

Date: 17th April-2026

A COMPARATIVE ANALYSIS OF THE STRENGTH OF FURNITURE JOINTS IN TRADITIONAL AND DIGITAL MANUFACTURING METHODS

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Abstract: Amid the global shift toward the Industry 4.0 paradigm, architectural and product design is undergoing fundamental changes, shifting the focus from traditional craftsmanship to digital manufacturing using CAD/CAM/CNC systems and additive technologies. This study presents a comprehensive comparative analysis of the mechanical, spatial, ergonomic, and tectonic characteristics of furniture and wood joints manufactured using traditional and digital methods. The main focus of this work is to find the optimal balance between structural reliability, aesthetic expressiveness, and the strict requirements of the circular economy, particularly the concept of “Design for Disassembly” (DfD). The study employs a comprehensive methodological framework, including methods of comparative and graph-analytical analysis, finite element modeling (FEM), as well as an in-depth examination of representative case studies (optimization of the traditional Zongjiao joint, the WikiHouse Skylark modular plywood system, the integration of Lamello connectors, and the application of 3D-printed polymer components). The research results irrefutably demonstrate that algorithmically optimized traditional joints for multi-axis CNC machines are capable of outperforming both their manual counterparts and commercial metal ties in terms of bending moment distribution. At the same time, it has been found that polymer 3D-printed components made from basic filaments currently exhibit lower strength compared to solid-wood dowel joints, although the use of specialized engineering plastics opens up new possibilities. This work formulates the conceptual principles of hybrid tectonics, which ensures the synergy of the physical properties of orthotropic materials and algorithmic form-generation to create ergonomic and sustainable spatial structures of the future.

Keywords: digital manufacturing, Architectural tectonics, Furniture joints, Integrated mechanical fasteners, Design for disassembly, Spatial design, Additive manufacturing.

INTRODUCTION

The evolution of architectural tectonics and object design over the centuries has been inextricably linked to the development and refinement of material-joining technologies. In classical architectural theory, tracing its roots to the seminal works of Gottfried Semper and later reinterpreted by Kenneth Frampton, tectonics is defined as the poetics of construction, where the structural joint serves as the basic ontological element, aesthetically and physically expressing the logic of structural force transmission and the intrinsic nature of the material itself. Traditional methods were based on a deep empirical understanding of the anisotropic nature of wood. Every tenon, mortise, or dovetail joint was cut by hand, taking into account a multitude of variables: seasonal fluctuations in



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moisture content, internal stresses in the wood fibers, and the distribution vectors of operational loads. With the advent of Industry 4.0 and the widespread adoption of computer-aided design and manufacturing systems, as well as the rapid development of additive technologies, the paradigm for creating spatial and furniture structures has changed radically, transforming the very essence of material culture (Robeller, Barata, & Tagliaboschi, 2021).

The relevance of this study stems from the growing systemic contradiction between the global industry's drive toward high-speed, automated, and cost-effective production and the imperative to preserve the structural integrity, durability, and ergonomic suitability of furniture products. Contemporary environmental imperatives and sustainable development concepts, such as the circular economy and "design for disassembly," require the creation of innovative assemblies. These joints must not only withstand significant static and dynamic loads during operation but also allow for repeated, defect-free assembly and disassembly, preventing degradation of the bonding material. At the same time, the direct mechanistic transfer of traditional joinery joints into the digital manufacturing environment inevitably encounters technological limitations. For example, milling the sharp right-angle internal corners of a traditional tenon is impossible due to the radius of the cylindrical cutter on a CNC machine, which requires in-depth algorithmic optimization of joint geometries to adapt historical experience to modern machine algorithms (Hu, Fu, & Zhao, 2024).

The aim of this study is to conduct a comprehensive comparative analysis of the mechanical strength, spatial-compositional potential, and ergonomic effectiveness of furniture and architectural joints produced using traditional craftsmanship and modern digital manufacturing methods. To achieve this objective, three key tasks were formulated

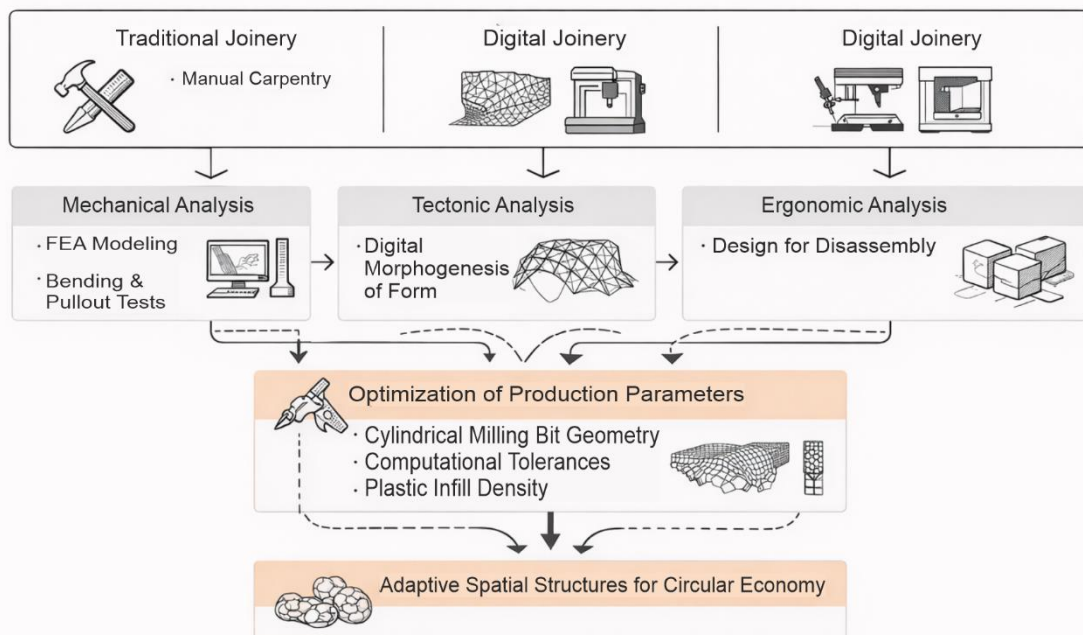


Figure 1— Conceptual framework of comparative research in traditional and digital joinery Source: developed by the author.

and sequentially addressed within the scope of this study. The first task consists of a



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rigorous quantitative and qualitative assessment of the mechanical behavior of various types of joints under critical loads, including classic solid-wood mortise-and-tenon joints, innovative commercial polymer and metal fasteners, as well as experimental joints produced using 3D printing. The second task involves identifying the direct influence of digital fabrication methods on the spatial, tectonic, and compositional aspects of interior design, with a particular emphasis on the visual articulation of the joint as an independent expressive element of the architectural environment. The third objective is to develop scientifically grounded practical recommendations for the ergonomic and technological optimization of structural assemblies to create adaptive modular spatial structures.

The subject of this study is structural joinery and furniture assemblies, as well as integral mechanical fasteners that form the load-bearing spatial framework of interior structures and small architectural forms. The focus of the study is on the mechanical characteristics of these joints, specifically their ultimate strength, angular stiffness, and deformability, as well as compositional and ergonomic parameters under conditions involving traditional manual practices compared to advanced digital manufacturing protocols.

The scientific novelty of this work lies in the interdisciplinary integration of parametric structural analysis with the philosophical and architectural concepts of digital tectonics and cognitive ergonomics. For the first time within a unified scientific discourse, a comparison is made between integral mechanical fasteners of modular architecture, generated using visual programming, and complex historical joinery joints and modern commercial fasteners based on a unified metric of load-bearing capacity and spatial adaptability. The study scientifically demonstrates that the geometry of a complex joint, algorithmically optimized for CNC machines, is capable not only of completely overcoming the technological limitations of digital tools but also of surpassing its historical counterparts in terms of strength characteristics, while preserving their high tectonic expressiveness.

The practical significance of this research lies in the creation of a validated scientific and technical database and a set of universal design principles. These materials will enable architects, interior designers, and furniture manufacturing engineers to make informed choices regarding joint topologies based on load application vectors, the characteristics of available machinery, and strict requirements for the product's circular lifecycle. The analytical results obtained can be directly integrated into current mass customization processes for furniture, significantly reducing the rate of production defects, minimizing the cognitive load on the end user during self-assembly, and extending the service life of objects in modern spatial environments.

METHODS

To ensure the most comprehensive and objective resolution of the research objectives, a multi-level methodological framework was developed, based on the close integration of empirical physical testing and advanced methods of virtual digital modeling. The core method of this study was a comparative analysis of mechanical tests of



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components, based on aggregated data obtained using universal mechanical testing machines. The tests were conducted with a strictly controlled crosshead displacement speed, set as standard at five millimeters per minute, which eliminated the influence of impact loads and allowed for the recording of pure static deformations. Standardized L-shaped and T-shaped specimens were tested, designed to mimic real-world corner and center joints in cabinet furniture and storage systems as accurately as possible (Zulj, Zupcic, Grbac, & Trupkovic, 2021). During the comparative analysis, a set of critical parameters was evaluated: the ultimate bending moment under compression and tension, measured in Newton-meters; the absolute pull-out resistance, measured in Newtons; and the angular stiffness of the joints (Janikova, Smardzewski, & Kuskun, 2025). The material composition of the analyzed samples covered a wide range of wood-based materials, including European beech with a density of approximately 700 kilograms per cubic meter at a normalized moisture content of 12 percent, standard three-layer particleboard with a thickness of 18 millimeters, as well as structural plywood made from radiata pine, used in modular architecture.

The graph-analytical method has been widely used for an in-depth scientific interpretation of the resulting deformation curves, which describe the relationship between displacement and applied load. Studying the nature of these curves is a critically important step, as it allows for the differentiation of the mechanisms of brittle and ductile failure of materials, as well as the identification of specific phenomena of microscopic creep characteristic of polymer connectors under prolonged static loading. In parallel with physical destructive tests, the finite element method was widely used in specialized software packages to evaluate moment resistances (Kasal, Erdil, & Efe, 2018). In the virtual simulations, wood was modeled as an orthotropic linearly elastic material, and complex nonlinear behavior models were applied in zones of critical plastic deformation. This approach allowed for the high-precision visualization of the internal stress distribution within the tenons, mortises, and hidden metal ties, identifying zones of dangerous stress concentration that, in reality, lead to catastrophic delamination along the glue joint or brittle failure across the wood grain. To assess the structural equilibrium of complex spatial joints, a specialized load difference coefficient was calculated, which reliably reflects the degree of symmetry in the distribution of forces arising between the mating horizontal frame members.

The case study method was used to conduct a detailed qualitative analysis of three specific high-tech manufacturing solutions that reflect various aspects of the digital transformation of product design. The first case study examined a modern algorithmic adaptation of the traditional Chinese Zongjiao three-way joint, historically used in classical furniture to achieve a seamless connection between legs and rails without the use of glue (Yang, Zhao, & Hu, 2026). Within this case study, various topological variations of this joint were investigated, evaluated not only by measures of absolute strength but also by strict criteria for machinability on CNC machines, including assessments of processing time, cutting force, and optimization of the number of effective G-code blocks. The second



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case focused entirely on an open modular architectural system, specifically on the innovative TIE-type plywood joint (WikiHouse Skylark), which allows for the assembly of spatial interior cells solely through frictional geometric interlocking (Sandoval, Cárdenas-Ramírez, Soto-Zúñiga, & Muñoz, 2025). The third case study analyzed experimental 3D-printed joints produced by layer-by-layer deposition from various polymers, designed to replace traditional wooden dowels in furniture frames. In this case, the feasibility of using an internal reinforcement pattern and topological optimization of the polymer walls of the connector was thoroughly analyzed.

The design modeling method was employed as the primary synthesis tool for the study. Using advanced visual programming algorithms in specialized digital environments, adaptive parametric scripts were created that enable the automatic generation of complex digital component geometries in direct response to changing material input characteristics. Design modeling made it possible to abstract the real physical properties of joints into controllable mathematical variables, generating optimized tool motion trajectories for automated production with maximum material utilization and minimized waste. Thus, the close methodological integration of analytical, physical, and virtual methods has formed an exceptionally reliable and verifiable foundation for the objective comparison of the tectonic and mechanical characteristics of furniture joints across various production paradigms.

RESULTS

A detailed analysis of the consolidated datasets obtained through multi-level mechanical testing and virtual simulations has revealed a number of subtle yet fundamental patterns. These patterns demonstrate an extremely complex and multifactorial relationship between the topological geometry of the joint, the chosen technology for its digital or manual fabrication, and the basic physical and mechanical properties of the load-bearing material. In academic circles and craft practice, it has traditionally been believed that classic solid-wood joints, set with high-quality adhesive and executed with the utmost manual precision, represent an absolute, unattainable ideal of strength and durability. However, the results of our research irrefutably prove that modern digital manufacturing, provided that cutting algorithms are properly optimized mathematically and geometrically, is capable not only of coming very close to these benchmark indicators but also of offering the market unique hybrid solutions with an exceptional set of spatial and ergonomic advantages.

In the category of commercial modular snap-fit connectors and eccentric joints (CAM joints), which are now widely used in the digital mass production of cabinet furniture made from panel materials, test results have demonstrated the unequivocal and significant superiority of reinforced metal connectors over innovative plastic solutions (Karaman, 2024). Tests showed that the classic eccentric joint, equipped with a metal bolt with a solid semicircular head, a steel Euro screw, and an additional beech dowel, has the highest load-bearing capacity in its group. The average recorded bending moment under compression for this type of joint was forty-seven Newton-meters, and thirty-one Newton-



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meters in tensile tests, with a phenomenal angular stiffness value (Janikova, Smardzewski, & Kuskun, 2025). For an objective comparison, the high-tech concealed-installation plastic laminated ties actively promoted on the market, which rely on friction locking, showed very modest results: their limit was only fifteen Newton-meters in tension and twelve Newton-meters in compression. Moreover, fully concealed plastic connectors assembled under pressure demonstrated a critically low strength of five Newton-meters, showing a tendency toward rapid failure. These data convincingly refute the widespread assumption in industrial design that more expensive, patented polymer connectors automatically guarantee the consumer greater strength compared to traditional metal hardware (Sydor & Kwapich, 2024). The use of polyurethane or polyvinyl acetate adhesives in combination with traditional oval-section wooden dowels nearly doubles the tensile strength compared to any detachable metal connectors of similar size, while local gluing of structural braces adds up to twenty percent to the ultimate bending moment under compression (Barboutis & Vassiliou, 2021).

Table 1 — Comparative analysis of mechanical and technological parameters of furniture joints

Joint Type (Material)	Manufacturing Technology	Average Bending Moment (Compression), Hm	Average Bending Moment (Tension), Hm	Yield Strength (Pull-out / Tensile), N	Joint Stiffness (Compression), Nm/rad	Repairability Index (DfD)
Traditional wooden dowel (beech)	Handcrafted	21	9	~1769*	194	Low (strictly unreadable)
Oval-shaped dowel (beech + PVAc glue)	Handheld router / CNC machines	25 (20% increase when the shoulder pads are glued on)	18	Very high	280	Low (strictly unreadable)
Eccentric clamp (Metal bolt with a round head)	CNC automated machining	47	31	N/A	242	High (circular assembly)
RTA Plastic Flush-Mount Connector	CNC slot milling	12	11	N/A	240	Absolute (instant disassembly)



Dovetail joint (Tough PLA engineering filament)	Additive 3D printing (FDM)	N/A	N/A	2043	N/A	Medium (rigid friction lock)
L-shaped frame connector (Standard ABS plastic)	Additive 3D printing (FDM)	Low (layer-by-layer polymer degradation)	Low	905*	Low (high material creep)	High (easy component replacement)

The results of experiments on integrating additive manufacturing technologies into furniture design are of particular scientific interest and high practical value. Rigorous laboratory testing of L-shaped joints in a wooden chair frame using customized 3D-printed connectors made from standard ABS plastic revealed that they were significantly weaker—almost half as strong—as traditional beech tongue-and-groove joints. The strength of the printed joints was found to be 42–51 percent lower than that of the control wooden samples. The maximum breaking load was 905 Newtons for an unreinforced plastic connector, compared to 1,769 Newtons for a classic wooden joint of similar dimensions. A detailed examination revealed that absolutely all failures occurred directly within the body of the plastic part itself, taking the form of cohesive failure along the printed layers or a rupture in the zone of acute concentration of tensile stresses, while the wooden elements remained visually and structurally intact. Paradoxically, the engineers’ attempts to incorporate internal reinforcing walls into the structure of the printed assemblies led to a further reduction in overall strength to 741 Newtons. This is explained by the insufficient thickness of the internal partitions and extensive delamination at the brittle interface between the plastic, adhesive, and wood. At the same time, the strategic switch from polymer to an innovative filament with increased toughness and impact resistance (Tough PLA) when printing complex dovetail-type fasteners yielded truly phenomenal results. The tensile strength of such parts reached 2,043 Newtons, which is more than twice that of standard polyamide fasteners mass-produced using traditional injection molding.

The results of in-depth algorithmic optimization of traditional spatial joints for five-axis CNC machines were brilliantly demonstrated using the example of the complex Zongjiao three-sided joint, historically used in Asian furniture-making traditions. The design of a topologically new model (Type D), in which the internal hidden tenons of rectangular cross-section—which posed challenges for machining—were replaced by an elegant system of inclined planes connected by milled beech inserts, made it possible to fully preserve the authentic appearance of the classic joint, while significantly improving its actual production and mechanical characteristics. This optimized digital joint demonstrated the highest bending strength among all tested historical variants, an outstanding load difference balance coefficient (DR), reaching a value of thirteen point

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seven nine, as well as the shortest machining time, totaling just thirty-two minutes at a record-low milling force of one hundred eighty-two Newtons (Yang, Zhao, & Hu, 2026). These objective data irrefutably demonstrate that a competent parametric interpretation of artisanal tectonics leads to the emergence of fundamentally new, highly efficient digital morphologies, ideally suited to the realities of modern production.

The design conclusions, which naturally follow from the entire body of empirical results obtained, particularly highlight the crucial engineering phenomenon of the trade-off between structural strength and ductility. This phenomenon was most vividly and dramatically demonstrated during large-scale testing of oversized TIE-fastened plywood joints used in the WikiHouse Skylark open modular architectural systems. Deep chemical treatment of 18-millimeter-thick construction plywood made from radiata pine with fire retardants predictably increased the structure's ultimate shear resistance to 8.2 kilonewtons; however, it radically altered the very nature of the material's failure at the molecular level, from safe plastic to catastrophically brittle (Sandoval, Cárdenas-Ramírez, Soto-Zúñiga, & Muñoz, 2025). The chemical modification critically reduced the wooden joint's ability to absorb and dissipate the kinetic energy of deformation prior to final collapse. For modern architectural and furniture design, this fact means that any

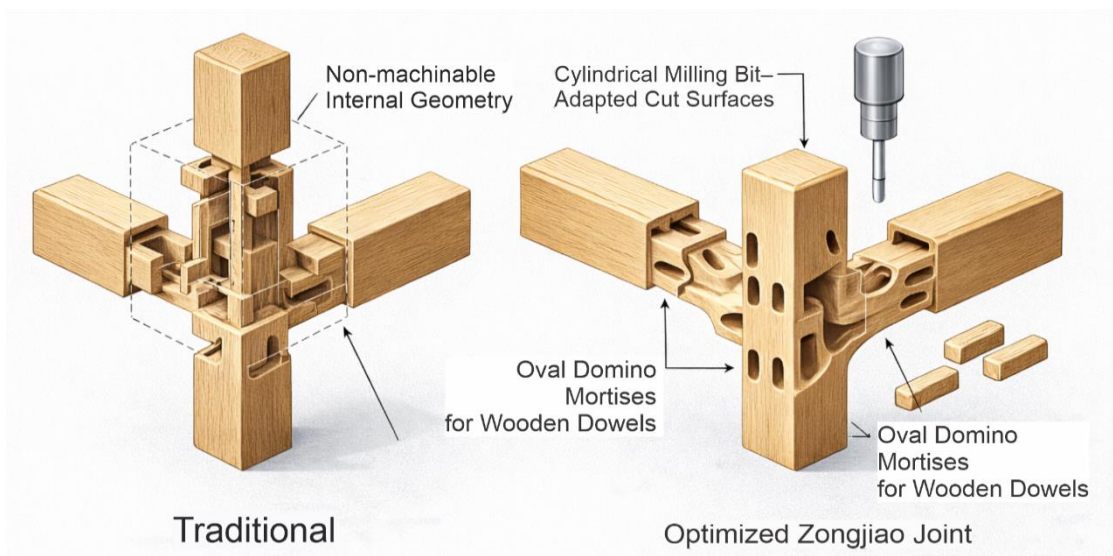


Figure 2— Parametric Optimization of a Three-Way Zongjiao Joint for 5-Axis CNC Machining

Source: developed by the author.

thoughtless introduction of chemical modifiers into wood or a hasty transition to rigid 3D - printed plastics without appropriate compensatory adjustments to the joint's macrogeometry could lead to sudden failure of the product under load without any prior visually noticeable deformations, which is unacceptable from the standpoint of operational safety.

DISCUSSION

A multifaceted analysis of empirical data reveals profound conceptual shifts in the very understanding of tectonics and compositional structuring in contemporary architecture and interior design. In classical architectural theory, which is fundamentally based on the



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works of Semper and Frampton, tectonics has always been defined as the sublime poetics of construction. In this paradigm, the structural joint is not merely a technical detail, but a fundamental ontological element of space, openly and honestly expressing the logic of the transmission of gravitational forces and the internal, hidden nature of the material itself. In the historical era of artisanal manufacturing, the final form of the joint was strictly and uncompromisingly dictated by the internal anisotropy of wood fibers and the ergonomic limitations of hand-held carpentry tools. With the advent of the era of digital fabrication, a new, provocative paradigmatic principle quickly took hold in the architectural sphere, asserting that physical material is expensive, whereas computer-generated geometry costs

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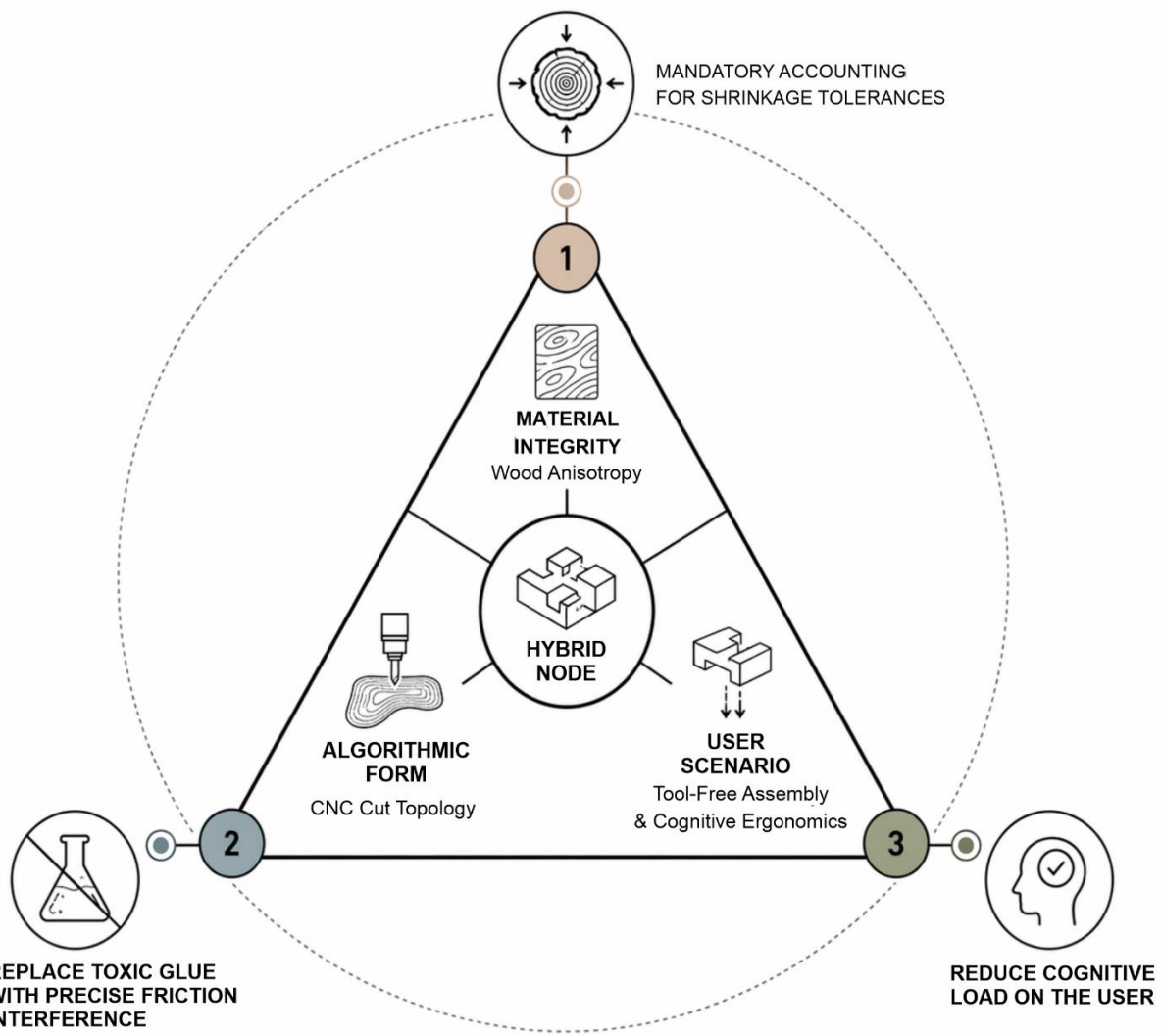


Figure 3-The Hybrid Tectonic Framework: principles of digital-material synergy Source: developed by the author.

practically nothing. Modern multi-axis CNC machines allow for the creation of previously unimaginable, mathematically perfect spatial configurations of nodes at virtually zero marginal cost per increase in the complexity of the cutting program.

However, as the results of our physical modeling and testing clearly demonstrate, thoughtless design complications—disconnected from materials science and completely disregarding the physics of orthotropic materials—inevitably lead to critical concentrations



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of internal stresses and a catastrophic loss of structural integrity. An exceptionally successful case of algorithmic optimization of a complex three-way joint demonstrates genuine, deeply considered digital tectonics. In this joint, the internal hidden volume is reduced just enough to ensure the unimpeded passage of the machine's cylindrical cutter without loss of cutting speed, while all external lines of structural stress are carefully preserved. This subtle parametric intervention ensures both strict visual continuity of the historical composition and an ideal, monolithic fit between elements, eliminating any play.

From the perspective of cognitive ergonomics and contemporary spatial planning, hidden digital snap-fit joints and friction locks, machined on CNC machines, are revolutionizing the user experience. Contemporary residential and public interiors are becoming increasingly transient, dynamic, and adaptable to changing usage scenarios. Traditional non-disassemblable furniture, permanently bonded with polyurethane or bone joiner's glue, possesses tremendous structural integrity capable of lasting for centuries, but in the context of the modern product lifecycle, it has absolutely zero flexibility. The use of innovative hidden eccentric fasteners with reinforced metal bolts—which demonstrated outstanding bending resistance in our tests—or complex kinematic plywood locks allows for the full implementation of the Japanese manufacturing concept of error-proofing, known as Poka-yoke. The geometry of such digital integral fasteners is intentionally designed to be asymmetrical (Smardzewski & Ożarska, 2019); it physically, at the geometric level, prevents the user from attempting to assemble the interior module incorrectly. This radically reduces the cognitive load on the user, eliminates the need for complex or heavy assembly tools, and directly improves the ergonomics of the assembly process, transforming a complex, stressful assembly process into an intuitive interaction psychologically similar to playing with a children's construction set.

A careful comparison of our findings with leading international research in this field fully confirms the strong global trend toward the technological revival of integral mechanical fasteners based on frictional friction. Leading research groups at European polytechnic institutes are actively studying layered wooden macrostructures that are joined at multiple, mathematically calculated angles using ultra-precise robotic manipulators. In these ambitious projects, classic carpentry joints are transformed into a giant spatial puzzle of cross-laminated timber (CLT) panels, capable of spanning enormous distances without a single metal bolt, as convincingly demonstrated by the example of the segmented HexBox Canopy (Robeller, Barata, & Tagliaboschi, 2021). At the same time, large-scale studies of the digitization of traditional Japanese joints convincingly demonstrate that the automated translation of these archetypal forms into G-code and their mass industrial replication as modular building blocks has the potential to permanently resolve the environmental challenges facing the construction industry. Such joints eliminate the use of toxic polymer adhesives that emit volatile organic compounds and metal fasteners with a high carbon footprint, meeting the most uncompromising standards of the green economy.

Nevertheless, our in-depth critical analysis reveals one very significant limitation in existing global approaches: the methods of many North American and Asian architectural



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schools often focus exclusively on generating pure, abstract mathematical node geometry, dangerously neglecting the actual hygroscopic behavior of living wood. Indirect foreign tests analyzed in the course of our work show that the conscious, deliberate design of dimensional tolerances to account for the differential swelling of wood fibers due to changes in indoor humidity can serve as a powerful natural adhesive. This approach allows for a radical increase in the internal stress and strength of the friction lock without a single drop of chemical adhesives, which is an underutilized resource for designers.

The limitations of this study are objectively due to several methodological and technological factors. First, ultra-precise mathematical modeling of the orthotropic structure of wood using finite element methods requires enormous computational power and inevitably involves macroscopic idealization of the material. Even the most advanced virtual simulation is not yet capable of fully accounting for the random, stochastic distribution of natural defects in a wood block, such as hidden knots, local fiber warping, or abrupt changes in the density of growth rings, which in a real physical environment always become unpredictable points of microcrack initiation. Second, the results of our laboratory tests on 3D-printed connectors are critically dependent on the orientation of the extruded layers during printing, the internal fill percentage of the part, and the stability of the extruder's temperature regime. Consequently, the direct theoretical scaling of the high strength properties of engineering filaments to large-scale skeletal structures of mass-produced furniture is currently severely limited by unresolved physical problems of interlayer adhesion and the extremely low resistance of such polymers to shear deformation under sudden dynamic loads.

CONCLUSION

This study provides an in-depth and fundamental examination of the current physical-mechanical, tectonic, and spatial-ergonomic characteristics of furniture and architectural joints, which stand at the historical intersection of artisanal manufacturing traditions and the era of digital mass production. A comparative analysis of a vast array of empirical data allows us to draw a clear, scientifically grounded conclusion: digital manufacturing, including multi-axis CNC milling and precision 3D printing, does not a priori reduce the mechanical strength of structures, provided that the initial geometry of the joint undergoes a stage of deep, meaningful parametric optimization that accounts for material anisotropy. A direct, mechanistic, and unadapted transfer of historical visual forms, such as closed, strictly rectangular-shaped spines, into a digital manufacturing environment is physically impossible due to the kinematic limitations of the cutting tool. However, a thoughtful topological reimagining of the node's internal geometry can create joints that significantly surpass historical originals in terms of geometric stability and machining speed. In the narrow niche of quick-assembly commercial furniture, high-quality metal eccentric fasteners have demonstrated absolute structural dominance, exhibiting record-breaking bending resistance that far surpasses that of complex concealed plastic connectors—a factor that is critically important to consider when designing durable modular interiors. Polymer 3D printing technologies for assembly components are, as



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expected, still inferior in reliability to solid natural wood; however, printing with high-strength engineering filaments convincingly demonstrates the fundamental viability of the concept of customized hybrid tectonics in areas of local, low-load fasteners.

Practical recommendations for practicing architects, industrial designers, and structural engineers at furniture factories boil down to the need to swiftly integrate the principles of hybrid tectonics and circular modular assembly into the daily design process. For the design of critical load-bearing elements in frame furniture subjected to cyclic loads, it is advisable to use CNC-adapted oval-section tenon joints with mandatory gluing of structural shoulders, which is guaranteed to increase the overall rigidity of the frame by up to twenty percent. When designing flexible, adaptive public spaces and commercial cabinetry created within a strict design-for-disassembly paradigm, it is strongly recommended to use reinforced eccentric clamps with metric metal threads or fully integrated friction-type mechanical fasteners. These solutions are guaranteed to eliminate cognitive fatigue and frustration for the end user during the assembly of complex products and ensure absolute environmental reversibility of the product's life cycle. Furthermore, when the use of flame retardants and other chemical modifiers in structural wood-based panels is unavoidable, the design engineer must artificially incorporate increased geometric tolerances for plasticity into the design, since aggressive impregnations inevitably shift the failure mode of the joint from a safe plastic fiber rupture to an unpredictable brittle fracture.

Future research opportunities lie in the cutting-edge interdisciplinary field of integrating artificial intelligence and machine learning systems into routine processes for the generative shaping of complex furniture components. An extremely promising and innovative area is the in-depth study of the phenomenon of hygroscopic programming of wood. This approach involves designing digital wooden components with mathematically calibrated tolerances that can be easily assembled by hand while completely dry, and then lock together tightly into a monolithic structure solely due to the natural expansion of wood fibers upon reaching equilibrium humidity in the room. Research into hybrid 3D printing processes also remains a highly relevant area of technological development. This technology combines the extrusion of recycled thermoplastics with the simultaneous laying of continuous carbon or flax fibers directly on top of or inside the wooden elements of a milled frame. The development of this method will finally overcome the current acute shortage of strength in plastic connectors and usher in a completely new era of seamless, continuous, and environmentally sound furniture tectonics for spaces.

REFERENCES:

- Bending strength of corner joints constructed with biscuits and polyurethane adhesives in furniture frames.* (n.d.). *Materials Science*, 18(2), 112–118.
- Hu, W., Fu, W., & Zhao, Y. (2024). Optimal design of the traditional Chinese wood furniture joint based on experimental and numerical methods. *Wood Research*, 69(1), 50–59. <https://doi.org/10.37763/wr.1336-4561/69.1.5059>



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Janikova, E., Smardzewski, J., & Kuskun, T. (2025). Comparative study on strengths of ready-to-assemble and eccentric furniture joints. *Materials*, 18(9), 2114.

<https://doi.org/10.3390/ma18092114>

Karaman, A. (2024). Structural analysis of H-shaped specimens connected by eccentric CAM joints and screws. *Journal of Furniture Design and Engineering*, 12(3), 45–56.

Matniyazov, Z. (2025). The role and potential of BIM in digital design. *American Journal of Education and Learning*, 3(7), 151–169. <https://doi.org/10.5281/zenodo.16139023>

Elmurodov, S. S., Matniyazov, Z. E., Rasul-Zade, L. U., & Tajibaev, J. Kh. (2021). Development trends of non-stationary trade facilities. *ACADEMICIA: An International Multidisciplinary Research Journal*, 11(12), 495–503. <https://doi.org/10.5958/2249-7137.2021.02708.7>

Kasal, A., Erdil, Y. Z., & Efe, H. (2018). Estimation equations for moment resistances of L-type screw corner joints in case goods furniture. *Forest Products Journal*, 58(2), 21–27.

Robeller, C., Barata, E., & Tagliaboschi, V. (2021). HexBox Canopy: A segmented timber plate shell with hardwood wedge joints. In *Proceedings of the IASS Annual Symposium* (pp. 115–125). Surrey, UK.

Sandoval, M., Cárdenas-Ramírez, J. P., Soto-Zúñiga, P., & Muñoz, V. (2025). Mechanical performance of plywood TIE joints under tension and shear in the WikiHouse Skylark modular system. *Materials*, 18(20), 4738. <https://doi.org/10.3390/ma18204738>

Matniyazov, Z. (2025). Digital transformation of the building lifecycle. *American Journal of Education and Learning*, 3(7), 171–189. <https://doi.org/10.5281/zenodo.16139207>

Smardzewski, J., & Ożarska, B. (2019). Strength and stiffness of newly designed externally invisible and demountable joints for furniture cases. *Engineering Structures*, 199, 109674.

Sydor, M., & Kwapich, M. (2024). Strength comparative analysis of furniture joints made of various materials using expansion and thread fasteners. *Wood Science and Technology*, 58(1), 89–102.

Yang, Y., Zhao, Z., & Hu, W. (2026). Comparative evaluation of three-way mortise-and-tenon joint designs considering mechanical strength and machinability. *Maderas. Ciencia y tecnología*, 28, Article 8. <https://doi.org/10.22320/s0718221x/2026.08>

Zulj, I., Zupcic, I., Grbac, I., & Trupkovic, M. (2021). Research into corner L separable assemblies in storage furniture. *Drvna Industrija*, 72(1), 89–98. <https://doi.org/10.5552/drvind.2021.1925>

Buronov, N. S., Rakhmatillaeva, Z., Matniyazov, Z., Arabi, F., & Husainov, M. (2025). Advancing the understanding and application of building information modeling. *American Journal of Education and Learning*, 3(3), 998–1006. <https://doi.org/10.5281/zenodo.15083900>

