International Journal of Economics, Management and Accounting

ISSN: 2988-7615 | Volume 4, Issue 1 (2026)
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Research Article

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Application of Evolutionary Prototyping to Maximize Product Output at Zamrud Mebel, Gunungsitoli City

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Received: July 26, 2026; **Accepted:** August 19, 2026; **Online:** August 29, 2026 | DOI: https://doi.org/10.47353/ijema.v4i1.399

Abstract: *Micro, Small, and Medium Enterprises (MSMEs) face increasing pressure to adapt their products to changing consumer preferences, technological developments, and market competition. This study examines the application of Evolutionary Prototyping in product development at Zamrud Mebel, a furniture MSME in Gunungsitoli City. The study aims to describe the implementation stages, identify challenges encountered during iterative development, and examine consumer responses to product modifications. A descriptive qualitative case study approach was employed, with data collected through direct observation, in-depth interviews with the MSME owner, production personnel, and consumers, and documentation. The findings show that Evolutionary Prototyping was implemented through three iterative cycles involving initial prototype development, functional testing and consumer feedback, and finalization and feature optimization. The process enabled the identification and correction of design deficiencies before mass production and reportedly reduced material waste by up to 25%. However, implementation was constrained by time, human resource adaptation, and additional development costs. Overall, Evolutionary Prototyping provides an adaptive and participatory approach to improving product quality and alignment with consumer needs in non-digital MSMEs.*

Keywords: *MSMEs, evolutionary prototyping, product development, iteration, sustainable innovation, Zamrud Mebel.*

Introduction

In an increasingly competitive business environment, continuous adaptation and product development have become essential for the sustainability and competitiveness of Micro, Small, and Medium Enterprises (MSMEs). Changes in consumer preferences, technological developments, and market competition require MSMEs to continuously improve their products and production processes. In the context of Industry 5.0, businesses are expected not only to respond to technological change but also to place greater emphasis on human-centered innovation, customer participation, flexibility, and the ability to develop products that are aligned with user needs. Therefore, product development within MSMEs should not be regarded as a one-time production activity, but rather as a continuous process involving experimentation, evaluation, feedback, and refinement.

MSMEs constitute an important component of the Indonesian economy. According to the Ministry of Cooperatives and SMEs (2024), more than 65 million MSMEs operate in Indonesia and contribute approximately 61% of national Gross Domestic Product (GDP), equivalent to around IDR 9,500 trillion. Despite their substantial contribution, many MSMEs continue to face difficulties in adapting to dynamic market conditions, particularly in terms of product innovation and production efficiency. Limited human resources, technical capabilities, financial resources, and conventional production practices may restrict the ability of MSMEs to systematically test and improve their products before entering the market. Consequently, products may fail to fully correspond to changing consumer expectations, while production errors and material waste may increase.

The challenge becomes particularly relevant in the furniture manufacturing sector, where product competitiveness is strongly influenced by design, functionality, ergonomics, material quality, aesthetics, and consumer preferences. Furniture manufacturers need to ensure that products are not only structurally functional but also comfortable, visually appealing, and appropriate for the intended users. However, conventional production practices often involve moving directly from an initial design concept to production without sufficient prototype testing or systematic consumer involvement. When deficiencies are identified only after production has progressed, manufacturers may need to repeat production processes, modify structural components, or discard materials. Such conditions can increase production costs, extend completion time, and create products that are less responsive to market requirements.

This condition is also experienced by Zamrud Mebel, a semi-manual furniture manufacturing MSME located in Gunungsitoli City. Historically, Zamrud Mebel had a strong position as a furniture supplier for government offices in the Gunungsitoli area and the wider Nias region. The enterprise was recognized for its solid timber products and distinctive craftsmanship. However, its competitiveness subsequently declined as conventional and relatively static production practices became less responsive to changing design trends and consumer preferences. The enterprise also lacked a structured product development system that could systematically involve consumers in the testing and refinement of new products.

To address this condition, an adaptive product development approach is required. One approach that has the potential to support such a process is Evolutionary Prototyping. Evolutionary Prototyping is an iterative product development approach in which an initial prototype is continuously evaluated, modified, and refined based on user feedback. Rather than attempting to establish all product requirements at the beginning of the development process, the approach allows requirements to emerge and become increasingly precise through successive iterations. Pressman and Maxim (2020) explain that evolutionary prototyping is particularly useful when requirements remain unclear or exploratory during the early stages of development. Lim, Stolterman, and Tenenberg (2008) similarly emphasize that prototypes can function as tools for exploring design possibilities, testing assumptions, and obtaining feedback. Sommerville (2011) further explains that evolutionary development allows a product to develop incrementally through repeated cycles of evaluation and improvement.

Evolutionary Prototyping provides several potential advantages for product development. Continuous feedback can facilitate early identification of design deficiencies, improve user involvement, support flexible adaptation of requirements, and reduce the risk of major errors occurring during large-scale production. The iterative process may also provide opportunities to evaluate both product functionality and aesthetic characteristics before final production. However, the approach also presents challenges, including uncertainty regarding development time and cost, dependence on user participation, repeated testing and modification, and difficulties in managing substantial structural changes. These considerations are particularly important in MSMEs because their resources are generally more limited than those of larger manufacturing organizations. Therefore, the applicability of Evolutionary Prototyping needs to be examined within the actual operational conditions of MSMEs rather than being assumed solely from applications in software and technology industries.

The present study therefore positions Evolutionary Prototyping as an adaptive approach for improving physical products through continuous interaction between the producer and users. In the context of Zamrud Mebel, the approach is applied through a sequence of identifying user needs, developing an initial prototype, testing the prototype, collecting feedback, evaluating the findings, revising the product, and finalizing the improved product. Product optimization is considered from the perspectives of product

quality, production efficiency, and market relevance. These dimensions are intended to provide an analytical basis for examining how iterative product development can address the limitations of conventional furniture production.

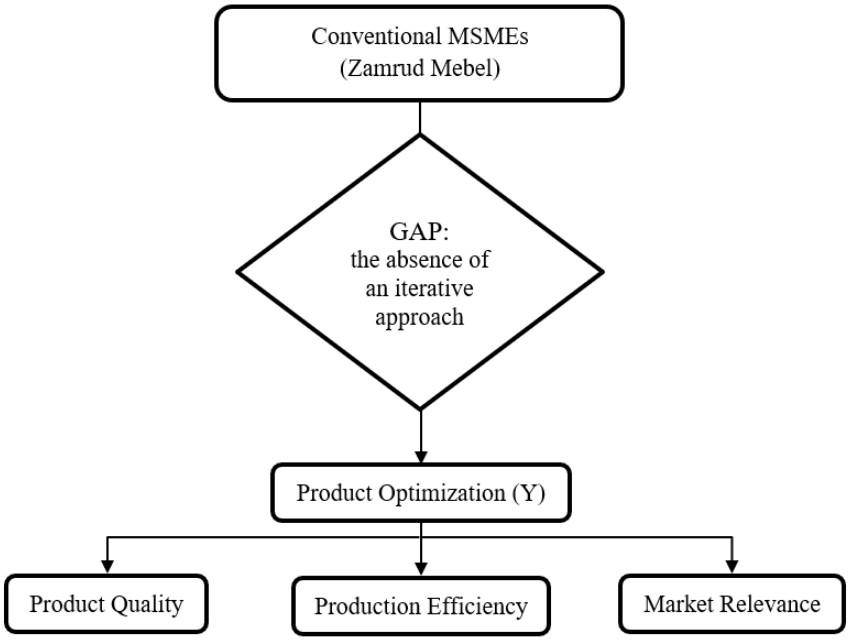

Figure 1. Research Framework
Source: Developed by the authors

As illustrated in Figure 1, the study begins with the existing condition of Zamrud Mebel as a conventional MSME facing a gap in adaptive product development. Evolutionary Prototyping is positioned as an iterative approach for addressing this gap through continuous product evaluation and user involvement. The resulting product optimization is examined through three dimensions: product quality, production efficiency, and market relevance. The framework therefore emphasizes that product development is not limited to the physical modification of furniture but also involves improving its quality, reducing inefficiencies, and ensuring greater alignment with consumer needs.

Previous studies have demonstrated the usefulness of Evolutionary Prototyping and related iterative approaches in various development contexts. Irnawati, Maulana, and Kuswanto (2021) examined the application of Evolutionary Prototyping in the development of a planetarium e-ticket information system and reported improvements in service management and operational efficiency. Carter et al. (2020) developed a risk-based Evolutionary Prototyping model and reported reductions in development costs and risks. Howard (2018) proposed an evolutionary prototyping methodology for managing large-scale system development, emphasizing active collaboration between users and developers. In the MSME context, Munir et al. (2020) developed a web marketplace prototype and reported user acceptance ranging from 77% to 92%. Bening (2024) similarly found that iterative prototyping improved feature alignment and usability in an MSME vendor management system.

Table 1. Summary of Relevant Previous Studies

No	Author(s)	Research Title	Focus / Variables Studied	Research Findings
1	Oky Irnawati, Amir Maulana, Andi Diah Kuswanto (2021)	Application of Evolutionary Prototyping in the	System Development	The study found that the system improved service management and

No	Author(s)	Research Title	Focus / Variables Studied	Research Findings
		Development of a Planetarium E-Ticket Information System	Using Evolutionary Prototyping	operational efficiency, achieving a 100% testing success rate.
2	R.A. Carter, A.I. Anton, L. Williams, A. Dagniho (2020)	Evolving Beyond Requirements Creep: A Risk Based Evolutionary Prototyping Model	Integration of Evolutionary Prototyping and Risk Mitigation Approach (EPRAM)	Reduced software development costs and risks and demonstrated greater efficiency than traditional approaches.
3	A. Howard (2018)	PROCONCEPT: An Evolutionary Prototyping Methodology for Managing Systems Development	Large Scale System Development Using an Evolutionary Prototyping Approach	Suitable for complex projects and promotes active collaboration between users and developers.
4	Munir et al. (2020)	Analysis and Development of a Web Marketplace Prototype for UMKM Juara	Development of a Marketplace Prototype for MSMEs	Achieved 77–92% user acceptance and improved the efficiency of user requirements validation.
5	Bening (2024)	Design and Development of a Vendor Management System Prototype Using Iterative Prototyping	Iterative Prototyping of an MSME Vendor Management System	Improved feature alignment and system usability among MSME practitioners through iterative prototyping.

Source: Compiled from previous studies.

The studies summarized in Table 1 consistently indicate that Evolutionary Prototyping and Iterative Prototyping can improve the alignment between developed outputs and user requirements. Irnawati et al. (2021) demonstrated improvements in service effectiveness, while Carter et al. (2020) emphasized the potential of evolutionary prototyping to reduce development risks. Munir et al. (2020) reported relatively high levels of user acceptance, and Bening (2024) demonstrated improvements in usability and feature alignment. Collectively, these studies indicate that iterative development and direct user participation can provide important benefits in identifying and refining requirements throughout the development process.

Nevertheless, the reviewed literature remains predominantly concentrated on software development, information systems, and digital MSMEs. Limited empirical attention has been given to the implementation of Evolutionary Prototyping in physical product manufacturing, particularly in traditional or non-digital MSMEs. This represents an important research gap because physical product development involves characteristics that differ substantially from software development. Changes to a physical product may require additional raw materials, labor, machine operation, production time, and structural modifications. In furniture manufacturing, for example, a seemingly simple change in dimensions or ergonomic features may require alterations to cutting patterns, joints, assembly procedures, and finishing processes. Therefore,

the application of Evolutionary Prototyping in a semi-manual furniture MSME requires empirical examination within its specific production context.

The gap is particularly relevant to Zamrud Mebel because the enterprise operates through a combination of manual craftsmanship and machine-assisted production while facing limitations in product development resources and adaptive production practices. The application of Evolutionary Prototyping provides an opportunity to involve consumers directly in product testing and to identify design deficiencies before mass production. Through successive prototype cycles, the producer can evaluate physical characteristics, respond to user feedback, and make targeted modifications while the product is still under development. Such a process may help reduce the risks associated with producing a product that does not meet consumer expectations and may provide a more flexible mechanism for product innovation in traditional MSMEs.

Accordingly, this study aims to examine the implementation of Evolutionary Prototyping in product development at Zamrud Mebel, Gunungsitoli City, with particular attention to three aspects: (1) the stages of implementing Evolutionary Prototyping in product development, (2) the challenges encountered during the iterative development process, and (3) consumer responses to product modifications. Rather than statistically testing a causal relationship between independent and dependent variables, the study seeks to develop an in-depth understanding of the implementation process and the experiences of producers and consumers involved in the development of the product.

The contribution of this study is twofold. First, it extends the empirical discussion of Evolutionary Prototyping from its dominant application in software and information-system development to the context of physical product manufacturing in a non-digital MSME. Second, it provides practical insights into how consumer participation and iterative product refinement can be integrated into semi-manual furniture production. By examining the interaction between prototype development, consumer feedback, production constraints, and product refinement, this study seeks to demonstrate the potential of Evolutionary Prototyping as an adaptive and participatory approach for strengthening product development and competitiveness among traditional MSMEs.

Method

This study employed a descriptive qualitative case study to examine the implementation of Evolutionary Prototyping in product development at Zamrud Mebel, Gunungsitoli City. A qualitative approach was selected to obtain an in-depth understanding of the iterative product development process, production challenges, and consumer responses to product modifications.

The study involved six informants: the owner/manager of Zamrud Mebel (P1), a craftsman/production supervisor (P2), and four active consumers (K1, K2, K3, and K4). The owner and production supervisor provided information regarding production activities and prototype development, while consumers provided feedback on product functionality, comfort, design, and modifications.

The study used primary and secondary data. Primary data were obtained through direct observation and in-depth interviews with the owner, production personnel, and consumers. Secondary data consisted of company documents, photographs, production records, and relevant literature concerning Evolutionary Prototyping and product development.

The researcher served as the primary instrument, supported by an interview guide, observation sheet, and documentation. These instruments were used to collect information concerning the implementation stages, product modifications, production challenges, and consumer responses.

Table 2. Research Instrument Details

No	Research Instrument Type	Instrument User	Status	Function
1	Researcher	Researcher	Primary	Designing, conducting, and evaluating the data collection process
2	Interview Guide	Researcher	Supporting	Gathering information from production personnel and consumers
3	Observation Sheet	Researcher	Supporting	Recording activities throughout the iterative product development process
4	Documentation	Researcher	Supporting	Recording visual data in the form of notes, photographs, or evidence of product changes

Source: Authors' data.

Data were collected through observation, in-depth interviews, and documentation. Observation focused on the stages of prototype development, testing, modification, and finalization. Interviews explored the experiences, needs, and responses of production personnel and consumers, while documentation was used to support the findings obtained from observation and interviews.

The Evolutionary Prototyping process consisted of identifying user needs, developing an initial prototype, conducting functional testing, collecting user feedback, evaluating the prototype, revising the design, retesting, and finalizing the product. In this study, the Modular Ergonomic Office Chair was developed through three main cycles: initial prototype design, functional testing and feedback, and finalization and feature optimization.

Data were analyzed descriptively by organizing interview, observation, and documentation data into themes corresponding to the research objectives, namely implementation stages, product modifications, development challenges, and consumer responses. Findings from different data sources were compared to identify consistent patterns and strengthen interpretation.

The credibility of the findings was strengthened through source and technique triangulation. Source triangulation involved comparing information from the owner, production supervisor, and consumers, while technique triangulation involved comparing interview findings with observations and documentation.

Results and Discussion

Implementation of Evolutionary Prototyping

The implementation of Evolutionary Prototyping at Zamrud Mebel was conducted through an iterative product development process involving prototype development, functional testing, user feedback, evaluation, and product refinement. The process was applied to the development of a Modular Ergonomic Office Chair and involved the owner/manager, production personnel, and consumers. The findings demonstrate that product development did not proceed directly to mass production but was carried out through successive prototype cycles that allowed product deficiencies to be identified and addressed at an early stage.

Cycle I – Initial Prototype Design

The first cycle focused on developing a low-fidelity prototype emphasizing the basic physical structure and dimensions of the chair. The prototype was intentionally produced without final finishing so that its structural characteristics could be evaluated before additional resources were invested. The owner

explained that the production team first developed a rough frame using leftover wood and presented it to prospective users for direct testing. This approach allowed the producer to obtain early feedback while minimizing the consequences of potential design errors.

Cycle II – Functional Testing and User Feedback

The second cycle involved direct testing of the prototype by consumers. Feedback from K1 and K2 identified two important ergonomic problems: the backrest was considered too upright and the seat width was insufficient. These findings prompted the production team to modify the structure before final production. The ability to make adjustments at this stage illustrates the practical value of iterative prototyping because product deficiencies could be addressed while the product remained in the development phase.

Cycle III – Finalization and Feature Optimization

The third cycle focused on finalizing the approved ergonomic design and adding supporting features, including adjustable armrests and wood finishing. According to the observation results reported in the study, the gradual development process reduced raw-material waste by up to 25% compared with the conventional approach of directly producing a new product. This finding indicates the potential of early prototype testing to reduce the consequences of design errors before full production.

Challenges in the Iterative Development Process

Although the iterative approach provided opportunities for product refinement, its implementation also generated several challenges. The main challenges concerned time, human resources, and development costs. Because consumer feedback could result in structural modifications, the final completion time could not always be determined at the beginning of the development process. Changes to wooden components sometimes required cutting patterns and production stages to be repeated, increasing the workload of production personnel.

The production personnel also needed to adapt to a different working pattern. Craftsmen who were accustomed to a linear “make it once and finish it” approach initially perceived repeated dismantling, modification, and testing as additional work. Furthermore, prototype development required additional materials, labor, and machine operation. Thus, although prototyping can reduce the risk of larger losses resulting from production errors, its implementation still requires careful control of development resources.

Consumer Responses

Consumer involvement generated predominantly positive responses. Consumers reported feeling valued because their opinions were directly considered during product development. They were also willing to tolerate imperfections in the initial prototype because they understood that the prototype was intended for testing and improvement. Most importantly, consumers expressed satisfaction with the final product because modifications were made according to their physical comfort and individual requirements.

The experience of K3 illustrates this process. The consumer was able to provide a specific suggestion regarding chair height during the rough-frame stage and subsequently perceived the finished product as comfortable and appropriate for the intended work desk. This finding indicates that direct consumer participation can provide practical information that may not be identified solely through internal production evaluation.

The findings indicate that Evolutionary Prototyping can provide a practical mechanism for addressing the mismatch between product specifications and consumer needs at Zamrud Mebel. Instead of committing immediately to full production, the enterprise developed an initial prototype, exposed it to users, identified deficiencies, and subsequently modified the product. This finding is consistent with McLeod and Schell (2007), who describe evolutionary prototyping as an approach that allows requirements to be progressively identified and refined through iterative development. The present study extends this principle to a physical furniture product, demonstrating that iterative refinement can also be applied within a semi-manual manufacturing environment.

The reported reduction in material waste of up to 25% also provides an important practical indication of the potential efficiency benefits of prototype-based development. By identifying design problems before mass production, the enterprise can potentially reduce the risk of producing larger quantities of products that require substantial modification or replacement. This finding is consistent with the broader principle of cost efficiency discussed in the manuscript, in which early identification of product deficiencies can help minimize material and financial losses. However, because the study does not provide the detailed calculation underlying the 25% figure, this result should be interpreted as an observation from the case rather than as a statistically established efficiency effect.

The challenges identified in the study further demonstrate that Evolutionary Prototyping should not be understood as a cost-free or automatically efficient process. Iterative modifications may increase production time, workload, and development expenses, particularly when structural changes are required. These findings are consistent with the limitations of evolutionary approaches identified in the literature, particularly the uncertainty of development schedules and the need for continuous user participation. Carter et al. (2020), as discussed in the original manuscript, proposed limiting the number of iterations as a strategy for controlling the risks associated with repeated revisions. In the context of Zamrud Mebel, establishing clear iteration boundaries could similarly help balance product refinement with time and cost constraints.

Another important finding concerns the transferability of Evolutionary Prototyping from software-oriented contexts to physical manufacturing. Previous studies reviewed in this research predominantly examined information systems, software, and digital MSME applications. The present case demonstrates that the underlying principles—incremental development, continuous evaluation, and user feedback—can also be applied to physical furniture products. However, the implementation requires adaptation because physical products involve materials, craftsmanship, machinery, and structural modifications that are not present in the same form in software development.

Consumer participation also represents an important dimension of the findings. Consumers were not merely recipients of the finished product but participated directly in testing and refinement. Their willingness to provide feedback during the early prototype stage enabled the producer to identify specific ergonomic requirements before finalization. This finding is consistent with the principle of value co-creation proposed by Prahalad and Ramaswamy (2004), in which value can emerge through interaction and dialogue between producers and consumers. In the context of Zamrud Mebel, the prototype served as a medium for this interaction, transforming consumer feedback into concrete product modifications.

Overall, the findings suggest that Evolutionary Prototyping offers Zamrud Mebel a more adaptive alternative to conventional linear product development. Its principal value lies not simply in producing prototypes, but in establishing a structured process through which users and producers jointly identify problems, evaluate alternatives, and refine the product before final production. At the same time, successful

implementation requires appropriate management of iteration limits, production schedules, human-resource adaptation, and material costs.

Conclusion

Based on the findings of this study, it can be concluded that the implementation of *Evolutionary Prototyping* at Zamrud Mabel follows a cycle of identifying user needs, designing the product, developing a prototype, testing, collecting user feedback, evaluating, revising, retesting, and finalizing the product. This iterative process enables products to be developed in a more adaptive manner, minimizes potential errors prior to mass production, and ultimately produces products that are more closely aligned with consumer needs and expectations.

During the implementation of *Evolutionary Prototyping* at Zamrud Mabel, several challenges were encountered, particularly in terms of time, human resources, and costs. Design changes based on consumer feedback sometimes required parts of the production process to be repeated, resulting in longer completion times. The craftsmen also needed to adapt because they were previously accustomed to a one-time production approach. In addition, prototype development required additional materials, labor, and machine use. Therefore, the iteration process needs to be properly managed and limited to prevent excessive increases in production time and costs.

Users responded positively to the changes made throughout the iterative process. They were able to accept the limitations of the initial prototype and felt more involved because their feedback was taken into consideration during product improvements. These changes resulted in a final product that was better suited to users' needs and comfort, thereby increasing their satisfaction and trust in the resulting product.

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