Mobilya ve Ahşap Malzeme Araştırmaları Dergisi
Furniture and Wooden Material Research Journal
Research Article - Araştırma Makalesi 2025 - 8(2), 404-419

Hybrid making in furniture design education: bridging digital fabrication and craft through experiential learning

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ABSTRACT: This paper analyzes a hybrid furniture design studio through the lenses of design pedagogy and experiential learning, investigating how hybrid making can integrate digital fabrication with craft-based practices while supporting thinking through making. Although digital fabrication has gained prominence in design education, empirical research on how digital and craft-based practices can be integrated within a coherent pedagogical framework for furniture design remains limited, indicating a clear research gap. To address this, the study adopts a qualitative case-study methodology, combining studio observations, students' written and verbal feedback, process documentation, and photographic records. A focused literature review on design education and hybrid making informed three guiding themes: material engagement, critical thinking, and creative discovery. The study contributes an empirically grounded pedagogical framework for hybrid furniture design education, demonstrating how digital modelling and printing, laser cutting, ceramic slip casting, and woodworking can support materially engaged experiential learning. Findings indicate that hybrid workflows enhance creativity and critical thinking while deepening students' material literacy. Students directly encountered the physical properties of materials, production constraints, and occasional unpredictability as part of an iterative, hands-on learning process that bridges digital and craft-based methods.

Keywords: hybrid design, craft, digital fabrication, furniture design education

Mobilya tasarımı eğitiminde hibrit yapım: dijital üretim ile zanaat arasında köprü kurmak

ÖZ: Bu makale, hibrit bir mobilya tasarım stüdyosunu tasarım pedagojisi ve deneyimsel öğrenme açısından inceleyerek hibrit üretimin dijital fabrikasyon ile zanaatı nasıl bir araya getirebileceğini ve "yaparak düşünme" yaklaşımını nasıl desteklediğini araştırmaktadır. Dijital üretim tasarım eğitiminde önem kazanmış olsa da, dijital ve zanaat temelli süreçlerin mobilya tasarımına yönelik tutarlı bir pedagojik çerçevede nasıl bütünleştirilebileceğine ilişkin ampirik çalışmalar sınırlıdır ve bu durum belirgin bir araştırma boşluğuna işaret etmektedir. Bu boşluğu ele almak amacıyla çalışma, stüdyo gözlemleri, öğrencilerin yazılı ve sözlü geri bildirimleri, süreç dokümantasyonu ve fotoğraf kayıtlarını bir araya getiren nitel bir durum çalışması yöntemi benimsemektedir. Tasarım eğitimi ve hibrit üretim literatürüne dayalı odaklı bir inceleme, üç temel temayı belirlemiştir: malzeme ile etkileşim, eleştirel düşünme ve yaratıcı keşif. Çalışma, dijital modelleme ve baskı, lazer kesim, seramik döküm ve ahşap işçiliğinin malzemeyle etkileşime dayalı deneyimsel öğrenmeyi nasıl destekleyebileceğini gösteren ampirik temelli bir pedagojik çerçeve sunmaktadır. Bulgular, hibrit iş akışlarının yaratıcılığı ve eleştirel düşünmeyi geliştirdiğini, öğrencilerin malzeme okuryazarlığını derinleştirdiğini ortaya koymaktadır.

Anahtar kelimeler: hibrit tasarım, zanaat, dijital fabrikasyon; mobilya tasarım eğitimi

Article history, Received: 08.10.2025, Revised: 12.12.2025, Accepted: 14.12.2025, Published: 18.12.2025, *handeatmaca@beykent.edu.tr
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To cite: Atmaca, H., (2025). Hybrid making in furniture design education: bridging digital fabrication and craft through experiential learning, *Furniture and Wooden Material Research Journal*, 8 (2), 404-419. DOI: 10.33725/mamad.1799731

1 Introduction

In recent decades, design education has been shaped largely by digital fabrication technologies, which prioritise efficiency, perfection, and precision, supporting design's capacity for mass production. Without dismissing the ways these advances have expanded studio teaching, they simultaneously raise critical pedagogical questions—when, how and why such developments should be part of the curriculum, and the learning outcomes desired with these technologies. Cheatham (2017) foresees the risk of falling into the trap of being formalist, as without a concrete base of intellectual, societal and humane dimensions, holistic understanding of a studio culture would be impossible to diffuse.

Critical debates advocate a shift from product-oriented to process-oriented teaching and learning, centred on holistic approaches (Cheatham, 2017), experimentation and material engagement with the hand as a core to design learning (Rowe, 2024). Design itself is iterative and exploratory by nature, and, for this, pedagogical approaches should question complete digitisation since it omits the natural loop of problem framing such as prototyping and testing; which are crucial for students to engage fully with the material themselves (Soomro et al., 2021). Design problems should be addressed by teaching a complete set of skills in education that definitely benefits from technology (Kahraman et al, 2024, Nasir et al, 2022); yet, digital modelling and fabrication can complement craft-based practices—not by erasing the tacit knowledge of craft-based labour (Boza, 2016), but by expanding its expressive and explanatory scope.

Hybrid making could be simplified as the embodiment of digital means with intuition (Bernabei and Power, 2018)—tactile senses meeting precision, thus constituting a 'pedagogical bridge' where expansion with technology is possible without the exclusion of the material senses and production skills. McCullough (2005) asserts that "digital fabrication improves tangible speculation", reaffirming making as both a reflective and cognitive process. Similarly, Ingold states that the concept of material agency situates making as a "dialogue with matter", a space of exploration through engaging with the material, but not its simulation (2012). As Leatherbarrow theorizes as the "skin of architecture"— surfaces act as boundaries of the maker and the user, they are interfaces that carry irregularities and traces of this dialogue and digital tools can act as reflective partners in making, enhancing rather than diminishing material awareness (2009). Additionally, digital tools can be used to support craft-based practices in the search for new and unexpected forms, as they are capable of generating structures that extend beyond the capacities of the human hand (Zoran, 2013).

In this study, the term *craft* is understood not merely as traditional handwork but as a form of embodied, material knowledge rooted in tacit skills, sensory engagement, and reflective interaction with matter. This definition aligns with Ingold's (2013) view of making as a material dialogue and with McCullough's (2005) framing of craft as a cognitive, exploratory practice—an understanding that allows craft to interface productively with digital fabrication within hybrid learning environments.

From a design education perspective, by asking the important questions of "how things are produced" and "how materials behave", students develop material and process literacy—that cannot be experienced solely by technological means. On the other hand, such tactile dialogue opens up possibilities, away from predetermined geometries, expanding creativity grounded in reflective observation, trial, and analysis.

However, looking at the existing body of scholarly work, very limited studies have tackled engagements of craft and digital fabrication (Ingold, 2013; McCullough, 2005; Zoran, 2013;

Zoran and Buechley, 2013), and these do not provide roadmaps for design education. Research on FabLabs and digital studios (Georgiev and Nanjappan, 2023; Soomro et al., 2021) has examined sustainability and collaborative work, but has not articulated a methodology that integrates digital and craft-based practices into a pedagogical framework that could be beneficial for design education. The interpretation of key theoretical positions and their translation into these three pedagogical dimensions are systematically outlined in Table 1.

Table 1. Interpretation of the Literature Underpinning the Hybrid Making Framework

Literature Focus	Key References	Concepts Extracted from the Literature	Framework Dimension
Material Engagement & Thinking Through Making	Frascara (2017); McCullough (1996); Ingold (2013)	Material Engagement & Enactive Making	Material Engagement
Hybrid Making & Digital Craft Integration	Zoran (2013); Zoran & Buechley (2013); McCullough (2005)	Hybrid craft; digital tools as mediators	Creative Discovery
Ceramic Processes and Material Uncertainty	Malafouris (2023); Pek et al. (2022)	Unpredictability; learning through error and material contingency	Creative Discovery
Experiential Learning & Iterative Design Pedagogy	McCullough (2005); Rowe (2024); Cheatham (2017)	Iteration; reflection-in-action; process-oriented learning trajectories	Critical Thinking

Furthermore, there remains an insufficiency of knowledge specifically within furniture design education for establishing a framework that encourages a multi-faceted design approach. The majority of research in furniture design that deals with technology focuses on the automation of CNC technologies or flat-pack production (Kılıç, 2016; Mujir et al., 2018, Yan et al., 2023). On the other hand, this study also underlines a new trajectory: the integration of ceramics within furniture education. While 3D printing is an emerging field (Zhang and Wei, 2024), research remains largely confined to small-scale or entirely digital forms in ceramic production. Previous works of artists have made use of 3D printing in ceramics for different surface finishes, and their claims also justify the aim of this work, as their approach has consistently treated these technologies as intermediate tools rather than final products (Zoran, 2013, p. 392). This perspective positions hybrid making as a productive space in which digital processes and ceramic practices can be combined to expand material engagement within furniture design education.

For this reason, this study focuses on a third-year elective furniture design studio with 18 students (Construction and Details in Furniture Design), centred on hybrid making that explicitly questions the gap between digital fabrication and craft-based practices in furniture design education. While previous research in furniture design has explored FabLabs and CNC-based production, empirical accounts of studios that integrate digital fabrication and woodworking practices together with a secondary material such as ceramics within a coherent pedagogical framework remain limited and therefore represent a distinctive contribution.

The aim of the study is to offer a hybrid furniture design education framework that specifically combines 3D modelling and printing, laser cutting, ceramic slip casting and manual ceramic production with woodworking to support experiential "thinking through making" (Ingold, 2012). To achieve this, a thorough literature review on design education, ceramic fabrication and hybrid making was conducted to examine the contributions of hybrid design methods, and from this review three key themes were identified that served as a roadmap: material engagement (McCullough, 1996; Ingold, 2013), critical thinking (McCullough, 2005; Cheatham, 2017; Rowe, 2024), and the encouragement of creative discovery (Zoran, 2013; Malafouris, 2023).

2 Method

2.1 Research design and context

The research is based on a third-year elective furniture design studio (One semester-15 weeks) offered to students from the Departments of Interior Architecture and Environmental Design and Industrial Design in the Faculty of Fine Arts and Design. The studio was conducted in a Maker Lab environment that combines a Woodworking Workshop, a Ceramics Workshop, and a Digital Fabrication Workshop. Students had been previously introduced to these facilities in earlier years, which allowed the course to build on existing technical familiarity and focus on deeper material and process-oriented learning.

The course was structured around three main standing points, to analyse and foster *material literacy*, *critical thinking*, and *creative discovery*, in students and learning objectives were also organized in a way to foster these three main themes derived from the literature review. The first objective was to encourage students to explore the potential and limitations of specific materials and construction techniques, by immersing them in a range of analogue and digital tools. The course utilised prototyping as "interactive systems central to design thinking" (Georgiev and Nanjappan, 2023), to highlight the integration of digital means as critical mediators, bridging the gap between idea and product. This process-oriented structure follows an iterative digital–craft learning cycle, illustrated schematically in Fig. 1.

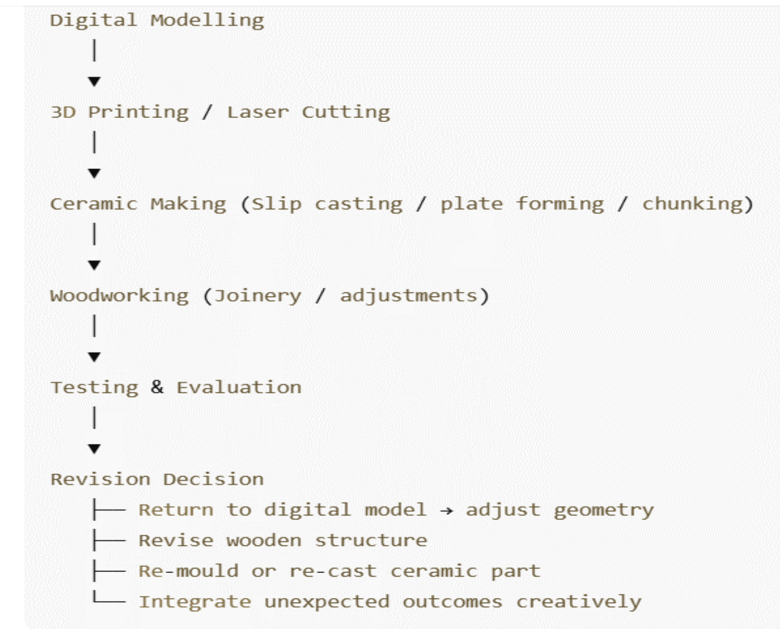

Figure 1. Iterative Digital–Craft Learning Cycle

Secondly, students were encouraged not only to acquire technical competence, but also to cultivate a deeper knowledge based on design and production in order to increase their capacity for critical reflection. In line with this understanding, the course prioritised iterative processes of starting over and discovery rather than a meticulous finished form. As shown in Fig. 1, iteration was positioned as a core learning mechanism connecting digital modelling, material experimentation, and revision. Accordingly, assessment in design education should focus not solely on final products but also on the learning trajectory and the critical reflection that accompanies it (Rowe, 2024), supporting students in becoming 'self-learners' of material constraints and possibilities, structural requirements and solutions, and designerly ways of problem-solving (Soomro et al., 2022).

Lastly, many scholarly works address how hybrid making can fortify new and previously unexplored forms due to the nature of 3D printing (Zoran, 2013; Zoran and Buechley, 2013). These forms can take shape in unprecedented ways that the human hand has never produced. They may also lead to creative and unexpected discoveries when blended with different materials; for example, ceramic slip casting over 3D-printed materials can introduce a new trajectory for engaging with material behaviour. For this reason, it was also important to analyze how students responded to such emerging possibilities and how they interpreted these discoveries within the design process.

Additionally, ceramic artists and designers (Prof. Sevim Çizer and Ayda Eriş) were blended into the teaching process to fortify the hybrid nature of the course structure and to expand students' exposure to expert craft knowledge and situated forms of material practice.

Table 2 clarifies the relationship between the study's research questions, qualitative data sources, and analytical strategies, enhancing methodological transparency.

Table 2. Alignment of Research Questions and Methodological Tools

Research Question	Relevant Data Source(s)	Analytical Approach
How do students develop material literacy?	Observations, reflections, ceramic/wood prototypes	Thematic coding (Material Engagement)
How does iterative making shape critical thinking?	Verbal feedback, revision logs, process documentation	Iteration analysis (Trial–Error–Revision)
How do students respond to unexpected outcomes?	Photographs, design revisions, critiques	Narrative reconstruction (Creative Discovery)
How does hybrid workflow affect design decisions?	All data sources	Cross-case synthesis

2.2 Data collection and analysis

Methodologically, qualitative observations, documentation of the process, and analysis of student reflections and work processes were utilized to understand how these three themes manifested specifically within the context of a furniture design studio and to determine students' responses and pedagogical impact.

To capture the cognitive, affective, and material dimensions of students' learning experiences, multiple qualitative data sources were employed. Studio observations were carried out throughout the semester, with the instructor documenting students' decision-making processes, problem-solving strategies, and interactions with materials and tools. Students' verbal feedback was collected at key stages of the project to trace how their understanding of material behaviour and hybrid workflows evolved over time. Process documentation—including sketches, digital models, intermediate prototypes, and photographic records of each stage—provided additional evidence of how ideas were translated across digital and craft-based media. Photographs of the studio environment and student work were used solely for research and documentation purposes, and all images were anonymised in accordance with ethical principles. An overview of the qualitative data sources and their respective roles within the methodological framework is provided in Table 3.

Table 3. Data Sources and Their Contribution to the Methodological Framework

Data Source	Description	Purpose in Study
Studio Observations	Weekly observation notes of student activities	Track material engagement, decision-making, hybrid workflow behaviour
Verbal Feedback	In-studio critiques and discussions	Capture spontaneous insights, peer learning, and iterative reasoning
Process Documentation	Sketches, 3D models, prototypes, moulds, firing records	Trace evolution of ideas across digital–craft processes
Photographic Records	Process and product visuals	Provide visual evidence of hybrid workflow

2.3 Materials, facilities and course task

Students were asked to design a small coffee table, measuring 50 × 50 × 50 cm in size composed of a wooden structure in pine with a circular or rectangular top in ceramic. This scale was chosen intentionally to encourage students to consider questions of joinery, stability and the interplay of materials within the timeframe of a semester.

The course unfolded across three overlapping phases:

- Digital Fabrication – Conceptual design, 3D modelling and printing, and laser-cut production
- Craft-based Fabrication (Ceramic and Wood): Mould-making, casting, firing, sanding and surface finishing. Preparations of wooden parts, cutting and assembling, sanding and surface finishing.
- Product Testing and Evaluation – Assessing stability, ceramic and wood profile coherence.

The aforementioned stages were introduced to the students, who were then tasked with choosing their own method in an iterative manner. The three main stages – drawing, modelling and making – were created and employed in a cyclical loop. This iterative process became an interplay between precision and the trial and error of material behaviour, fostering the core learning outcomes.

Students discovered that, unlike wood, ceramics resist complete prediction: moulds cracked, slip-cast pieces warped and fired dimensions diverged from digital models. Each instance of error became an opportunity for critical reflection, resulting in design revisions and re-evaluation of the structure, the way in which the wood meets the ceramic top and its weight-bearing tolerance.

This structured yet flexible approach encouraged students to perceive digital tools as instruments for exploration rather than as the final production endpoint. Failure and adaptations/revisions were reframed as essential learning experiences, aligning with Ingold's (2013) notion of thinking through making. The project's load-bearing requirements and cross-material dependencies further deepened awareness of performance and craft precision. Meanwhile, shrinkage and deformation imposed authentic constraints that demanded creative adaptation.

2.4 Course Structure and Hybrid Workflow

The course employed a studio-based Maker Lab, composed of a Woodworking Workshop, a Ceramics Workshop and a Digital Fabrication Workshop, where analogue and digital tools were introduced to students before their third year. This previous knowledge of the tools in the laboratory made the process smoother, and should be noted as a pedagogical method. These spaces were intentionally interwoven to form a cohesive learning environment. The selection of materials, digital tools and power machines was deliberately controlled to achieve a harmonious end result, both physically possible to produce by hand and digitally crafted by machines.

The effectiveness of this pedagogy was reinforced by the integration of Maker Labs and workshop facilities, which functioned as a transformative learning environment (Ylioja et al., 2019). As Soomro et al. (2022) note, makerspaces are dynamic, adaptable learning contexts that foster creativity, exploration, and interdisciplinary collaboration. The course therefore utilized a wide range of fabrication facilities: a 3D printing atelier for rapid prototyping and additive experimentation; laser cutting machines for precision processing of geometric forms; a woodworking workshop for traditional joinery and structural assembly; a ceramics atelier with kilns for clay-based exploration; and a model-making studio dedicated to iterative prototyping. These diverse facilities collectively supported a pedagogy of experimentation, enabling students to move fluidly between two modes of making.

Primary materials utilized:

• **Pine wood**: Optimal since it is lightweight, machinable and low in cost. It allows, hand carving/sanding/ joinery experimentation, or can be formed by power tools. Dimensions were standardized (18–20 mm thickness, 20–25 mm circular profiles, and up to 60 mm rectangular sections) to assure correlation across projects, also forcing students to create structural integrity.
• **Ceramic clay**: Selected for its plasticity, versatility, and expressive surface qualities. Students explored glazing, carving, and sanding techniques to discover material behaviour. Dimensions were standardized, but students could produce hollow, solid, or carved forms, could explore slip casting or coiling methods, encouraging direct engagement with clay's behaviour. Clay's shrinkage ratios, drying process and deformations in production or sanding, and surface response during firing were selected as educational tools of craft-based production.
• **PLA filament**: Employed in 3D-printed models for mould production to produce prototypes for the ceramic parts
•**Plexiglass sheets**: Selected for the laser-cut process to bring together 3D printed parts of the top part.

•**Plaster (gypsum)**: Utilised in producing gypsum moulds for slip casting and chunking methods.

Three workshops are utilised for the course:
• **Woodworking Lab** – Power and hand tools, with supervisor assistance
• **Ceramics Lab** – Manufacturing, drying and firing equipment and kilns, production surfaces, with supervisor assistance
• **Digital Fabrication Lab** – 3D printers, laser cutters, and modelling computers

The intended dialogue of these spaces and the method of interaction among them brought about a continuous workflow between all mediums, whilst ensuring that students learn from each of them. Students were left to take design decisions based on this experience to translate their ideas into a research question, termed as "problem-based learning" by Frascara (2017) to negotiate between prototype and final result. Imperfections or "happy accidents" led the way to explorations, reinforcing critical thinking around physical constraints and inquiry based on making.

2.5 Integration of crafts and digital pedagogy

This study employed a critical thinking-based reflective iteration model to encourage problem solving and adaptation, which are generative and mind-opening rather than being corrective. This approach started a dialogue between human action and material response, which negates absolute precision, reaffirming the pedagogical importance of manipulating physical matter. Within this framework, the subsections that follow tackle how modelling, ceramic fabrication and woodworking techniques blended in the study.

2.6 3D modelling/printing/molding

Through a structured exercise, 3D modelling (Figure 2) and 3D printing were explained to students, mostly to create basic awareness of limitations of digital fabrication, such as 3D printer dimensions, 3D models' form and surface quality, and mould compatibility of the design outcome. Through this, they experienced first-hand that complex geometries may require multi-part moulds, which increase fabrication complexity and demand careful alignment. In order to accommodate the constraints of the 3D printer, the models were divided symmetrically into four segments for later assembly, thus transforming the 3D printing phase into a problem-solving exercise, rather than a reproduction exercise.

Figure 2. The visuals of the 3D initial model of a student project

A laser-cut plexiglass base was designed to facilitate mould formation (Fig. 3), while hot silicone proved effective for assembly provided that the final surfaces were thoroughly cleaned. The mould was formed by applying plaster directly over 3D-printed PLA. This method revealed the fragility of the thin shells typical of slip casting, which frequently fractured during sanding due to the large size of the mould. However, students observed that the same process offered new aesthetic possibilities, particularly when natural print textures and layer patterns were intentionally preserved as design features.

Another important experience similar to 3D printing was the ceramic kiln. The kiln itself introduced physical limits—size constraints, thermal deformation, and material shrinkage. Students were therefore encouraged to design within these conditions, selecting either circular or square ceramic top geometries depending on their design idea. At this stage, the design process was simplified intentionally to enable iterative feedback and a smooth integration with wooden structural components and the ceramic part.

Digitally printed 3D models were coated with a release agent and a mould was fabricated by a quick-setting plaster mixture, which was allowed to dry for at least 72 hours until fully dehydrated. A properly cured mould felt warm and dry to the touch, indicating the expulsion of all residual moisture—a critical step in ensuring the integrity of subsequent slip casts.

Figure 3. The 3D printed model (left), shown both inside and outside the mould, illustrates its role as an intermediary medium in the fabrication process rather than a finished tabletop.

These digital–material preparations set the stage for the ceramic phase, where variability during forming and firing required calibrated tolerances and responsive decision-making.

2.7 Ceramic Production Phase

Students were introduced to one of three ceramic production techniques: slip casting, plate forming, or chunking (press-filling the mould).

Slip casting involves pouring liquid clay (slip) into a mould to produce thin, shell-like, hollow forms, used for achieving a lightweight, uniform body that can be easily reproduced. The thin shell can trace the texture of the mold, making the exercise exciting, since several textures can be tried digitally and transferred to the mold. Large moulds (50 × 50 cm or 50 cm diameter) presented challenges in non-industrial environments, as emptying the mold and drying without deformation is crucial and requires consistent testing to eliminate warping or cracking.

Secondly, another traditional method that is widely utilised is plate forming. This technique enables the creation of large sheets that can be used for trays/tiles. Control of evenness and thickness of the material is crucial (Fig. 4).

Chunking (press-filling) is applied by pressing and filling small chunks of clay, preferably into a mould. This technique is useful for sustainability as leftover material can be revitalised. Aesthetically pleasing surfaces can be reached by manipulating the mould, and chunking allows organic textures by playing with these small clay pieces. Extensive time and labour are required for this method, and pressing and kneading the clay are crucial for students to exclude any air pockets that can cause cracks in the kiln.

Figure 4. Prof. Çizer explaning chunking method

Chunking (press-filling) is applied by pressing and filling small chunks of clay, preferably into a mould. This technique is useful for sustainability, as leftover material can be revitalised (Hernández García et al., 2024). Aesthetically pleasing surfaces can be reached by manipulating the mould, and chunking allows organic textures by playing with these small clay pieces. Extensive time and labour are required for this method, and pressing and kneading the clay was crucial for students, in order to exclude any air pockets that can cause cracks in the kiln.

In short, there is a growing need to enlarge training in ceramic within design education and hybrid environments can link traditional craft expertise and newly developing digital tools (Pek et al., 2022)

2.8 Woodworking phase

The woodworking phase included designing and building the base structure of the project that will carry the ceramic component, focusing firstly on; structural and load-bearing quality, coherence with the ceramic part and their unity. The material nature of wood was prefered as it is suitable for interactive and experiential learning (Hanták and Konceková, 2023). Students were lectured on proportion, joinery, and balance to grasp the idea of building a structure—how wooden components are joined, to reach a steady load bearing top without compromising aesthetic design considerations (Fig. 6).

Techniques of mortise-and-tenon, cross-lap, and dowel joints were introduced as lectures to fortify the theoretical basis of the students. These techniques are not only for the sake of structural integrity, but can also be starting points of a project that will lead the design idea. Considering the ceramic parts as well, students were encouraged to experiment with the traditional techniques by including ceramic parts. Through this exercise, they grasped how assembly is crucial for structural quality and small deviations lead to unbalanced outcomes, and may risk the ceramic top parts' integration.

After the wooden structures were set, students went back to revising the 3D models, part of the iterative work, to improve joinery methods and details, for more accuracy and strength. This recursive process—digital-craft-revision-adaptation—or "test, simulate, revise/adapt", made their results based on not form, but material and production based as well. Dialogue between tangible woodwork and digital modelling underscored a central pedagogical insight: digital tools become most effective when informed by hands-on understanding.

Ultimately, the woodworking phase cultivated spatial reasoning, material empathy, and compositional judgment. Students understood that furniture is a structural system of forces and tolerances, held together by aligning craft sensibility with digital precision (Fig. 5).

Figure 5. Wood workshop production phase for a working prototype

2.9 Production testing phase

The testing stage marked the end of this iterative workflow dialogue, setting the crucial reflective component of the project. Once the ceramic and wooden parts had been formed, physical embodiment required to go back and forth to digital modelling. Through iterative testing and judgement processes, the students progressed to shape components for achieving final structural coherence and aesthetic quality.

One of the most critical parts was the discrepancies between the fired ceramics and the wooden structure, where students used their judgement either to adapt the wooden structure of the ceramic part—or add new details to combine both parts, to achieve the intended compositional value (Fig. 6). This negotiation was one of the crucial learning outcomes, to foster creativity and critical thinking. Wood allowed sanding, carving and adjustments, while ceramics were more fragile when requiring caution after firing. Other iterative solutions could be changing the top part completely, 3D printing a different top part—moulding/producing the top again/firing could be one of the many options to opt for (Fig. 7).

It is possible to state that the product testing stage enhances the capacity to assess joinery, material limitations and evaluation of the process, rather than focusing on the end product. The tactile qualities, refined surfaces and roughness of wood and ceramic are considered by students with utmost care. This analytical approach of misalignments, cracks, mistakes and opportunities bridges control and ambiguity, and overall creativity is achieved with exploration (Fig. 8).

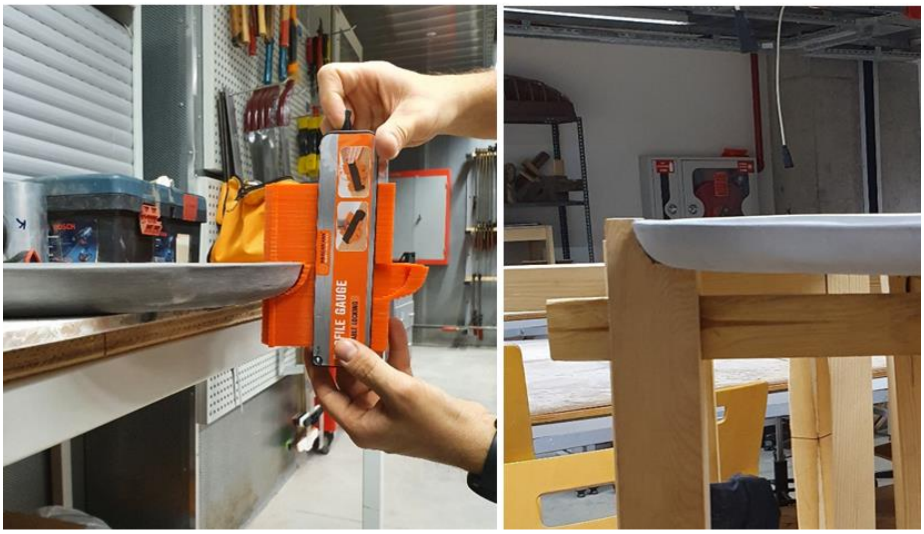

Figure 6. The ceramic top and cross joinery display an intentional degree of imperfection, in contrast to the precision typically achieved through 3D modelling.

Figure 7. A student work before firing (on the left), which joins the top and the structure with a smaller central cross as it could cause breakage otherwise (on the right)

Figure 8. Wood parts should be revised since the top is not perfect anymore

3 Findings and Discussion

The analysis of the qualitative data revealed three interrelated themes that characterise students' learning experiences in the hybrid furniture studio: (1) developing material literacy, (2) cultivating critical and reflective thinking through iterative workflows, and (3) engaging with unexpected outcomes for creative discovery.

The themes can be summarised as follows:

- Material literacy: understanding material behaviour, production methods, and different qualities, from structural integrity to tactile qualities.
- Critical thinking: cultivating experience in an iterative workflow between trial, error, and revision to achieve the desired outcome.
- Creative discovery: negotiating perfection and approaching uncertainty as a tool for creativity, opening new opportunities when precision is needed for structural or aesthetic concerns.

According to the findings of the study, the area in which students provided the most substantial feedback was material engagement. Learning about the material and its associated production methods not only captured their interest but also increased their level of knowledge. For example, students who became familiar with the shrinkage properties of ceramic adapted their wooden structures accordingly, and later approached the revision of broken ceramic pieces with this understanding in mind. As students developed a deeper familiarity with materials, their engagement extended beyond the requirements of the assignment; several students began experimenting with ceramic casting techniques in their free time, suggesting that this knowledge will transfer to other courses and to lifelong learning practices.

A second theme, critical thinking, also developed directly through material literacy. Students learned about material weight, fragility, firing conditions, and structural behaviour, and this expanded their analytical thinking beyond formal concerns. After their initial attempts, many students entered the revision phase with a more holistic mindset, considering not only form but also structure. These reflexive decisions during the second iteration positively influenced the outcome and strengthened their capacity for design judgement.

In addition, the hybrid workflow strengthened students' ability to anticipate material timelines—such as drying, firing, and printing durations—and adjust their design strategies accordingly. Over time, some students began organising informal, time-dependent divisions of labour, coordinating tasks among themselves to manage these material constraints more effectively.

The final theme, creative discovery, appeared in a smaller number of students, yet it was evident that some integrated unexpected results into their design process. One example was a student who designed a table with a cross-joint; upon recognising the risk of breakage, the student revised the joint detail by reducing its size, thereby turning a structural concern into a design opportunity.

Notably, none of the students proceeded to redesign their moulds through 3D printing for a second iteration. This outcome may be attributed to the limited time available in an elective course. Since redesigning the mould and altering the table's structure requires the mould to dry again—a time-consuming step—this finding suggests the need to allocate a longer timeframe for this stage or to incorporate additional course content that encourages deeper engagement with the digital-to-ceramic workflow. Reluctance to explore alternative geometries also suggests that some students perceived the hybrid process as carrying a higher risk threshold, prompting them to remain within safer procedural boundaries.

The hybrid studio operated as a living laboratory, redefining design and material literacy by expanding beyond technique to encompass environmental, sensory, and contextual knowledge. Students' reflections repeatedly emphasised the interdependence of craft, technology, and creativity. Altogether, the findings affirm that hybrid pedagogy bridges these domains and enables students to internalise methods and skills essential for developing as designers capable of navigating complex problems and practices within the furniture industry. These findings collectively correspond to the three pedagogical pillars outlined earlier, reinforcing the framework presented in Fig. 9.

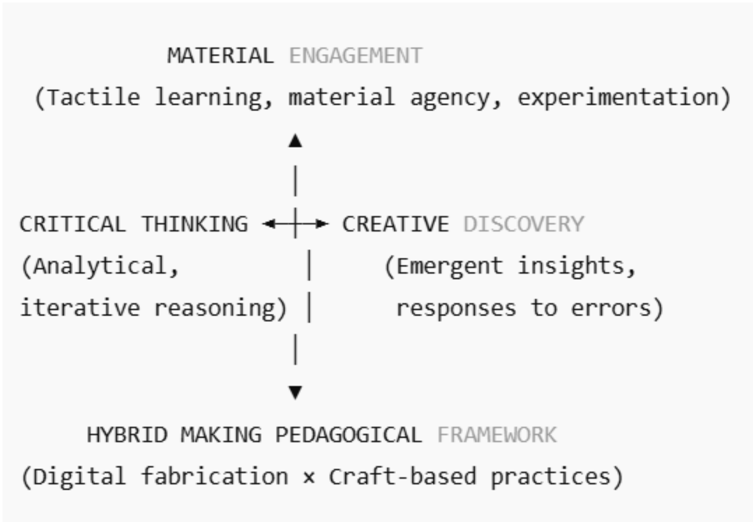

Figure 9. Three Pillars of the Hybrid Furniture Design Pedagogy

4 Conclusion

The conclusions of this work can be summarised as follows:

- Design education that embodies a hybrid workflow unites digital mediums and craft-based practice without denying innovation that is led technologically, with tactile intuition and sensorial feedback.
- Imperfection becomes a learning environment, expanding creative negotiations between trial and error rather than mistakes needing to be corrected and avoided.
- Collaborative, interdisciplinary pedagogical environments—supported by practitioners, artists, and makers—foster expanded forms of knowledge dissemination within the studio.
- Hybrid workflow enhances critical thinking, reflection, and analytical judgement, strengthening students' capacity to revise, adapt, or reconfigure a given brief and to develop personal strategies across diverse modes of production.
- The study additionally shows that students' ability to anticipate material timelines—such as drying, firing, and printing durations—developed as part of the hybrid process, strengthening time-based decision-making and collaborative task coordination.
- A further implication is that risk perception plays a decisive role in students' engagement with digital iteration; reluctance to redesign 3D-printed moulds suggests the need for structural adjustments in curricula to better support experimentation, risk-taking, and extended cycles of digital–material iteration.

- The study also highlights a structural limitation: a significant proportion of students did not pursue secondary iterations of 3D-printed forms. This pattern suggests that time constraints, perceived technical difficulty, or hesitation toward high-risk digital–material transitions may inhibit exploratory behaviour. Addressing this gap in future course structures may strengthen the creative dimension of hybrid making.

Acknowledgement
I would like to express my sincere gratitude to Stefano Pugliese, Argun Tanrıverdi, Prof. Sevim Çizer, and Ayda Eriş for their invaluable expertise and generous support throughout the theoretical, practical, and laboratory phases of this study.

Author Contributions
Hande Atmaca: Conceptualization, Data curation, Methodology, Visualization, Writing – original draft, Writing – review and editing.

Funding statement
No financial support was received for this study.

Conflict of interest statement
The author declares no conflict of interest.

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