



Time-Motion Study: Uncovering the Bottleneck in Jepara's Chair Design Development

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Abstract. This study examines efficiency improvements in the research and development (R&D) process of Jepara's furniture industry in Indonesia. Despite its international reputation as a wood-carving hub, Jepara remains constrained to an original equipment manufacturer (OEM) model, leaving it vulnerable to competitors in China and Vietnam. Transitioning to an original design manufacturer (ODM) model requires structured R&D. However, traditional frameworks like time-motion Study (TMS) prioritize linear mass production rather than iterative, culturally grounded creative workflows. To address this gap, a TMS, work pattern analysis, and technology evaluation were conducted across the Inspiration/Immersion, Ideation, and Prototyping stages across three designer setups. The findings reveal that time allocation varied significantly by organizational structure: Designer 1 spent 25–27% of time on Immersion and Prototyping due to production conflicts; Designer 2 allocated 41–44% across Ideation and Prototyping; and Designer 3 spent only 9–10% on Immersion and Ideation by using Computational 3D modeling to merge the design into prototyping. The study confirms that Immersion preserves local cultural identity, while digital 3D tools dramatically compress R&D lead times. To support Jepara's OEM-to-ODM transition, the research recommends establishing dedicated prototyping units to shield R&D from production demands and integrating computational 3D modeling to accelerate design iterations.

Keywords: *computational 3D modeling; craft innovation; furniture R&D; Jepara furniture; OEM to ODM; time-motion study.*

1 Introduction

Jepara, as a furniture industry center, plays a crucial role in the economic and social system rooted in its culture. In the economic sector, Jepara furniture has been a leading Indonesian export commodity for decades. Based on data from the Jepara Regency Government, in 2019, there were 344 companies with an investment of Rp. 895 billion. This number subsequently increased (post-Covid-19) in 2023 to 522 companies, although investment decreased to Rp. 338 billion. However, there was an increase in export volume from 45.9 million kg (USD166

million) in 2017 to 52.3 million kg (USD287 million) in 2023 [1]. As a cultural space, Jepara has successfully maintained its traditional wood carving skills and earned recognition as the World Center of Carving [2] and received Geographical Indication status for its carved furniture [3-4].

However, the Jepara furniture industry still relies on non-original or foreign designs, positioning it as a manufacturing hub instead of a center for innovation. This prevents Jepara from competing with Chinese and Vietnamese producers. To overcome this challenge, Association of Furniture and Craft Entrepreneurs (HIMKI) DPD Jepara Raya and Association of Indonesian Furniture Designers (HDMI) collaborated to build the Jepara Design Collection—a database of original designs by Indonesian designers focused on research and development (R&D) as a strategic transition from an OEM (original equipment manufacturer) to an ODM (original design manufacturer) model. This shift requires the ODM to assume full responsibility for product development, including research, design, engineering, and often intellectual property (IP). While OEMs focus solely on production, ODMs typically maintain dedicated in-house teams for design and R&D [5]. Collaboration between designers and craftsmen in R&D is key to maintaining product relevance in the global market [6]. Design innovation, product diversification, and entrepreneurship are essential to help craftsmen adapt to changing consumer tastes and market conditions [7]. The challenge is that the R&D process, which involves a creative process, lacks definite time standards. Therefore, efficiency measurement research is needed for the Jepara furniture industry's transition from a manufacturing hub to a center for innovation.

The Jepara carved furniture industry is closely linked to the patterns, behavior, and cultural values of its society [8]. Designer-industry collaboration in the R&D process requires process adjustment, considering that craft products are not only function-oriented but also represent community identity and technical proficiency in material processing [9]. Craft is an experience about the material beyond pragmatism [10], where action and thought occur simultaneously [11] and emotion guides the process [12]. In this context, measuring the R&D time for new product design development becomes crucial to identify workflow efficiency and resource allocation.

The integration of time motion study (TMS) with lean manufacturing can also be adopted to streamline the R&D process without compromising on quality, as applied in furniture SMEs throughout Asia [13]. Furthermore, the utilization of digital tools (such as TMS software) allows for real-time monitoring of the design and production process, particularly for original design R&D that requires complex iteration [14]. TMS has been widely used in the manufacturing and service industries, including the furniture design sector, yet the application of TMS for traditional craft R&D, such as in Jepara, is relatively novel. The existing

literature often focuses on mass production, leaving a gap in understanding how time management principles can be adapted for implementation in the design development process. Unlike manufacturing production processes, design development involves the acquisition of inspiration, imagination, and an iterative creative process. This study fills the gap from previous TMS research conducted on manufacturing production processes by providing a detailed analysis of R&D time specifically for furniture production in Jepara.

The novelty of this research lies in its focus on design development that bridges traditional expertise with modern efficiency techniques, offering a unique perspective that connects cultural heritage and innovation. The results of this study will be beneficial for knowledge development by enriching the discourse on sustainable practices in the furniture industry, emphasizing the importance of efficiency without sacrificing quality. Furthermore, this research provides a new perspective on how time management principles can be adapted for application within the creative realm, in this case, the development of chair design. The recommendations resulting from this study will be applicable to the Jepara furniture industry, helping it to transform from OEM into ODM so that it can compete with other furniture industries, such as manufacturers in China and Vietnam.

2 Methodology

This study uses a mixed-methods approach, combining quantitative applied time motion study and qualitative methodologies to gain a comprehensive understanding of the furniture product design R&D process in Jepara. It utilizes a sequential explanatory mixed-methods design. In the first phase, a time motion study was conducted concurrently within an action research framework to generate quantitative efficiency metrics. In the second phase, qualitative designer self-reflections and interviews were deployed to explain, contextualize, and deeply understand the quantitative variations and the participants' experiences during the action cycles

2.1 Quantitative Approach (Time Motion Study – TMS)

TMS was the primary method used in this study to obtain empirical data on the duration of each step in the design development (R&D) process. TMS, a scientific management technique created by Frederick Taylor (1856-1915) and his two disciples Frank and Lillian Gilbreth [15], analyzes time and motion to enhance efficiency and work output. This method measures the time required to complete tasks with the goal of finding the most efficient working method, improving productivity, quality, and work standards, as well as reducing the potential for accidents [16]. The application of TMS has proven effective in increasing the

productivity of the furniture industry through task analysis, bottleneck elimination, and the reduction of time wasted by up to 20%. [17] Moreover, the TMS approach in craft-based industries (such as wood carving) is capable of blending technical precision with cultural flexibility [18] and can be adopted to streamline the R&D process without compromising quality, as applied in furniture SMEs in other Asian countries. [18]

In this research, the task was broken down into three parts: designer immersion, designer–craftsman collaboration in ideation, and prototyping. Direct observation conducted on designers and craftsmen as they were working, recording the time spent on each part of the task, and identifying potential delays or inefficiencies. Modification of the repetition pattern in the TMS measurement was done by calculating the task done by three pairs of designer-craftsmen in parallel. The modification was applied because the design development process for craft-based products cannot be identically repeated, thus making a standard repetition method less appropriate. The unit of time used in time measurement was minutes. The data set consisted of time taken by each part of the task done by three pairs of designer-craftsmen. The researchers (designers) conducted action research. This approach was chosen because design research is situational, context-dependent, and needs to be developed within its natural context [19]. Action research involves practitioners creating new ideas to improve practice and proposing those ideas as their personal theories of practice. Time measurement was done by the designers and research assistants. The three designers were academics but also design practitioners and the industries were established manufacturers and craftsmen in Jepara, members of the Association of Furniture and Craft Entrepreneurs (HIMKI) DPD Jepara. While the three designers had similar backgrounds and experience, the industries had different profiles, which allowed potential data variations that enriched the research.

Potential bias was reduced by real-time recording of each activity in every part – immersion/inspiration, ideation, prototyping – including break time between the process. Data collection was done through self-recording by the designers and the research assistants assigned to each designer. All the research assistants were final year students in the product design department.

2.2 Qualitative Approach (Action Research and In-Depth Interviews)

This research was conducted by the practitioners themselves, rather than by professional researchers studying practitioners [20]. This study was participatory, focused on the experiential dimension, and emphasized action, dialogue among participants, practice, and the learning process [21]. In this research, the researchers acted as designers working in the Jepara furniture industry. The relationship between the researchers and the other involved actors was crucial for

determining the procedures for participation throughout the entire process, which also meant paying attention to the collective, collaborative, and self-reflective actions that represent a significant part of the process. The qualitative data collected through the designers' self-reflection and in-depth interviews. The designers reflected on the quantitative time measurement data. In the reflection phase of the action research cycle, the designers scrutinized the quantitative data to evaluate each designer–craftsman pair's operational habits, such as exact durations spent on each part of the task, the iterative loops, and other events to diagnose friction points, bottlenecks, and the idea of alternative solutions. In-depth interviews were conducted with key stakeholders in the Jepara furniture industry, including with designers, production managers, and craftsmen. These interviews aimed to provide deeper context for the quantitative data, helping to identify underlying issues that may not be revealed solely through time measurement.

3 Design Development Stages

Data were collected through action research and TMS across three design stages: Immersion/Inspiration, Ideation, and Prototyping. This approach captured variations in time consumption relative to each designer's distinct work habits, individual cognitive workflows, and the operational processes and priorities of each industry partner. Furthermore, it tracked the evolving collaboration dynamics within each designer–craftsman pair, specifically focusing on the designer's immersion during inspiration, their joint collaboration during ideation and prototyping, and the final production of the prototype by the craftsman. Figure 1 illustrates the designer craftsman dynamic during the design development process.

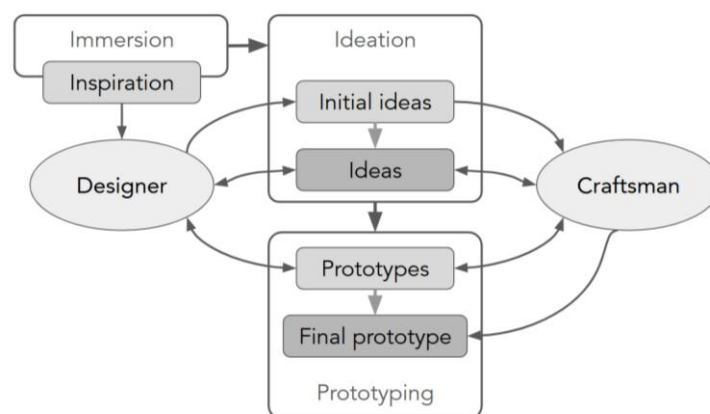


Figure 1 Designer-craftsman dynamic during the design development process.

3.1 Immersion

The inspiration process began with the designers' immersion (melting/blending in) through a visit to Jepara. This activity aimed for the designers to recognize Jepara's geographical conditions, natural potential, philosophy, values, and the character of its community. This is crucial, because the Jepara carving furniture industry is strongly linked to the patterns, behavior, and cultural values of its people.

Familiarization with Jepara was carried out through visits to several places important to the general life of the Jepara community, historical sites, and locations directly related to the Jepara furniture industry. During these visits, the designers conducted observations, collected visual inspiration in the form of photos and videos, and held informal interviews with the community and key figures. This activity lasted for five days, covering Jepara City and the surrounding Jepara Regency area up to Keling, located at the foot of Mount Muria. Unlike the Ideation and Prototyping stages, the Immersion stage was carried out uniformly by the three designers, using the same itinerary, observation methods, and information-gathering process, establishing a common foundation of cultural and contextual understanding. However, each designer absorbed and interpreted this shared experience individually, drawing different points of focus and inspiration shaped by their individual design sensibilities and prior professional experience, which became a starting point for the divergence observed in their subsequent Ideation processes.

This journey provided an overview of Jepara's natural conditions, which offer a complete range of natural resources for its community (see Figure 2). The immersion trip also highlighted that the Jepara community has historically upheld gender equality and valuing tolerance and harmony among religious communities.



Figure 2 Nature and culture in Jepara.

The immersion program not only covered Jepara's nature and culture but also actively mapped the wood and craft industry in the region (see Figure 3). This

involved interviewing craftsman/business owners, observing the production process, and visits to suppliers and log cutting facilities, which supply the raw material for furniture.



Figure 3 Craft production in Jepara.

The Immersion stage was followed by the Ideation stage, which involved searching for additional references, creating concept sketches, 3D drawings, and implementation. Implementation entailed the construction of prototypes using wood materials, carried out by the craftsman collaboratively with the designers.

3.2 Ideation

Ideation is the stage of generating new product concepts based on insight and inspirations gained during the Immersion stage. This stage was completed by all three designers, though each employed a distinct workflow tailored to their individual creative process, immersion outcomes, and choice of tools and materials.

The process began with an initial ideation phase in Jakarta (Figure 4), where the designers independently developed preliminary chair concepts and design ideas. The study then transitioned to Jepara for a secondary (Figure 5), collaborative ideation phase. Here, the initial concepts were reviewed and discussed with local industry partners and craftsmen. During this phase, student research assistants initiated data collection by documenting the collaborative dynamics between the designers and the craftsmen. Throughout the consultations in Jepara, design concepts were iteratively refined to ensure strict alignment with practical production capabilities, local material availability, and direct manufacturer feedback.

The resulting divergence in individual creative workflows is clearly reflected in the time allocation data recorded during this stage. Designer 1 spent 25–27% of their total design development time on Immersion and Prototyping. Designer 2 allocated 41–44% of their time to the combined Ideation and Prototyping phases. In contrast, Designer 3 spent only 9–10% on Immersion and Ideation, dedicating

the vast majority of their time to Prototyping; for this designer, the integration of computational 3D modeling effectively allowed the Ideation and Prototyping stages to merge (see Section 4.1.3).



Figure 4 Ideation process in Jakarta.



Figure 5 Ideation process in Jepara.

3.3 Prototyping

Ideation was followed by prototyping activities carried out in Jepara by the industry/craftsmen (Figure 6). At this stage, the role of the Jepara craftsmen is highly critical, considering that craft products are not only function-oriented but also represent community identity and technical material processing skills [9][10], where action and thought occur simultaneously [11] and emotions guide the process [22].

Methodologically, the designers maintained remote design oversight from Jakarta, while student research assistants provided on-site workshop supervision in Jepara. Communication between the designers and the research assistants was maintained through intensive online coordination. This structure allowed the designers to guide and review the prototyping phase remotely, while the craftsmen leveraged their technical expertise to translate the design concepts into physical products. Throughout this process, the student assistants meticulously documented the craft workflows and tracked the exact time allocation required for each prototype creation.

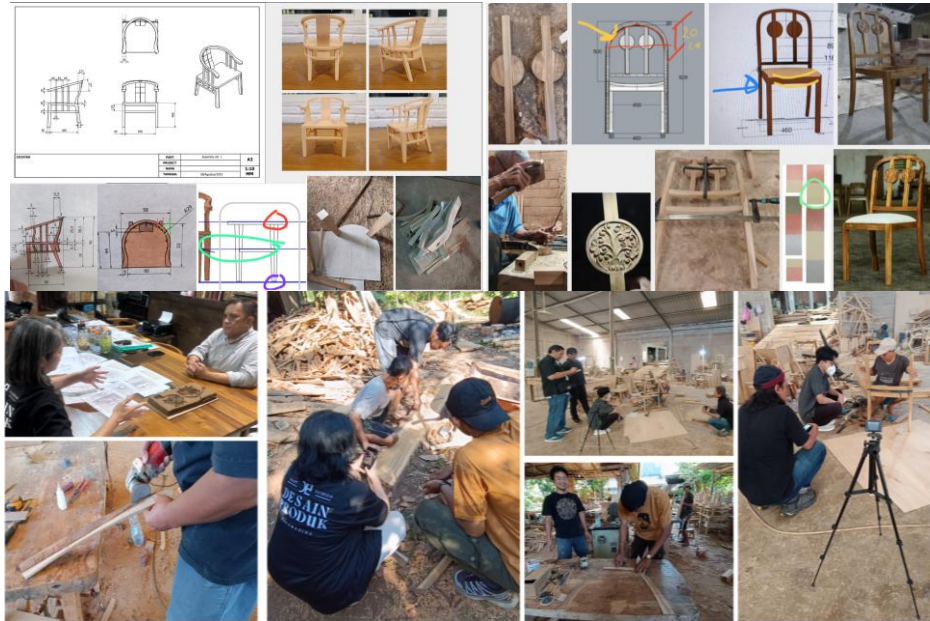


Figure 6 Prototyping process in Jepara.

4 Result and Discussion

This study successfully obtained time measurement data for the design development process (R&D), data analysis, and implementation recommendations for the Jepara furniture industry.

4.1 Design Development Process Time Measurement Results

Time consumption was measured across the entire furniture design development process for all three participating designers. The data tracked time expenditures for immersion, ideation, and prototyping activities across both the Jakarta and Jepara sites, grouped by stage for each designer. The study demonstrated that every designer maintained unique iteration patterns, timelines, and total durations. Additionally, the adoption of computational 3D modeling yielded varying degrees of workflow efficiency among the designers during the development cycle.

4.1.1 Iteration Pattern

The data shows that the time allocation and specific workflow required by each designer differed across the three stages. The results align with the view that creativity emerges unexpectedly from an iterative and improvisational process [23], suggesting that ideas do not appear suddenly but are born from a cycle of

repetition, reflection, and improvisation in work. Furthermore, prior research indicates that employing an iterative process by alternating between generating and evaluating ideas will result in more original solutions [24]. This is particularly relevant because the process aims to generate original solutions rather than modify existing products.

This confirms that every individual has a different way of structuring the stages—some tend to be linear and others iterative. These structural variations reflect how designers adapt their processes to specific project requirements and the operational realities of their collaborating industrial partners and craftsmen. This understanding is reinforced by neuroscientific studies which demonstrate that creative thinking is fundamentally dynamic and metastable, emerging from the interaction between large-scale brain networks [25]. Thus, it is expected that each designer navigates a different process path shaped by their unique cognitive dynamics. Figure 7, shows that Designer 1, 2, and 3 began the process with inspiration, followed by ideation. Designer 2 and 3 repeated (iterated) this process before moving on to prototyping. Designer 1 proceeded to prototyping after the first inspiration and ideation phase. All three designers performed ideation and prototyping repeatedly (iteration) and the entire process concluded with prototyping.

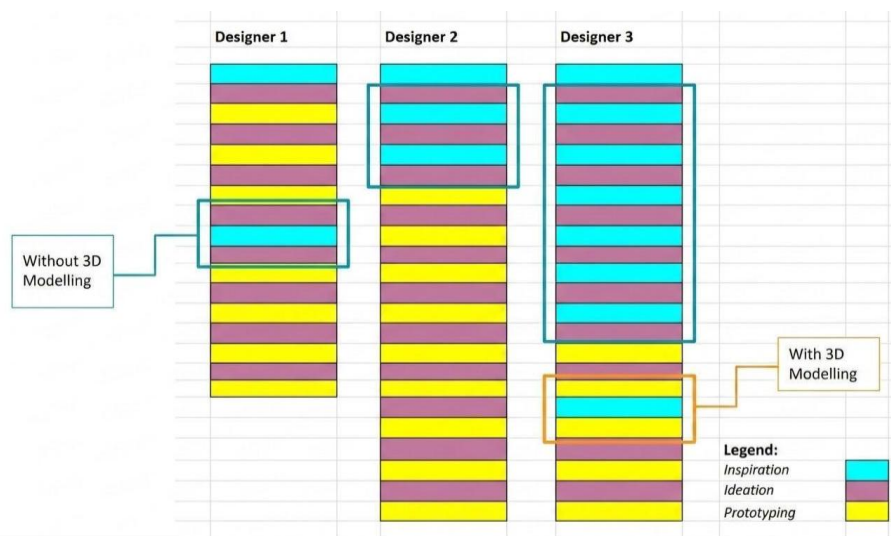


Figure 7 Comparison of the working process of Designer 1, 2, and 3.

4.1.2 Time and Duration of the Design Development Process

The design development (R&D) process for Jepara furniture required varying durations for each stage. For Designer 1 and Designer 2, the most time was spent on the ideation process, while for Designer 3, it was on prototyping. Designer 1

used nearly the same amount of time for inspiration and prototyping, namely 2,593 minutes and 2,428 minutes, respectively, accounting for 25–27% of the total design development time. Unlike Designer 1, Designer 2 used nearly the same time for ideation and prototyping, namely 5,664 minutes and 5,265 minutes, which is 41–44% of the total design development time. Meanwhile, Designer 3 used nearly the same time for inspiration and ideation, namely 1,155 minutes and 1,095 minutes, accounting for 9–10% of the total design development time. These findings confirm that designers allocate different amounts of time across the stages of the design development process. The variation in time allocation indicates that designers adapt their working time to the specific requirements of the design process rather than following a uniform time distribution.

Table 1 Time allocation of Designer 1, 2, and 3.

Designer	Inspiration	In/TW	Ideation	Id/TW	Prototyping	Pr/TW	Total Time
1	2593	0.27	4506	0.47	2428	0.25	9527
2	2048	0.16	5664	0.44	5265	0.41	12977
3	1155	0.10	1095	0.09	9309	0.81	11559

4.1.3 Design Development with Computational 3D Modeling

The utilization of computational 3D modeling in furniture design offers various advantages. This technology boosts creativity while simultaneously accelerating the iteration process during the ideation stage, as concepts can be immediately realized into three-dimensional models, allowing the product visual to be seen instantly. The creative flow and design implementation also become shorter, with more realistic visualization results. With these capabilities, 3D modeling also plays a role in visual testing and aesthetic assessment of the product, particularly concerning dimensions, proportions, and the form's suitability for the design goal. This capability strengthens decision-making accuracy, especially in maintaining the balance between function and aesthetics. In terms of efficiency, the digital model can reduce costs and time typically spent on creating multiple physical prototypes, leading to material savings and more optimal development. This technology also facilitates the precise review of constructive and technical product details. Another advantage is its integration with modern manufacturing technology. The resulting digital model can be sent directly to production systems based on CNC, 3D printing, or other digital fabrication methods. Consequently, the workflow from design to production becomes more concise and efficient. This approach aligns with the concept of fabrication-aware design, which emphasizes the optimization of material use for furniture, while also simplifying the transition from the digital model to the actual fabrication stage [26]. Furthermore, the evolution of CAD and 3D printing strengthens the function of 3D modeling in building a smarter, more interactive design environment integrated with the manufacturing process [27]. This study shows that the use of computational 3D

modeling allows the ideation process to merge with the prototyping process, as demonstrated by the workflow of Designer 3 shown in Figure 7.

4.2 Recommendations for Efficiency Improvement

This research identified several inhibiting and crucial factors in the design research and development (R&D) process for wooden furniture in Jepara. The variations in time allocation and workflows observed through the time motion study indicate that process efficiency is influenced not only by the duration of individual activities but also by how designers and manufacturers prioritize and organize the design development cycle. Furthermore, this study demonstrates that the immersion process is an essential stage. It enables designers to generate novel product design ideas that preserve the distinctive traditional cultural heritage, representing its industry (in this case, the Jepara wooden furniture industry) and aligning with the industry's unique character and production capacity.

Consistent with these findings, the development of digital technology, particularly computational 3D modeling, offers an opportunity for designers to optimize the ideation and prototyping stages. This technology allows ideas emerging from the immersion process to be visualized faster and explored in various alternative forms without always relying on physical prototypes. In this way, ideas rooted in cultural distinctiveness and manufacturer's character can be visually tested immediately, both in terms of proportion, function, and aesthetics. This will strengthen the design decision-making process.

At the same time, the design process will become more efficient if designers possess in-depth knowledge regarding the character of the partner industry. Understanding the production capacity, available technology, workforce skills, and even the working habits of the industry enables designers to formulate more realistic and applicable decisions. In this way, the resulting designs can be not only visually innovative but also compatible with local manufacturer capabilities, thereby accelerating the transition from concept to actual product. This is demonstrated by the work of the designers who showcased carvings with a touch of novelty and a distinct interpretation of traditional expression. This study recommends that the immersion process in Jepara should be the starting point for every design development (R&D) process for Jepara furniture products.

This research involved three industries with diverse characteristics: the first industry had a large production capacity with export capability, owned by an entrepreneur lacking a background in carving expertise and furniture-making techniques; the second industry also possessed a large production capacity with export capability, but was owned by an entrepreneur who did have a background in carving expertise and furniture-making techniques; finally, the third industry

maintained a limited production capacity and was owned by a craftsman who was proficient not only in carving and furniture-making techniques but also in the creation and operation of CNC (computer numerical control) machines. In the first industry, a bottleneck occurred due to the technical production knowledge of the business owner not matching that of the craftsmen. Furthermore, the owner of the first industry prioritized the craftsmen to work on projects rather than prototype creation (R&D) activities. This was because projects have a clear predicted time usage, whereas the duration required for prototyping is unknown. In the second industry, the owner was both a craftsman and an entrepreneur, enabling them to manage time for prototype creation alongside other ongoing projects. The third industry prioritized prototype creation, placing prototyping on par with other projects.

Based on these findings, this research recommends the establishment of a specialized work unit or division for prototyping activities. This unit could be located within the company, operate as a business division of a furniture association, or be a company specifically providing prototyping services located in Jepara to support the design development (R&D) process for new products that the industry needs. This is significant if the Jepara furniture industry wishes to shift from the original equipment manufacturer (OEM) model to the original design manufacturer (ODM) model. One other recommendation based on this research is the utilization of computational 3D modeling to shorten the development time for Jepara furniture design.

5 Conclusion

This research confirmed that the design development (R&D) process for Jepara furniture is inherently complex, characterized by the diverse and non-linear working patterns exhibited by the designers, where time allocation varied significantly across the Inspiration, Ideation, and Prototyping stages. The study highlights that the immersion process and the designer's deep knowledge of the partner industry's capacity and cultural context are essential prerequisites for generating innovative yet manufacturable designs that preserve Jepara's traditional heritage. This human-centric foundation is crucial, as differences in industrial structure (ranging from entrepreneur-led to craftsman-led firms) revealed bottlenecks, especially when project execution was prioritized over dedicated R&D activities.

To significantly boost efficiency and support the industry's shift from an OEM to an ODM model, the research strongly recommends two strategic actions. Firstly, the utilization of computational 3D modeling should be maximized, as it allows the Ideation and Prototyping stages to merge, thereby accelerating iteration and testing without the time and cost burden of numerous physical

prototypes. Secondly, to safeguard R&D efforts, a specialized prototyping unit or division must be established—either within large firms or as an independent service—to provide dedicated resources and expertise, ensuring that new product development is consistently prioritized and effectively integrated into the Jepara furniture ecosystem.

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AI Disclosure

The authors used AI language models to assist with manuscript preparation. Claude (Anthropic) was used to assist with language refinement and structuring of manuscript revisions in response to reviewer comments. Gemini (Google) was used to translate Indonesian-language text within figures and tables into English. All content, data, and interpretations were reviewed and verified by the authors, who take full responsibility for the accuracy and integrity of the manuscript.

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