Rule-Based Generative Design Principles for Discrete Mortise-Tenon Timber Assemblies

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The computational design and digital fabrication of timber architecture have been sweeping the field of the built environment in recent years, enabling the creation of complex timber structures using traditional mortise-tenon joints (MTJs). This study proposes a set of architectural design principles and rules that integrate shape grammars and discrete assembly strategies to generate adaptable and reconfigurable timber systems. By employing voxel-based discretization and parametric shape grammars, principles of traditional timber framing and MTJs are reinterpreted to meet the growing demands for design adaptability in contemporary architecture. The research adopts a structured process to explore how different design principles and shape rules influence the generative process and spatial outcomes of timber assemblies. This is demonstrated through three design cases: 1) reinterpret Dougong principles to create layered configurations that emphasize structural stability and logic; 2) explore integrated architectural elements, merging column and wall functions into fluid spatial forms that embrace complex geometries; and 3) apply parametric and voxel-based techniques to develop reconfigurable curved assemblies, generating double-curved geometries through adaptive rules. These explorations validate the effectiveness of the proposed methods in achieving design flexibility and developing reconfigurable timber architecture. Structural analysis and optimization refine the assemblies, enhance structural performance. Robotic milling is utilized to fabricate MTJs, providing further validation of the feasibility of physically realizing the designed timber assemblies. Ultimately, this study advances reconfigurable practices, offering scalable, agile, and prototypical design solutions that respond to the complexities of contemporary architectural and environmental contexts.

Keywords: *Mortise-Tenon Joints, Discrete Timber Blocks, Digital Timber Architecture, Shape Grammars, Generative Design.*

INTRODUCTION

Given that the built environment lies at the intersection of complex ecological, socioeconomic, and cultural crises, timber is no longer regarded as an outdated material rooted in the past but instead positioned as a constructive solution for the future (UNECE, 2023). Today, computer-aided design and robotic manufacturing go hand in hand with a revival of craftsmanship and timber architecture, which allows for the re-visiting of traditional mortise-tenon joinery. This interlocking joinery technique, rooted in systems such as the Chinese Dougong, enables wood elements to join without fasteners. As a bracket-based system, Dougong reflects rule-based logic and spatial articulation, making it culturally grounded and broadly applicable to discrete timber construction. Comparable principles appear in Japanese Kumiki and Nordic log joints.

Recent research has extensively examined traditional timber joinery to uncover new configurations and systems that facilitate the creation of complex spatial forms and innovative structural solutions. Thoma et al. (2019) explored the design space of dowel-laminated timber beyond planar geometries, extending it to include more complex and curved forms. Kunic et al. (2021) introduced reversible construction kits composed of discrete timber elements, enabling flexible reconfiguration through joinery logic. This work was later extended into digitally traceable, reconfigurable slabs built from small-scale beam components (Kunic et al., 2024). Mostafavi et al. (2020) developed a computational workflow for robotic fabrication of a free-form timber pavilion, addressing reciprocal tessellation in complex geometries. Mostafavi et al. (2023) advanced this by enabling collaborative assembly of discrete components, progressing from stacking to self-interlocking reciprocal systems. Collectively, these studies show how computational design and digital fabrication have advanced timber architecture through geometric flexibility, structural adaptability, and reconfigurable assembly systems.

Despite significant advancements, a notable gap persists in effectively integrating computational design with timber joinery to create complex timber structures with intricate shapes and forms. Existing systems often rely on standardised geometries, lacking discretization strategies for reconfigurable design. This paper investigates how traditional mortise-tenon joints (MTJs) can be computationally reinterpreted to enable reconfigurable timber architecture. Through three design cases, it demonstrates how shape grammars and voxel-based discretization generate layered, integrated, and curved timber assemblies. Building on previous work (Xu, Teixeira and Shafiei, 2024) , which leveraged computational design tools to transform timber elements into flexible framed systems, this study further develops a generative design approach that formalizes architectural rules through shape grammars within discrete strategies. The study focuses on enhancing the reconfigurability of timber structures composed of discrete mortise-tenon blocks through the application of these design rules, which are demonstrated by generating and visualizing various timber design configurations as tangible representations of the proposed rule-based system. The significance of this research lies in advancing the field of reconfigurable timber structures, which preserve cultural heritage while promoting sustainable architectural practices. By leveraging digital technologies, the study unlocks the transformative potential of timber architecture, offering scalable and sustainable solutions for future applications.

METHODS

This research develops a computational framework that formalizes traditional MTJs principles into a rule-based generative system for designing adaptive timber assemblies. The method integrates shape grammars, voxel discretization, combinatorial aggregation, and structural feedback to generate diverse configurations. As shown in Figure 1, the process includes four phases: defining rules, generating block combinations, aggregating assemblies, and optimizing performance. This workflow preserves the logic of historical joinery systems while enabling iterative refinement and spatial exploration..

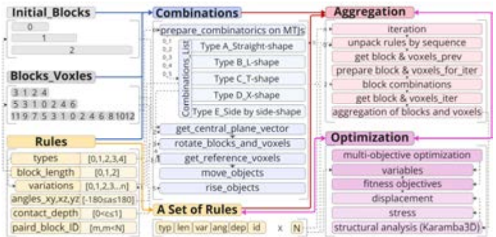

Figure 1
Generative design workflow for rule-based discrete timber assemblies: from rule definition to aggregation and optimization

The computational system is built in Grasshopper using custom Python components for rule application, block manipulation, and assembly aggregation within a voxel discretization framework.

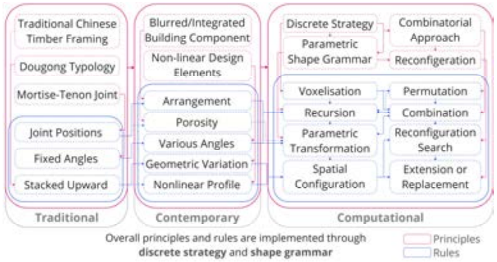

Figure 2
Evolution of design principles and rule systems for discrete timber assemblies across traditional, contemporary, and computational paradigms

Structural simulations are conducted using Karamba3D (Preisinger and Heimrath, 2014), while Wallacei (Makki et al., 2018) supports multi-objective optimisation. These tools enable an integrated environment guided by design logic, with structural and fabrication feedback informing refinement. Toolpaths are derived from voxel-based mortise-tenon geometries, and then simulated and exported using the Robots plugin for execution with a 9.5 mm diameter straight bit on a compact router mounted to a UR10 robotic arm, operating at 10 mm/s. This setup ensures accurate milling of interlocking joints within a design-led generative system.

To contextualize the preceding design workflow, Figure 2 illustrates the conceptual development and evolution of mortise-tenon joinery rules across traditional, contemporary, and computational paradigms. Traditional mortise-tenon systems exemplified by the Chinese Dougong are characterized by fixed joint positions, stacked formations, and axial symmetry, offering structural stability through interlocking connections (Liang, 1983). Contemporary reinterpretations introduce greater geometric variability, nonlinear spatial configurations, and porous arrangements. Computational strategies extend this flexibility by encoding joinery logic into parametric rule sets. These include voxel-based discretization, recursive aggregation, and reconfigurable connection algorithms that adapt to varied spatial conditions. The rule-based approach applies shape grammars and combinatorial logic through permutation, recursion, and transformation to generate reconfigurable timber blocks. This methodology builds upon prior studies on computational interlocking assemblies (Tessmann and Rossi, 2019) , combinatorial architectural systems (Sanchez and Andrasek, 2017), and shape grammars as rule-based generative frameworks that support both coherence and flexibility (Stiny, 1980). This conceptual foundation directly informs the discrete grammar developed in the following section, where parametric rules and voxel-based strategies are operationalized into a generative design system.

The rule-based system encodes MTJ logic into a discrete generative grammar, defining a set of parametric rules for block generation, combination, and aggregation. Each rule specifies the block type, length, variation, angular relationship, connection depth, and paired block ID. These parameters are stored and accessed as a structured dataset of rule combinations, as shown in the “A Set of Rules” panel in Figure 1. Shape grammars are used to control how these rules are sequenced and applied across the voxel space. By defining rules as recursive operators acting on localized inputs, the system can rapidly test combinatorial possibilities and generate valid configurations of discrete timber blocks.

Following rule definition, the framework proceeds to the aggregation of timber blocks through an iterative combinatorial process. As shown in the “Aggregation” sequence of Figure 1, each iteration applies a set of encoded rules to assess block relationships, unpack rule parameters, and assign voxel positions in 3D space. At the core of this process are “Combination” operations, which involve identifying reference planes and vector alignments, rotating and translating blocks, and positioning them within the discrete voxel grid. These localized combinations are applied recursively and cumulatively, forming the basis for higher-level aggregation. Each aggregation step verifies geometric fit and rule coherence to maintain continuity and spatial logic across the system. This recursive mechanism enables the generation of increasingly complex structures from a limited library of components, supporting rapid design exploration across varied architectural conditions.

To assess the structural performance of the generated assemblies, the framework incorporates an integrated optimisation loop. Structural analysis is conducted using Karamba3D, which evaluates displacement, stress distribution, and overall load response under gravitational conditions. These simulation results feed into Wallacei, which applies multi-objective optimisation using a genetic algorithm. Objectives include minimizing displacement and stress while satisfying rule-based spatial constraints. The optimized results inform adjustments to rule parameters such as block rotation angles, contact depths, or sequencing logic, enabling feedback-driven refinement of the generative process. This process enables the generation of reconfigurable timber assemblies that balance joinery logic, spatial adaptability, and fabrication feasibility, setting the stage for design explorations in the next section.

RULE-BASED TIMBER DESIGN

This section demonstrates how the proposed rule-based approach not only generates feasible timber configurations but also establishes a replicable and scalable design system grounded in joinery logic. The paper explores three design cases that illustrate the application of shape grammars across traditional, contemporary, and computational design paradigms. Each case presents a unique configuration of discrete timber forms, with distinct shape rules, procedural logic, and generative steps. By tracing the evolution of foundational traditional principles into hybridized systems that integrate contemporary computational strategies, these cases investigate the potential of shape rules in generating reconfigurable timber architectural designs.

To formalize these principles as computational rules, traditional spatial relationships are encoded as parametric inputs within a shape grammar logic. The paper next introduces the foundational elements of the shape rules, illustrated in Figure 3, which define how timber blocks interact spatially. These relationships form the basis for generating procedural rules within the shape grammar framework. The basic shapes are timber blocks with identical cross-sections, discretized into voxels for precise spatial positioning, numerical labeling, and computational manipulation. The spatial relationships between these blocks are classified based on the connection characteristics of traditional Chinese MTJs, particularly their joint locations and angular orientations. In this process, voxel indices are used to calculate all possible pairwise combinations through Cartesian products, generating a list of voxel pairings between two blocks. Each shape type (e.g., Straight, L, T, X, and Side-by-Side) has a corresponding set of voxel pairings, represented by the Combinatorial_List formulas shown in Figure 3 to guide block positioning. The orientation of each connection is determined by the vector relationships between voxel pairs, establishing the planes for specific angular rotations. Moreover, the contact depth between blocks is a critical parameter for generating MTJs geometry. Expressed as a percentage of the timber block's total depth, a greater contact depth increases the geometric constraint area and enhances structural stability. Conversely, shallower depths allow for more efficient stacking, though often with reduced stability.

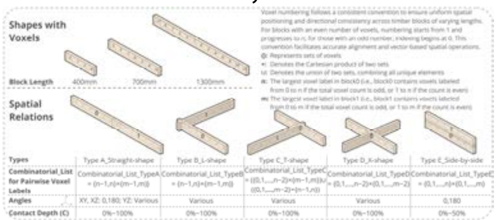

Figure 3
Basic shapes and spatial relationships for shape grammar design

Figure 4
An example of a parametric rule set with sequential logic for generating discrete timber assemblies

With these established elements for the shape rule, a structured sequence of rules can be defined to iteratively generate timber forms. Figure 4 provides an example of a rule set, illustrating the sequential rules and their corresponding parameters. Each rule step includes its corresponding type, block length, combinatorial variation, angular adjustment, contact depth, and the paired block ID. These parameters, represented by a series of indexed values, guide the generation of the next block by referencing its paired previous block ID. This parametric rule set forms the generative backbone of the system, enabling automated evaluation, transformation, and expansion of discrete timber assemblies across varying architectural contexts.

This form of shape grammar, with its rule logic as a foundation, establishes an adaptable framework for producing diverse timber configurations. By adjusting parameters such as block positioning, connection angles, and contact depths, the system supports a range of design intentions and practical requirements. In the following sections, three design cases illustrate how specific rule sets are developed and applied within distinct architectural contexts, demonstrating the versatility and potential of the proposed approach.

Design case 1 traditional timber framing language

Traditional Chinese timber framing systems, particularly the Dougong brackets, embody a highly logical structural system and remarkable constructional aesthetics. Their characteristic layered stacking forms and precise mortise-tenon joint positions provide a strong foundation for deriving a design language. As shown in Figure 5, this design case extracts the inherent rules of this traditional system. It translates them into a set of rules for timber block configurations, establishing the basis for the application of shape grammars.

Each shape rule defines the generation of a new Block 1 in relation to an existing Block 0, using specific combinatorial types, rotation angles, contact volumes, and the length of the new block. The execution of this shape grammar involves step-by-step application of a finite set of rules, with each rule assigning an ID to the newly generated timber block. The assigned ID corresponds to blocks produced in previous steps, ensuring traceability and consistency in the construction process. The combinatorial voxel indices also serve as a critical input, defining the spatial relationship between pairs of blocks, thus enabling the accurate positioning of new blocks relative to the existing ones.

Through the sequential application of these shape rules and logical operations, a timber structure emerges, comprising columns and beams that reflect traditional construction methods. The resulting configuration features a top structure characterized by upward-stacking layers, outward extensions, and a roof that ascends incrementally in a stepped formation. This final structure adheres to the principles of traditional timber framing, ensuring stability while also offering the potential for further generative extensions at the discrete block ends.

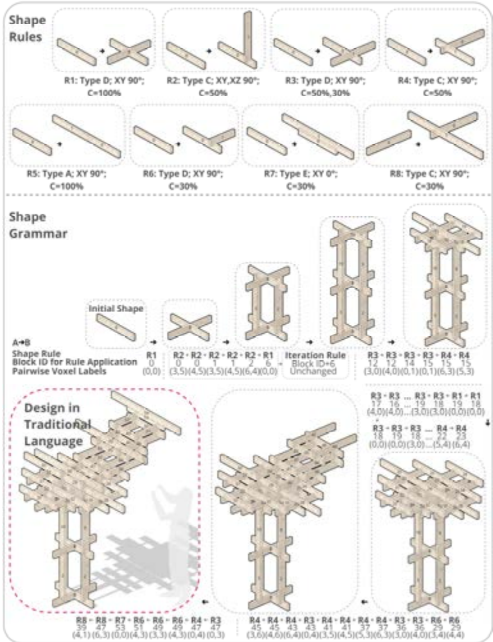

Figure 5
Parametric shape rules and grammar derived from traditional Dougong joinery for upward-stacked timber assemblies

Design case 2
contemporary architectural elements

In contemporary timber architecture, the boundaries between architectural elements, such as columns, beams, and walls, have become increasingly fluid. These elements are often treated as integrated systems rather than distinct parts. For example, the timber architecture of Kengo Kuma demonstrate this integration, employing small timber blocks to assemble architectural forms (Kuma et al., 2019). While not computationally designed, these structures share similarities with discrete computational assemblies in their modular design and construction approach.

The design case, as shown in Figure 6, explores a similar architectural element that integrates column and partial wall functions. The shape grammar process begins from a central base and generates a structure through iterative, diagonally offset arrangements. While the generated angles between timber blocks remain fixed at 90°, the varying degree of misalignment between successive layers introduces a flexible, curved profile. This process highlights the potential of combining spatial relationships and rules derived from traditional mortise-tenon joinery to create more adaptable and fluid architectural elements.

This design case demonstrates how traditional spatial principles and connections can be reinterpreted to generate contemporary timber architectural elements that blur the boundaries between structural and spatial roles.

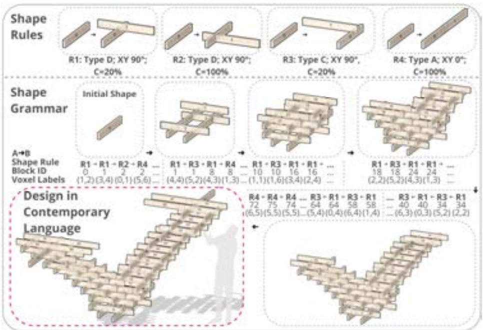

Figure 6
Generative grammar for spatially integrated timber elements inspired by contemporary discrete assembly systems

Design case 3
computational curved timber assemblies

Parametric design methods provide a powerful means of extending shape grammars to generate highly flexible and reconfigurable timber forms. This design case explores how integrating parametric operations with curve-based properties can expand the possibilities for discrete timber assemblies, offering a novel approach to creating complex and adaptable structures.

As shown in Figure 7, the shape rules employed in this case introduce significant variability in rotation angles, distinguishing it from the previous design cases. The process begins with two foundational inputs: an initial shape and a base curve, which define the geometric starting point and the directional framework for generating the timber configuration. The base curve is divided into vector line segments based on the size of the timber blocks, and the angles between adjacent segments are calculated. These angles are further subdivided into smaller increments to determine the precise rotation angles between individual timber blocks, enabling recursive generation within defined sets of blocks. Following the directional guidance of the base curve, the structure is generated in a Z-shaped stacking pattern, with each subsequent layer slightly shifted outward.

This process creates a hyperbolic wall configuration that transitions seamlessly from the curve's base to its double-curved geometry. The parametric system allows for real-time adjustments by modifying the control points of the base curve, which automatically recalculates the rotation angles between timber blocks. This capability facilitates the rapid creation of reconfigurable timber forms that are adaptable to diverse architectural requirements.

Figure 8 demonstrates the voxel-based generative process underlying the spatial transformation and assembly of discrete timber structures. This process leverages the unique identifiers of voxels to define the positioning, orientation, and combination of timber blocks in space. The grid vectors, along with their sequential numbering, visually represent the order in which the timber morphology is generated.

At the foundation of the process, a base curve provides calculated angular values that are directly applied to the initial layer of timber blocks, forming the basis of the shape grammar. These angular

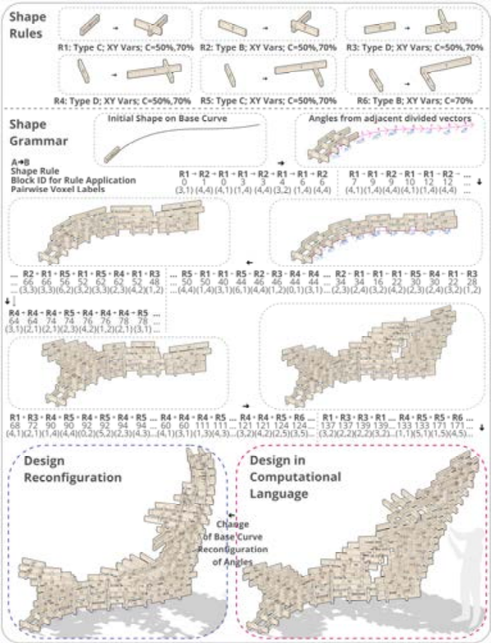

Figure 7
Recursive shape grammar for reconfigurable timber assemblies using segmented base curves and parametric rotation logic

Figure 8
Voxel-based generative computation for discrete timber design

values are further utilized to guide the adaptive placement and alignment of subsequent timber blocks across higher layers, dynamically adjusting the spacing between elements. This methodology facilitates the creation of a free-form, reconfigurable timber structure, aligning with principles of computational design and material efficiency.

This case highlights the potential of computational parametric shape grammars to produce timber structures that are aesthetically complex and highly versatile, enabling reconfiguration through simple geometric inputs.

Structural analysis and optimization

Structural analysis and optimization were performed using Karamba3D for finite element simulation and Wallacei for multi-objective optimization. The aim was to minimize maximum displacement and stress to ensure both stability and material efficiency. The assemblies used MGP10 pine with orthotropic properties modeled to simulate anisotropic material behavior. Timber blocks measured 90×35 mm in cross-section and were subjected to gravitational self-weight, with fixed supports applied at the base layer to simulate realistic conditions. MTJs allowed rotational movement while constraining translation, replicating physical joinery behavior.

To further reflect mechanical performance of MTJs, customized joint definitions were implemented using Karamba3D's Beam Joint component. Rotational stiffness values were defined as 100 kNm/rad along the X and Y axes and 1000 kNm/rad in the Z axis, while translational stiffness values were set to 100 kN/m in the X and Y axes and 1000 kN/m in Z. These parameters allowed limited lateral displacement while preserving vertical rigidity, thereby enhancing the accuracy of gravitational load simulation. Stiffness settings were applied at both beam ends to model bidirectional interaction between connected elements, ensuring the model captured the localized flexibility and global integrity of the assembled structure.

To optimize the design, variables derived from the shape grammar rules were encoded as genes in

Wallacei's genetic algorithm. These included angular variations of the base curve at the bottom of the assemblies and the rotation angles of the upper timber blocks. The base curvature influenced the overall form and structural stability, while rotation angles determined block interlocking and load distribution. Defining these parameters allowed the optimization process to explore design iterations that minimized displacement and stress. This integration of structural feedback into the generative design system illustrates how computational analysis supports informed development within rule-based workflows.

Structural analysis in Karamba3D revealed considerable displacement in the upper regions of the timber assemblies due to their cantilevered configuration. As illustrated in Figure 9 (top), stress concentrations were also identified around the base joints, where load transfer was most pronounced. The initial structural response exhibited a maximum displacement of 2.36 cm and a peak localized stress of 0.156 kN/cm², highlighting key performance limitations and the need for targeted optimization.

To improve structural performance, the design was subjected to 200 optimization iterations across 20 generations using Wallacei. Each variant was evaluated in Karamba3D, with displacement and stress values informing the fitness function. The process progressively refined the design by prioritizing configurations with improved structural behavior. Following optimization, the maximum displacement was reduced by approximately 26.3%, from 2.36 cm to 1.74 cm, while peak stress decreased by 14.7%, from 0.156 to 0.133 kN/cm². As shown in Figure 9 (bottom), the resulting configuration exhibited more uniform displacement across the upper layers and better-distributed stress at the joints, leading to enhanced stability and reduced risk of localized failure.

These results validate the structural feasibility of rule-based timber systems and illustrate the capacity of parametric optimization to resolve performance issues through iterative evaluation. The design process efficiently progressed toward structurally robust configurations by leveraging the parametric flexibility of shape grammar rules. Orthotropic material modeling in Karamba3D enhanced the accuracy of structural predictions by capturing the anisotropic behavior of pine wood, while semi-rigid joint definitions ensured realistic deformation behavior in timber assemblies.

Through the multi-objective optimization capabilities of Wallacei, deformation and stress were reduced while preserving the structural intent of the original design. This reinforces the need to treat structural evaluation not as a post-rational check, but as a formative step in rule-based generative workflows. By embedding performance evaluation into the generative process, the approach strengthens the methodological contribution of rule-based systems to digital timber architecture.

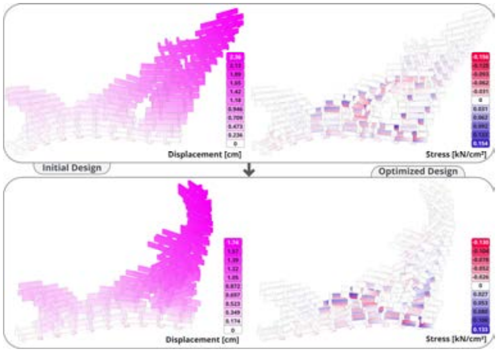

Figure 9
Structural analysis and optimization results.
top: Initial design with displacement and stress analysis.
bottom: Optimized design with reduced displacement and stress

Robotic milling of mortise-tenon joints

Robotic milling was employed to fabricate the timber assemblies, providing a precise and adaptive method for translating digital designs into physical components. To accommodate blocks of varying sizes and joint configurations, an adjustable fixation system was developed, ensuring stability, repeatability, and accessibility during the milling process (Figure 10a, b). This setup addressed limitations of conventional clamping techniques and supported consistent fabrication quality.

Toolpaths were generated by offsetting the negative geometries of the joints, accounting for the milling tool's radius to prevent material over-removal or undercutting (Figure 10c). Special attention was given to the formation of rounded corners on concave mortises, which were addressed by chamfering or rounding the corresponding tenon corners to ensure a precise interlock. Assembly-direction tolerances were introduced to compensate for material variability and facilitate smooth connections. The physical fabrication of MTJ Types A and D (Figure 10d) confirmed the accuracy and effectiveness of this method, closely matching digital models.

This fabrication process demonstrates the feasibility of translating parametric joinery logic into buildable components with high precision. As part of a closed-loop design-to-fabrication system, robotic milling grounds the generative process in material execution and reinforces the practical integration of traditional jointing principles with computational workflows. By enabling repeatable and scalable physical prototyping, this approach strengthens the contribution of rule-based design systems to timber architecture, bridging conceptual design and construction practice.

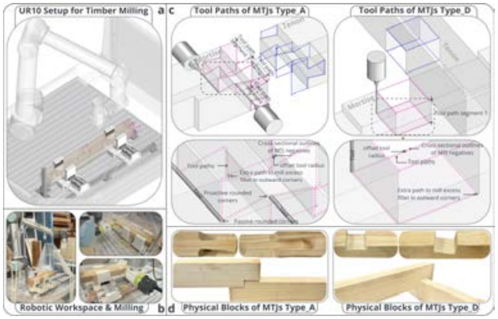

Figure 10
a: UR10 Robotic setup for timber milling. b: Photos of UR10 milling setup. c: The milling tool paths for MTJs Type A and D. d: Photos of physical timber blocks with MTJs

CONCLUSION AND DISCUSSION

The study investigates how discrete blocks with MTJs contribute to the development of reconfigurable timber systems through computational reinterpretation. It establishes a foundation for modular, adaptable, and structurally coherent assemblies by translating traditional joinery logic into spatial rules and integrating these with voxel-based discretization.

The research proposes a set of scalable, rule-based design principles for reconfigurable timber structures. These principles are articulated through three interrelated logics: combinatorial connection defines how timber blocks interlock based on joint typologies; geometric configuration governs spatial relationships through voxel positioning, angular variation, and contact depth; and procedural aggregation organizes the step-by-step generation of assemblies through referencing and sequencing discrete blocks. By encoding these principles into a computational grammar, the framework supports the systematic generation of layered, integrated, and curved timber configurations that preserve structural logic while allowing formal adaptability.

Each design scenario responds to distinct architectural objectives, illustrating how formal complexity can emerge from well-defined rule sets. Rather than treating digital tools as ends in themselves, the design process positions joinery as a materially grounded and spatially generative logic. Structural simulation and robotic fabrication reinforce this approach: the former refines configurations under physical constraints, while the latter verifies precision and constructability, enabling translation into buildable solutions.

Beyond methodological development, the study contributes conceptually by rethinking joinery as a central driver of architectural formation rather than a secondary structural detail. This generative framework demonstrates how rule-based design can integrate performance evaluation and fabrication workflows, supporting a more adaptive and systemic mode of architectural production. Its alignment with modular construction and digital manufacturing suggests practical value for scalable and sustainable timber systems.

Future research will focus on full-scale physical prototyping derived from these principles, with particular emphasis on assessing their feasibility in real-world contexts and examining the scalability of the proposed design rules.

REFERENCES

Kuma, K., Imperadori, M., Clozza, M., Hirano, T., Vanossi, A. and Brunone, F. (2019) 'KODAMA: A Polyhedron Sculpture in the Forest at Arte Sella', *Digital Wood Design: Innovative Techniques of Representation in Architectural Design*. Cham: Springer International Publishing, pp. 1255–1286. Available at: https://doi.org/10.1007/978-3-030-03676-8_51

Kunic, A., Angeletti, D., Marrone, G. and Naboni, R. (2024) 'Design and construction automation of reconfigurable timber slabs', *Automation in Construction*, 168(B), 105872. Available at: https://doi.org/10.1016/j.autcon.2024.105872

Kunic, A., Naboni, R., Kramberger, A. and Schlette, C. (2021) 'Design and assembly automation of the Robotic Reversible Timber Beam', *Automation in Construction*, 123, 103531. Available at: https://doi.org/10.1016/j.autcon.2020.103531

Liang, S. (1983) *Yingzao Fashi Zhushi*. Vol. 1. Beijing: China Architecture & Building Press.

Makki, M., Showkatbakhsh, M. and Song, Y. (2018) *Wallacei: An evolutionary and Analytic Engine for Grasshopper 3D*. *wallacei*. Available at: https://www.wallacei.com (Accessed: 29 January 2025).

Mostafavi, S. (2020) 'Design Computation to Robotic Production Methods for Reciprocal Tessellation of Free-from Timber Structures - Design, production, and assembly of 100 years Bauhaus wood Pavilion', *Anthropologic: Architecture and Fabrication in the cognitive age - Proceedings of the 38th eCAADe Conference - Volume 2, Berlin, Germany, 16-18 September 2020, pp. 413-422*. Available at: https://doi.org/10.52842/conf.ecaade.2020.2.413

Mostafavi, S. (2023) 'Cobotic Matters – Collaborative Robots and Discrete Assembly Design: From Stacking to Self-Interlocking of Reciprocal Components', *HUMAN-CENTRIC - Proceedings of the 28th CAADRIA Conference, Ahmedabad, 18-24 March 2023, pp. 241–250*. Available at: https://doi.org/10.52842/conf.caadria.2023.2.241

Preisinger, C. and Heimrath, M. (2014) 'Karamba - A Toolkit for Parametric Structural Design', *Structural Engineering International*, 24 (2), pp. 217–221.

Sanchez, J. and Andrasek, A. (2017) 'Bloom', in *Fabricate 2014*. DGO-Digital original. UCL Press (Negotiating Design & Making), pp. 98–103. Available at: https://doi.org/10.2307/j.ctt1tp3c5w.16

Stiny, G. (1980) 'Introduction to Shape and Shape Grammars', *Environment and Planning B: Planning and Design*. SAGE Publications Ltd STM, 7 (3), pp. 343–351.

Tessmann, O. and Rossi, A. (2019) 'Geometry as Interface: Parametric and Combinatorial Topological Interlocking Assemblies', *Journal of Applied Mechanics*, 86 (11), 111002.

Thoma, A., Jenny, D., Helmreich, M., Gandia, A., Gramazio, F. and Kohler, M. (2019) 'Cooperative Robotic Fabrication of Timber Dowel Assemblies', in *Research Culture in Architecture: Cross-Disciplinary Collaboration*. Birkhäuser, pp. 77–88.

United Nations Economic Commission for Europe (UNECE). (2023) *Circularity concepts in wood construction*. Geneva, Switzerland: UNITED NATIONS. Available at: https://unece.org/sites/default/files/2023-05/ECE_TIM_DP95E_web.pdf (Accessed: 28 March 2025).

Xu, Q., Teixeira, F. F. and Shafiei, M. (2024) 'Exploring Rule-Based Discrete Timber Design With Mortise-Tenon Joints', in *Proceedings of CAADRIA 2024,* 1, pp. 313–322. Available at: https://doi.org/10.52842/conf.caadria.2024.1.313