesh resolution is also essential to achieve suitable physical outcomes (Wang et al., 2016). Alternatively, a mesh can be a visual medium in computer graphics that viewers can visually interact with (Sorkine, 2006).

This paper investigates mesh visualization options as the visual medium, which interacts with users rather than retaining the high resolution of the geometric data. First, irregular log pieces were 3D scanned as digital mesh data. Then, the following mesh visualization options, (1) photogrammetry, (2) solid mesh, (3) transparent mesh surface with the outline, (4) triangulated mesh edges, and (5) Mesh edges with surfaces, are generated in Grasshopper and transferred into the MR environment. Each mesh visualization option was assessed based on evaluation factors, including visibility, materiality, informativeness, and computing speed. (Figure 6) This assessment has informed the selection of mesh visualization settings for the MR environment in which users can intuitively experience both visualization and design processes using irregular log geometries. Photogrammetry, for example, has conspicuous visibility and materiality since the texture of the original log is mapped onto the mesh surfaces.
It also delivers the visual information of the natural logs such as bark or tree-knots. However, photogrammetry was not chosen because of the computational overhead that significantly delays the MR processing. Alternatively, mesh surfaces with an outline are used as a default mesh visualization setting. The surface colour and transparency can be adjusted to increase visibility. Mesh Edges are also selected as one of the visualization options. Even though significant computing time is required to transfer high-resolution mesh edges into the MR environment, mesh edges effectively illustrate the natural log's arbitrary geometry and visually highlight subtracted information of the logs such as centerlines and cross-section. Moreover, the proposed UI allows users to toggle on and off this option according to their preference.

3.3.2. Centerline

It is crucial to extract the geometric properties to understand the non-standardized logs due to their irregularity. The abstracted centerline works as a simple but powerful information. Furthermore, the discarded forks can be exploited to create idiosyncratic architectural structures such as trusses or joinery (Devadass et al., 2016). Hence, centerline as a design parameter allows users to identify the overall shape of irregular log geometry and gauge the approximate angle of tree forks. Centerlines are extracted by interpolating the subdivided cross-sections of the log (Figure 7).
The research illustrates the UI, enabling the user to toggle on and off the centerline throughout the pre-design process (visualization). Thus, users can understand the abstracted properties of irregular tree logs such as the formation of tree forks, approximate fork angle, and scale solely through 3D holographic view without using the supplementary 2D proxies, including Rhinoceros or Grasshopper.

3.3.3. Cross Section and Dimension

Cross-sections are also one informative factor extracted from the scanned irregular log geometry. Wood Chip Barn, for example, extracted the cross-sections of the log by contouring them along with one direction (Devadass et al., 2016). In our previous project, Timber De-standardized 1.0, cross-sections were used more closely throughout the design process as essential design parameters. In regular roundwood processing, the cross-section can also become a parameter for straightening the log without excessive material waste. Cross-sections of the irregular log establish the primary subdivision of the longitudinal dimension of the material (Lok et al., forthcoming). Rather than cutting the sections horizontally, a log geometry is discretized using the planes perpendicular to the vector of each subdivision point of the centerline at the optimized distance, 2.5". Moreover, the dimensional information of the cross-sections is computationally measured and visualized. Both maximum and minimum diameters are displayed due to a log's natural asymmetrical and multi-axis form. The text size of each diameter is displayed relative to the values of diameters to make dimensions discernible and interactive (Figure 8).

Figure 8. Minimum and Maximum Diameters of Cross Sections and Visualization Options.
Within the MR environment, users can toggle cross-section and section diameter buttons via holographic UI to utilize this abstracted information as a visual reference to decide the primary subdivision of the irregular log geometries (Figure 9). In doing so, the MR UI empowers designers to visualize the information without using 2D platforms. The visualization schemes and operating methods are expected to enable users to visually interact with the geometric data in the full-scale 3D environment.

Figure 9. Holographic UI and Visualized Cross Sections and Diameters.

3.4. DIGITAL HARVESTING: SLICING, INDEXING AND BAKING

The workflow in this paper includes a virtual log processing protocol that digitally harvests the discrete log elements from the digital tree library. This process enables users to have a direct impact on the design of discretized tree logs that would otherwise have been discarded in standardized manufacturing. The ‘slicer,’ a plane for slicing the digital tree log, is used to determine the cut locations for each log. This process previously required the toggling between the MR UI and operations in Grasshopper. In this paper’s refinement, the entire design operations are implemented and visually optimized within the MR UI for digital harvesting: (1) Slicing, (2) Indexing, and (3) Baking. Users can subdivide the log geometry by moving, placing, and rotating slicing planes. The extracted log information such as cross-section or section diameter can be turned on as a visual guide to aid user’s decision-making. After pre-placing all slicing planes, the indexing operation automatically catalogues the material parts with indices organized in the Z direction (Figure 10). Lastly, the sliced log can be harvested with the bake button. The baked logs are copied with the index alongside the original log geometry. The harvested discrete members can be distinguished by different mesh visualization such as surface colour and outline (Figure 11).

Figure 10. Slicing and Indexing for Digital Harvesting
4. 4. Results

This paper demonstrates that this immersive process motivates the user to work iteratively according to their own design exploration. The mixed reality workflow enables users to modify and make unique parts without altering any of the discretized physical tree logs until the final design is set. The following research methodologies are illustrated to enhance the interactivity and work efficiency for user experience. (1) Mesh visualization studies that investigate options for optimizing visibility and the computing process. (2) Cataloguing and extracting the essential properties of non-standard log geometries such as centerlines, cross-sections, and section diameters. This information enables the user to evaluate the irregularity of the natural logs for further design processes. (3) Finetuning the MR environment with custom UI, design operation process including indexing, slicing, and baking allow users to toggle on and off the UI buttons to manipulate the digitally harvested timber elements. By leveraging this MR framework, users can seamlessly manage the irregular construction material and generate innovative timber structures in 1:1 scale (Figure 12).

5. 5. Discussion

Timber De-Standardized 2.0 highlights a mixed reality (MR) user interface (UI) that rethinks how we interpret and utilize timber in our current design and construction models. More importantly, it presents a viable minimum-infrastructure solution to our environmental crisis regarding the manufacturing and processing of lumber-based products. The research started by focusing on defining the expanded notion of “usable” timber and questioning how we might re-purpose the discarded logs as a renewable
construction material by leveraging emerging technologies and platforms. While this paper focused on development of digital cataloguing, visualizing, and design protocols, further investigation will tackle integrating the visualization of structural analysis and similarly minimizing the toggling between computational platforms for fabrication and assembly. Regarding further application and material usage, the workflow can be applied towards creating viable conventional structural systems such as trusses using both irregular logs and standard round wood members. For the user experience, the hands-on workflow presents a small learning curve and provides the user with a greater sense of design authorship. Moving forward, there is potential in exploring how the workflow can engage multiple users to coordinate and work together as a team in the MR environment. A team dynamic would restructure and introduce new variables to the current framework.

References


