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Timber Joinery Database

Documenting and designing traditional and contemporary wood-wood connections in a teaching environment utilizing an online OER platform

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The rapid advancements in technology call for a new approach to disseminating knowledge, emphasizing inclusivity, open accessibility, and collaborative intelligence. This shift towards an inclusive, open-source community facilitates global online connections that enhance the exchange of techniques and knowledge, further enabled by digital planning tools integrating design and execution seamlessly. Such advancements have revived interest in timber joints, combining traditional craftsmanship with digital design and manufacturing innovations. The Timber Joinery Database was established to preserve and expand this heritage by creating an open-source online platform for documenting both traditional and innovative timber joints. The development of the database included the structuring, design and technical conception as well as the integration of the first entries for evaluation. This work allows for the continuous implementation of joint analyses, developments and physical models production, bridging traditional craftsmanship with modern manufacturing methods. As the database evolves, it is enriched with more parameters and a parametric framework to cater to user-specific customization needs, ensuring the project's relevance and application in current and future timber joinery practices. This initiative represents a blend of tradition and innovation, leveraging digital tools and open-source principles to advance the field of timber joinery.

Keywords: *OER-resources, wood-wood connections, digital design and manufacturing*

INTRODUCTION

The swift progression of technology calls for an innovative approach towards the dissemination of knowledge, emphasizing inclusivity, open access, and collective intelligence (Ratti & Claudel 2015). Digital information, capable of being duplicated and distributed at virtually no cost and without quality degradation, embodies this shift (Anderson, 2012). Such files encapsulate all necessary data for replication, illustrated by John Maynard Keynes's analogy: "it is easier to ship recipes than cakes and biscuits" (Anderson, 2012). Platforms for Open Educational Resources (OER) embody this ethos by offering information to an unlimited user base, drawing inspiration from the open-source model. This transition from proprietary, solitary knowledge to a shared, open-source collective is highlighted by the "power of many" concept, paving the way for globally connected online communities. These communities excel in the exchange of work methodologies and knowledge (Papavlasopoulou, Giannakos, & Jaccheri, 2016), mirroring traditional crafts where knowledge transition occurred from master to apprentice or within networks like guilds.

Ultimately, these communities serve an essential role in creating a collective knowledge base.

Wood joinery

The qualitative understanding of wood's anisotropic structure and the strategic application of its distinct properties in construction frameworks are deeply entrenched in artisanal crafts (Schindler, 2009). This specialized knowledge is shaped by direct, tactile engagement with the material (Ingold, 2007). Within the domain of timber structure design, joints are identified as pivotal elements (Weinand, 2016), facilitating the static interplay among structural components through their intersecting geometries (Zwerger, 2015; Menges et al., 2016). Such joints are characterized within the paradigm of mechanical joining techniques (Messler, 2006), wherein the complexity and precision of the intersecting geometries enhances the structural assembly process.

The continuous development of timber joints, responding to the dynamic environmental and technological changes, reflects the adaptive craftsmanship passed down through generations from master to apprentice (Messler, 2006). By modifying or combining the geometry of interlocking features, the functionality of joints can be adapted to new use cases (Kanasaki & Tanaka, 2013).

As timber is a natural material with limited dimensions, the joining of timber has always played a vital role in the development of new technologies (Tang & Chilton, 2019). The evolution of timber joints is closely linked to the emergence of novel tooling solutions, indicating a reciprocal relationship between tooling innovation and joint development (Gerner, 1998).

Digital Design and Manufacturing in timber construction

Technological advancements and economic factors have catalyzed a revitalization of interest in timber connections (Schindler, 2009). Design- and construction processes have undergone a significant transformation, now leveraging the integration of material-specific, constructional, and fabrication parameters directly within design tools (Buri & Weinand, 2011). The advent of digital technologies, including generative design and CNC (Computer Numerical Control) machining, has facilitated the efficient fabrication of bespoke products (Kolarevic & Klinger, 2013). (Kolarevic & Malkawi, 2005) assert that for a CNC milling machine, producing a thousand distinct objects is as economically viable as manufacturing a thousand identical items.

Wood's amenability to machining renders it an exemplary candidate for digitally controlled woodworking equipment, positioning the timber industry at the forefront of adopting such technologies (Buri & Weinand, 2011). Furthermore, technologies such as laser cutting and 3D printing have streamlined the process of rapid prototyping within the design phase (Atsumi, Hanazato, & Kato, 2021), significantly alleviating the development challenges associated with crafting novel joint configurations, particularly for those lacking special expertise.

Such capabilities have ushered in the era of flexible industrial prefabrication, or "mass customization" (Eekhout, 2008; Chai et al., 2019), liberating architectural design and execution from the constraints of uniformity. Computational design and manufacturing tools have been instrumental in incorporating material-specific parameters into both the design and construction phases (Kolarevic & Klinger, 2013), thereby enabling designers to fully exploit the unique properties of timber (Allner et al., 2021).

Technological advancements have changed the nature of materials. After an era of standardization due to mechanized production (Eekhout, 2008), digital tools enable architects and designers to move beyond traditional timber products to leverage basic elements like chips, fibers, veneers, lamellas, and solid wood. This approach unlocks new material possibilities, offering a broader range of custom building elements and forms that challenge standard notions of timber products. By understanding the transformation and aggregation processes of industrialized timber, designers can invent tailored solutions that fit specific design requirements more closely than standard products. However, to fully leverage the potentials of timber, there must be an emphasis on understanding timber's basic elements and design criteria early in the project. This informed design process helps to integrate material concepts before architectural solutions (Svilans et al. 2019). Here, the knowledge rooted in crafts plays a crucial role. The tacit knowledge passed down through generations of carpenters can now be augmented digitally, presenting the opportunity for material specific-design approaches that were increasingly lost over the last two decades (Menges et al. 2016).

Parametric design models allow the generation of data based on predefined factors (Barthel et al. 2010). Joints were traditionally documented in relative dimensions (Gerner, 1998), and can thus be easily described as parametric elements. As components with integrated attachments, wood joints can be designed and controlled as part of generative process (Sass et al. 2006). Self-registering joints can adapt geometrically to specific local requirements in the construction (Tamke et. al. 2008). Material-specific parameters create a relationship between the size of the base members and the proportions of the joint design. The traditional proportions, tried and tested, ensure the dimensions change accordingly to ensure both the visual design and the structural resilience of the connection (Heesterman & Sweet, 2018)

Research investigations into parametric joinery are manifold. (Tamke et. al. 2008) developed a digital process chain based on a parametric geometric model, including the control and application of joints to the CNC machinery. (Kanasaki & Tanaka, 2013) explored parametric adaption of traditional geometries. (Vestartas, 2021) took inspiration from traditional log building techniques such as scribing and investigated the adaption of parametric joints to non-uniform elements. (Lharchi et al. 2022) developed a workflow to identify the fundamental data to describe a given half-lap geometry for machine-independent fabrication procedures and convert the joint into a usable output for both fabrication and assembly simulations.

Consequently, ongoing research endeavors are dedicated to uncovering new joint configurations, driven by objectives to simplify design intricacies and streamline the construction process (Adelzadeh et al., 2023), illustrating a concerted effort to marry technological innovation with traditional construction methodologies for enhanced efficiency and accessibility.

RESEARCH PROBLEM

Despite the current research endeavors, aiming to refine and optimize wood-wood connections, crucial challenges with utilizing traditional wood joints in architecture still persist. However not only, the scarcity of carpenters proficient with these connections in today's workforce, coupled with the rarity of master craftsmen, remains as a poignant issue. Also, the loss of the nuanced knowledge inherent to these traditional techniques, as it vanished alongside the very craftspeople who harbored it, has created a knowledge gap that current and future generations struggle to bridge (van Nimwegen 2023).

While the documented literature on timber joints offers substantial insight (Satō & Nakahara, 1995; Graubner, 1994), the granularity of these documents in detailing precise dimensions and proportions is often lacking (Gerner, 1998), highlighting the knowledge gap in this field and the indispensable nature of such skilled craftsmanship. Moreover, these documents are often highly sought after, thus making them difficult to obtain.

(Zwerger, 2015) states "It is just that we no longer know what this material is capable of and lack the skills to work it. And that is something we can change." As this knowledge is often stored in form of skills, it is in danger of being lost completely if not applied (DeLanda, 2004).

In addition, the shift from handcrafted joinery to machine-assisted production has introduced new sets of challenges. Characteristics inherent to CNC machines, such as the inability to produce sharp corners due to the milling tool's circular motion, necessitate a reevaluation of joint designs to accommodate these mechanical limitations. This adjustment often requires the geometry of joints to be adapted to ensure compatibility with a variety of machine types, highlighting a significant departure from traditional handcrafted methods (Kanasaki & Tanaka, 2013).

Moreso, the question for new connections arises, which due to economic and technical reasons could not be fabricated with traditional methods (Schindler, 2009) and innately are aimed at digital manufacturing technologies. This, by itself, further deepens the gap between the declining traditional knowledge of Joinery and modern-day construction methods in timber architecture.

RESEARCH OBJECTIVE

In order to reinstate the relevance of wood-wood connections for architecture and construction, it is imperative to preserve and disseminate the nuanced expertise of traditional woodworking as well as establish a systemic approach to make the integration of this knowledge into contemporary design practice accessible.

These aspects necessitate deep integration of this knowledge into pedagogical approaches within forward-looking architectural education. Addressing and educating young architects and engineers in such a way is not only crucial for advancing the field of wood joinery but also to introduce its implication from an interdisciplinary and multidisciplinary perspective.

Thus, the research objective is to educate students via an accessible database system that aggregates and interconnects joint designs. This technical infrastructure is dedicated to the documentation, technological transfer and enhancement of timber joinery. Embedded into an elective course, we seek to analyze application and design guidelines, explore both traditional and contemporary manufacturing technologies and examine their benefits and constraints. Following this analytic step, these joints are then adapted to the manufacturing constraints found in digital fabrication and implemented into the database. Hence, it also serves as a vehicle to support this educational method of the course.

While implementing a database of traditional and newly created joints, in a way that eases further integration into digital design and CNC fabrication, the project endeavors to offer an accessible, user-friendly interface that enables users from different educational backgrounds to efficiently explore, contribute and collaborate on data related to timber joinery, thus fostering a dynamic and sustainable knowledge exchange ecosystem within this specialized field.

METHODOLOGY

To ensure the attainment of synergistic outcomes, we embarked on a parallel development trajectory of both the pedagogical framework and the course structure, in conjunction with the online timber joinery database. This concurrent advancement facilitated the seamless integration and mutual reinforcement of educational strategies and technological functionalities. To ensure close alignment with student needs and pedagogical best practices, the process is accompanied by Teaching Analysis Polls (TAPs). These polls focus on elucidating learning opportunities, identifying learning barriers, and deriving actionable recommendations. Following this process a continuously refinement and evaluation using further TAPs, ensuring that the elements not only provide technical knowledge but also enhance the teaching and learning experience in the field of timber technology. This approach ensures the project delivers a holistic educational resource, melding theoretical knowledge with practical application.

Teaching Concept & Course Structure

Our teaching concept is inspired by the spiral curriculum (Bruner et al 1970) and ensures a

sequential build-up of knowledge, where each phase (analyze, design, make) informs and enriches the next, facilitating comprehensive education in this field. Drawing inspiration from The Connected Curriculum framework (Fung, 2017), our methodology encompasses its core aspects:
Integration with Ongoing Research, Connected Sequence of Learning Activities, Cross-Disciplinary and Global Connections, Output Production and Collaboration and Sharing Among Students.

As the content created is based on existing literature and knowledge and is publicly available, several steps were taken to ensure no copyrights are infringed. It was acknowledged that traditional joint dimensions could be used freely since they are not covered by copyright, even though direct illustrations from literature are not permitted. The team limited the use of information from any one source to 15% in accordance with open educational resources (OER) guidelines to steer clear of any copyright concerns. Students contributed by modeling the joints and creating illustrations, thus owning the copyright to their work. They provided their consent for these works to be published, with special care to violation of copyright laws.

For modern joints created by companies, permission was secured from the copyright owners before including their designs, confirming the lawful use of such materials in the publication.

Development of Technical Infrastructure
This phase targets establishing a robust digital infrastructure for effective documentation, seamless information implementation, and access. It encompasses selecting and configuring database software and crafting intuitive user interfaces to facilitate efficient interaction, supporting both information input and retrieval in a user-friendly manner. Newly developed joints from the course will be integrated into the database in order to document them in a coherent way and test the current structure.

To maximize the impact and reach of the database, strategies will be developed to disseminate results and promote the platform to a wider audience within the academic and professional community.

RESULTS
The results are of very different nature, the tangible outputs — such as the fully functional, user-friendly online platform and its integrated educational materials accompanied by the physical models — but also the less visible, yet equally significant, achievements including acquired knowledge by students, enhanced collaborative opportunities, and the evaluated course structure.

Experimental Joint Design in course environment
Acting as a practical application within the course, this segment involves the creation of a case study centered around the experimental development of a timber joint. This hands-on experience encourages students to apply theoretical knowledge, engage in creative problem-solving, and contribute novel insights and solutions to the database, enriching its content.

During the Design phase, an evaluation of manufacturing technologies is conducted to ascertain their potential applicability and limitations. The selection of a suitable manufacturing technology is pivotal to ensuring that the project's execution aligns with theoretical expectations. The design process includes the adaptation of joint geometry to meet the requirements of the selected manufacturing technology and the available stock material, ensuring that the designs are both innovative and feasible. Documentation in this phase is updated to include new joint geometries, the manufacturing technology chosen, and any identified constraints, thereby clarifying design intentions and guiding the realization process.

In the make phase, detailed research into manufacturing parameters—such as workpiece fixation, machining sequence, feeds, and speeds—is undertaken to facilitate the successful fabrication of prototypes. This phase integrates theoretical knowledge with practical application to optimize the manufacturing process.

The creation of prototypes involves the preparation of stock material and the careful planning and programming of manufacturing operations, transitioning conceptual designs into physical artifacts. Comprehensive documentation of the completed prototypes is achieved through photographs and detailed descriptions in a new factsheet, providing a record of the project's progression from concept to realization and contributing to the body of knowledge for future research and development in timber joinery. For his project, a student engaged in an in-depth analysis of two traditional joints through literature review and practical exploration by creating 1:1 scale models in wood. The investigation initially focused on the lap joint with a double dovetail, noted for its robustness, aesthetic appeal, and self-sufficiency without the need for additional fasteners, despite its complexity, time, and skill requirements for correct execution. The next phase of research examined the sao-tsugi, a Japanese mortise and tenon joint characterized by external connectors that enhance its tension resistance. This joint similarly combined aesthetic qualities with structural integrity but shared the lap joint's drawbacks in terms of skill level, time, and cost (Figure 1).

The design phase embarked on a creative quest to amalgamate the advantages of both joints, aiming for a construction that inherited the durability and tension resistance of the dovetail alongside the reversibility and assembly-focused resilience of the sao-tsugi. Initial concepts were materialized through sketches and cardboard prototypes (Figure 2), assessed for functionality via laser-cutting, leading to the establishment of a mortised dovetail configuration reinforced by two external elements as the foundational design principle.

Realization of the design in timber posed several challenges, particularly due to the specific geometry of the mortised dovetail, which necessitated the adoption of 5-axis CNC milling as the manufacturing

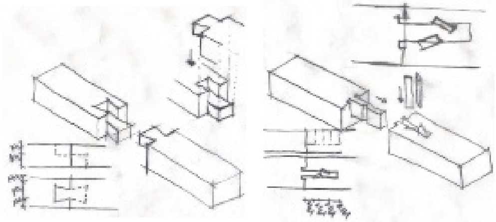

Figure 1
Literature review – investigating design principles of traditional joinery

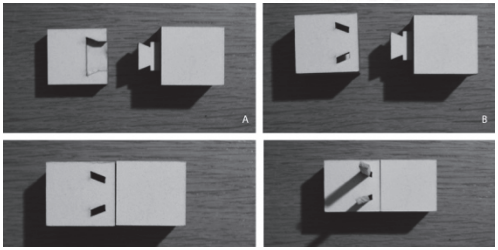

Figure 2
Manufacturing adaption – laser-cut cardboard prototype for assembly tests

technology of choice (Figure 3). The process involved meticulous adaptation of the joint geometry to accommodate the operational constraints and tooling available, including the strategic addition of dog-bones to the design.

Encountering difficulties with integrating rectangular external connectors because of tool radius limitations, a solution was identified in the Festool Domino—a ready-made industrial product whose rounded geometry and size variety perfectly matched the milled contours (Figure 4).

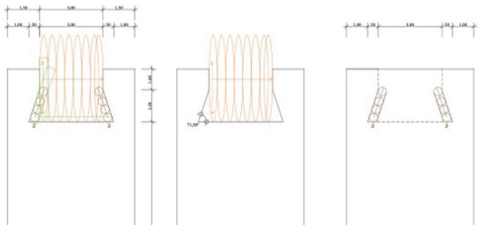

Figure 3
Adaption of female geometry joining features to manufacturing restraints

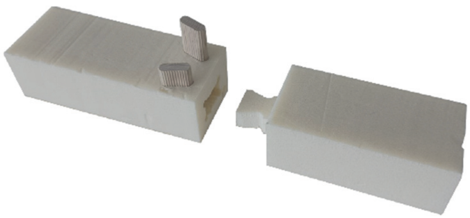

Figure 4
CNC-fabricated Styrofoam prototype of the student's developed design

The development of Computer-Aided Manufacturing (CAM) workflows was a collaborative effort between the student and teachers, embodying a dynamic feedback loop that continuously reconciled design intentions with the practical constraints of manufacturing.

This iterative process not only facilitated the physical making of innovative joint designs but also underscored the importance of integrating theoretical research with practical application in the field of woodworking.

Technical Infrastructure

The objective in developing a technical infrastructure is to present and edit information in a format that is easily accessible. Consequently, the website serves as the primary medium for the dissemination of information, hosting vital details on wood joinery and material properties through an open-source Kirby CMS platform. Kirby's headless CMS architecture greatly simplifies the process of data aggregation, incorporating extensive user and rights management features to streamline content management and accessibility (Figure 6).

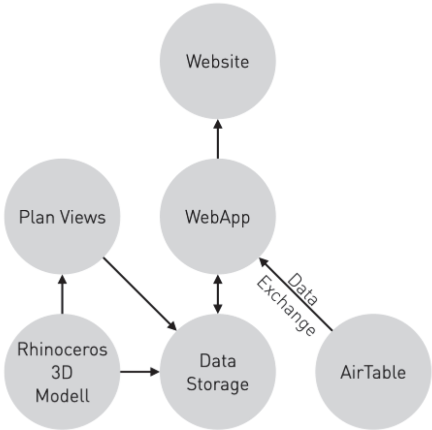

Figure 6
Technical structure showing data flows

For the stored Rhino model, specific requirements and constraints are established to maintain consistency across digital representations and facilitate the straightforward exportation of plan drawings. This includes enforcing closed b-reps for individual elements, adhering to fixed dimensions (45mm x 60mm cross-section, 300mm length), and maintaining a clear organizational structure in layering.

An interface for data aggregation is developed using Airtable, a cloud-based platform, enhancing the efficiency of online data entry for text and illustrations. This tool supports the creation of factsheets for data entry, a taxonomy for joint categorization (based on joint family, primary force resistance, and connection geometry), and the definition of plan views to depict assembled joints, individual components, and dimensions from an isometric perspective.

Additionally, the infrastructure accommodates offline use, enabling users to generate and download PDF datasheets of selected joints directly from the website. These datasheets, featuring detailed plan drawings in three-plane projections and isometric view, provide comprehensive access to joint information, ensuring the database's utility extends beyond online interactions.

To ensure that the database can be added to and managed easily and consistently, we use Python for the automated generation of standardized visual representations and adaptation of CAD data. Furthermore, the simplicity of generating a basic 3D model of a joint and inputting necessary data into the Airtable form facilitates effortless contributions to the database and enables the seamless implementation of extensive modifications to the stored CAD models. In particular, this eases collaboration with other teaching institutions from different backgrounds and implementation of knowledge created within the network.

DISCUSSION

Initiating the discussion, it is pivotal to acknowledge that, contrary to the documented, established joints, all developed joints within this project are at the prototype stage. Unlike traditional joints, which have been refined and validated over generations through extensive practical application, these newly developed prototypes necessitate rigorous testing before their integration into live projects. This testing is essential to ensure their reliability, functionality, and safety in real-world applications.

Besides this, already established joints can be implemented without further investigations, documentation includes design principles, scope of application and structural boundaries.

Crucially, establishing a collaborative network with academia, research institutions, and industry practitioners can amplify the project's scope and impact. This consortium would not only facilitate a multidisciplinary exchange of knowledge but also accelerate the refinement and application of the project's outputs across different contexts and scales in timber construction and design.

CONCLUSION

The adaptation of traditional joinery and its implementation within the course environment has proven effective. The joints collected in the database serve as a bridge between theory and practice, promoting technology transfer between academia and industry.

In the TAPs, students rated the course highly, citing the practical and interdisciplinary methodology used to analyses and create physical prototypes. It is clear that hands-on experimentation is invaluable in carpentry. This comprehensive approach has proven to be an invaluable tool in deepening students' understanding and engagement with the material. The simple implementation of joinery details into the database was achieved without the need for prior technical knowledge, making it accessible to a broader range of users. The ability to use the database during the course facilitated a detailed analysis of and comparison with other types of joints, enriching the learning experience. Moreover, the opportunity to gain hands-on experience in both analogue and digital manufacturing techniques provided students with a deeper insight into the technologies, highlighting their potential applications and limitations.

The complexity of programming the 5-axis CNC machining demonstrates that the course is ambitious in its technical scope. The project database is expected to make a significant contribution to the body of knowledge in this field, offering valuable insights for both research and real-world applications.

OUTLOOK

Looking ahead, future work should prioritize the implementation of parametric models to enhance their adaptability for user-defined projects, necessitating the development of a robust parametric logic. Additionally, refining the categorization scheme and factsheets will further enrich the database, offering detailed insights into assembly steps, the number of elements, and degrees of freedom for each joint type.

Exploring a broader spectrum of joint types also constitutes a significant area for expansion. This encompasses investigating external connectors and various modes of mechanical joining, as highlighted by (Messler 2006), and leveraging material properties in innovative joint designs, such as snap-fit joints and swelling connectors or self-registering joints that can adapt geometrically to specific local requirements in construction. Diving into diverse joining cultures, such as Dou-Gong or roundwood connections can provide a richer, more varied repository of joinery methods.

The involvement of partners from diverse backgrounds will continuously refine the methodology and expand the knowledge base. This interdisciplinary collaboration will significantly enhance the repository of information.

Integrating the database into academic courses and projects ensures continuous content development. Moreover, this approach embeds content creation as part of the learning and research process, enriching the database with fresh content and teaching students the importance of collaboration and knowledge sharing.

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