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Exploring decision-making in manufacturing process selection: an interview study

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ABSTRACT: The manufacturing process selection (MPS) greatly influences possible design decisions regarding the product's embodiment. However, a gap remains in understanding how design engineers make these selections and what data and resources inform them. Through semi-structured interviews with engineers across various mechanical engineering industries insights into current decision-making processes are gained. The findings reveal that MPS is mostly guided by personal and collective experience, with influencing factors such as functionality and product quantities. The use of support tools remains limited. A systematic integration of data-driven tools and structured knowledge management is mostly absent. It's concluded that reliance on experiential knowledge risks overlooking alternative processes and integrating systematic tools with existing experience-based practices could enhance MPS.

KEYWORDS: design process, design for x (DfX), decision making, manufacturing process selection, interview study

1. Introduction

In the early phases of product development, foundational design and strategic decisions shape the trajectory of the entire project. In these initial stages, the majority of a product's total costs are set, with studies estimating that more than 50% of these costs are determined at this stage (Abdoli & Kara, 2020). This impact is largely due to key design choices, particularly the selection of the manufacturing process, which influences aspects such as production costs, material efficiency, and environmental footprint, including CO2 emissions from production (Medyna & Coatanéa, 2011).

Selecting the appropriate manufacturing process is therefore a critical decision within product development (Lovatt & Shercliff, 1998). Manufacturing techniques like machining, casting or additive manufacturing differ not only in efficiency but also in suitability for specific materials, production volumes, and component geometries (Shercliff & Lovatt, 2001). Decisions made here are fundamental; a misalignment between design and manufacturing capabilities can lead to costly redesigns or inefficient adaptations, potentially delaying market launch or compromising product functionality (Christophe et al., 2010).

Systematic and data-informed decision-making is thus essential for manufacturing process selection (Ghaleb et al., 2020; Khaleeq uz Zaman et al., 2017). Various support systems and tools have been developed to assist design engineers in making informed decisions regarding manufacturing process selection, factoring in technical and economic considerations, such as material properties, part complexity, tolerances, volume, and cost. The complexity of this decision-making process is clear from the extensive research on material selection alone, where multiple methodologies exist to guide engineers (Rahim et al., 2020). Within manufacturing process selection, the predominant focus has been on developing decision support systems, particularly those based on multi-criteria decision-making (MCDM) methods. Ghaleb et al. (2020) provide an overview of different MCDM approaches and how they can be applied in the context of manufacturing process selection, while Khaleeq uz Zaman et al. (2017) propose a decision methodology based on MCDM tools to select appropriate manufacturing processes. In addition to MCDM-based approaches, research has investigated the use of Ontology-Enabled Case-Based Reasoning (Mabkhot et al., 2019) and data-driven approaches (Mumali & Kałkowska, 2024), where numerous models and frameworks can be found in the literature. The data-driven approaches leverage geometric data for manufacturability analysis (Hoefer & Frank, 2018; Z. Wang & Rosen, 2023), cost optimization (Tlija & Al-Tamimi, 2023), and resource efficiency (Buchert et al., 2019). Some models also integrate geometric and additional process data to systematically eliminate unfeasible manufacturing options (Yurdakul et al., 2014). Other approaches are aiming to integrate expert knowledge into decision-support frameworks, for example through a decision-centric design process representation scheme (R. Wang et al., 2021) or through the integration of design heuristics (Kadkhoda-Ahmadi et al., 2019; Liu et al., 2020). These different approaches highlight the need for systematic and data-driven decision-making when selecting manufacturing processes and illustrate the range of methods available to help engineers tackle this complex task. The practical application and adoption within industrial contexts of the above-mentioned methods is still unclear. Questions remain about whether these theoretical approaches match the real-world decision-making processes within companies.

To understand the needs of design engineers, previous research has sought to address some of these questions through interview studies on specific challenges in design and manufacturing, such as *manufacturing fixation in design*, a tendency to favour certain processes due to organizational or experiential constraints, or the unique pressures of start-up environments, where rapid and cost-effective choices are paramount. For example, Bracken Brennan et al. (2022) found that organizational limitations and designers' familiarity with certain processes often drive process choices, sometimes at the expense of exploring innovative solutions. Budinoff & Kramer (2022) highlighted the additional constraints faced by start-ups, where decisions are often made under significant time and budget pressure. However, these studies don't focus on how decision-making may vary by industry or company size, and they provide limited insights into how designers access and utilize decision-relevant information within established companies.

The problem is the lack of understanding of how design engineers select manufacturing processes within corporate settings, along with what data and resources inform these decisions. Without a clear framework, engineers risk making suboptimal or uneconomical choices, as they must balance complex, often competing demands such as functionality, material efficiency, and production costs. Therefore, this paper seeks to address two central research questions:

> ***How do design engineers in established companies determine the manufacturing process for mechanical components and what data, resources, and decision-support tools influence this decision?***

2. Materials and methods

2.1. Scientific approach

This study primarily aimed to examine and understand the selection processes for manufacturing methods used by design and system engineers, along with the specific requirements and constraints that drive these decisions across different industries. To capture detailed insights directly from engineering practitioners, semi-structured interviews were chosen as the method of data collection. This method allowed flexibility in exploring topics deeply and enabled follow-up questions to be asked on significant points that naturally emerged during the interviews (Ahmed, 2007).

Semi-structured interviews provide a balance between structured guidance and open-ended exploration. Although a core set of questions was used to ensure consistency across interviews, the format allowed participants to expand on responses relevant to their roles and industry contexts (Hussy et al., 2013). By interviewing design engineers, system engineers, and development leads, we gathered perspectives from various organizational levels, providing a comprehensive view of the factors that influence the selection of manufacturing processes across a broad range of professional functions.

To ensure that the findings represented diverse perspectives, we recruited participants from companies of varying sizes (50 to 19.500 employees) and from industries including special machinery, power tools, plant engineering, automotive, and general mechanical engineering. This variety helped to minimize bias that might arise from the specific practices of a single industry or company. Due to the exploratory nature of the study, statistical generalizations are not the intended outcome. Instead, this approach aims to provide an overview and foster an understanding of the current selection processes, uncovering context-specific practices and information needs relevant to supporting engineers in making informed manufacturing choices. An interview guide was developed to support this exploration:

1. **Manufacturing process selection in the development process:** Participants were asked to describe how and when manufacturing processes were selected within their respective development workflows. This phase focused on identifying the stages in which manufacturing choices occur, and the typical factors influencing these choices.
2. **Company- and domain-specific requirements and supports:** This phase addressed specific requirements inherent to the participants' domains and explored any tools or support mechanisms provided by their companies to assist in manufacturing process selection.
3. **Retention of design knowledge:** The final phase focused on how design knowledge related to manufacturing processes was documented, retained, and made accessible for future use. This phase was created due to the repeated mention of experience as the most important resource in the decision-making process by Budinoff and Kramer (2022).

Based on this guide, the interviews were structured into three core themes: the timing and decision-making process of manufacturing process selection within the development process, company-specific requirements and constraints, and practices around storing design knowledge. Participants were first asked to describe the development process and the stages at which manufacturing options are considered, including who is responsible for the final decision and what factors and data influence the choice. They were also asked about variations in approach for new versus customized designs and circumstances that might prompt a change in the manufacturing process.

In discussing company-specific requirements, we also gathered insights on common restrictions and support tools used in the selection process, by asking participants to reflect on the tools' effectiveness and any challenges encountered. Finally, to understand knowledge retention practices, participants were additionally questioned to describe methods for storing and passing on design knowledge, as well as how new knowledge is built for unfamiliar manufacturing processes.

The interview guide's structured yet flexible format enabled in-depth exploration of each participant's responses, with follow-up questions tailored to uncover details specific to their experiences. This iterative questioning approach allowed the interviewer to clarify and expand upon topics as they arose, ensuring comprehensive data capture across the three focal areas.

2.2. Data analysis

After mapping the interview responses to the guiding questions, a thematic analysis was conducted (Thomas, 2006). First, we organized responses according to the core interview topics to outline the participants' approaches to manufacturing process selection, company-specific requirements, and knowledge retention. For each question, we iteratively examined responses to identify patterns of commonalities and variations across participants. We reviewed the mapped excerpts to ensure consistent and coherent themes emerged. Once key themes were established, these themes were used to address our research question, with a focus on shared factors influencing process selection and variations in approach based on context. Specifically, we noted consistent factors in the decision process and the type of data available, that multiple participants described as impacting their choice of manufacturing process. Unique responses outside the manufacturing process selection focus (e.g., company practices unrelated to design) were not included. This analysis allowed us to identify shared decision-making strategies, which provides insight into the participants' manufacturing process considerations during design.

To determine at which stage in the design process the manufacturing method is selected, responses from the interviews were aligned with the design stages defined by French (1985). According to this framework, the development process can be divided into four key stages: task clarification, conceptual design, embodiment design, and detailed design. *Task clarification* involves understanding the problem requirements and constraints, ensuring that the designer has a clear grasp of the objectives and limitations before proceeding. In the *conceptual design* stage, various innovative ideas and solutions are generated and evaluated, allowing for the exploration of multiple possibilities without going into detailed specifics. This is followed by *embodiment design*, where the selected concepts are transformed into physical forms and structures, detailing how the design will function and interact with its environment. Finally, the *detailed design* stage focuses on refining the chosen embodiment, specifying materials, dimensions, and manufacturing processes to ensure the final product meets all necessary criteria and standards.

3. Results

3.1. Study participants

We conducted semi-structured interviews with nine professionals from nine different companies, representing a broad range of expertise and company sizes. A detailed list of the participants and the companies can be found in Table 1. Interviews took place either at participants' workplaces or were conducted online, when in person meetings were not feasible. Each session lasted between 30 and 60 minutes, during which the interviewer both recorded the conversation and took supplementary notes. The recordings were subsequently transcribed to ensure accurate analysis.

The choice to conclude data collection at nine interviews was based on the consistent repetition of themes across the final interviews, indicating a sufficient depth of information had been achieved for this study's exploratory purpose.

Table 1. Data of participants of the study

Interviewee Characteristics				**Company Characteristics**	
#	*Gender*	*Job Title*	*Years of Experience*	*Sector*	*Number of Employees*
1	M	Design Engineer	3,5	Special Machinery	1100
2	M	Systems Engineer	8	Powertools	19500
3	M	Head of Development	35	Special Machinery	1200
4	M	Department Leader	20	Plant Engineering	1800
5	M	Development Engineer	13	General Mechanical Engineering	1200
6	M	Design Engineer	7	Automotive	120
7	W	Design Engineer	3,5	Special Machinery	500
8	M	Development Engineer	3	General Mechanical Engineering	50
9	M	Department Leader	9	Special Machinery	2600

3.2. Manufacturing process selection in the development process

3.2.1. Design stage for manufacturing process determination

The selection of the manufacturing process is typically established in the conceptual design stage, as reported by eight out of nine designers. Only one participant indicated that this decision occurs during the embodiment design stage. This early selection establishes a crucial foundation for subsequent design choices. According to most interviewees, the selection process begins with determining the material, which is fundamentally guided by the functional requirements of the product. The choice of manufacturing process is then influenced by this material selection, linking the two components closely. Importantly, it was often mentioned that the decision regarding the manufacturing method is often not a deliberate or active choice; rather, it is frequently predetermined by a combination of intuition and specific boundary conditions, such as the expected production quantity and cost constraints.

3.2.2. Influencing factors and data

In addition to the material selection, various other factors play a significant role in influencing this decision, including functionality, time limitations, cost considerations, tolerances, surface quality, material properties, and the expected production quantity. Each of these factors weighs differently depending on the usage context and industry, further complicating the decision-making landscape. Figure 1 lists the most frequently mentioned influencing factors, sorted by their frequency of mentioning.

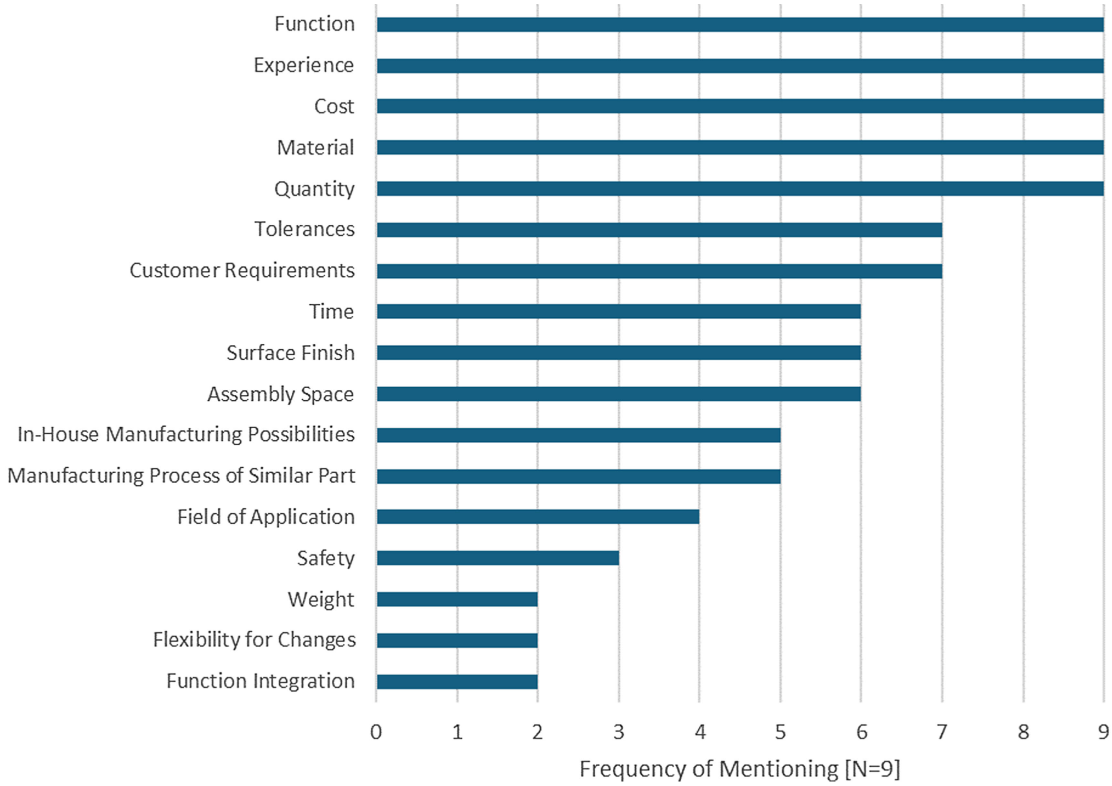

Figure 1. Factors and data influencing the manufacturing process decision, sorted by frequency of mentioning by participants

3.2.3. Experience as key ressource

Participants noted that their selections rely heavily on prior experience, which serves as a guiding principle in the decision-making process. Experience is primarily gained through collaborative exchanges with colleagues, insights from in-house production capabilities, and engagement with external manufacturers. Participants emphasized the importance of this experiential knowledge, stating that their ability to make informed decisions would be severely hampered without access to their own production facilities. As one participant articulated: *"I would struggle without my own production; there is a lot of knowledge."*

3.2.4. Support used

In addition to personal expertise and experience, participants frequently cited insights from their own production teams as valuable resources when selecting an appropriate manufacturing process. Experience and knowledge shared by in-house production teams, along with tools used occasionally by suppliers, helped to inform decisions; however, more formalized support resources, such as supplier-provided lists or design guidelines, were used sparingly. Formal support tools like Design for Manufacturing (DfM) guides were rarely applied until after the manufacturing process had already been chosen. The full list of support tools mentioned can be found below (Figure 2).

The limited availability of structured support prompted some participants to create their own documentation and guidelines *"out of necessity"*. This included lists of commonly used materials, wikis containing accumulated design knowledge, and checklists to streamline and standardize certain design choices. These ad-hoc resources represent an effort to establish internal guidelines that could reduce the dependence on informal knowledge-sharing, making design choices more consistent and informed.

A few participants also expressed an interest in developing a structured knowledge management system to capture and retain manufacturing process knowledge. While specific types of data for this system were not detailed, the desire reflects a recognized need for a centralized repository to serve both current and future design engineers, enhancing the accessibility of accumulated expertise and improving decision-making consistency.
Currently, digital tools used to support decision-making remain limited, with feasibility analyses in CAD identified as the primary data-driven method applied during process selection. While CAD-based analyses assist in evaluating the compatibility between design choices and manufacturing methods, participants did not mention using additional systematic, data-based tools during the selection. Overall, participants expressed a strong desire for more comprehensive support tools that could actively guide manufacturing process selection in the early stages.

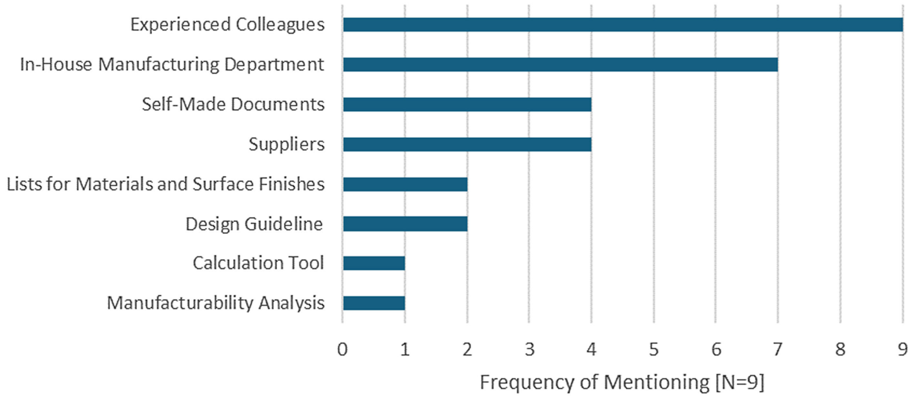

Figure 2. Support used in the manufacturing process decision, sorted by frequency of mentioning by participants

3.3. Company- and domain-specific requirements and support

In the selection of manufacturing processes, company-specific factors such as production volume and materials are primary drivers. The area of application and specific use cases also play a pivotal role, as these influence critical boundary conditions, including material selection, weight, and reparability. These factors can vary widely by industry, with each sector prioritizing different criteria based on product requirements and functional demands.
A key difference observed among companies is the degree of in-house production capability and the level of vertical integration. Companies with in-house production facilities are often able to cultivate significant expertise in manufacturing processes, but the extent to which this knowledge influences product development varies. In companies where production teams are engaged early in the development process, design issues can be identified and resolved at an early stage, enabling a smoother and more efficient transition from design to manufacturing. One study participant noted: *"You also have to go down to the manufacturing floor and work on products together with the people there in order to get to know them and then later draw on their experience and be able to approach them when problems arise and listen to their ideas"*. Conversely, other companies maintain limited interaction between design and production teams, often resulting in a more disconnected workflow where finalized drawings are handed over to production with little opportunity for input on manufacturability or potential simplifications. As one participant said: *"The exchange is: we throw our drawings to the manufacturing department and close the door and then hear nothing more about it"*.
For companies without internal production facilities, building knowledge of manufacturing processes relies heavily on external collaboration. In these cases, companies often establish knowledge by engaging in exchanges with suppliers. However, the effectiveness of this communication can be hindered if procurement departments mediate the flow of information between design teams and suppliers. To work around this limitation, some designers seek direct interactions with suppliers to discuss production requirements at the conceptual level, enabling both sides to develop a clearer understanding of feasible and optimized component designs.

3.4. Retention of design knowledge

Efforts to retain design knowledge are often limited by resource constraints, including both time and personnel. While some companies have taken initial steps to document design decisions and knowledge, these efforts are typically ad-hoc and lack the necessary support for long-term sustainability. Often, the foresight to formalize knowledge retention practices is absent, and valuable insights are lost when experienced colleagues leave, taking their expertise with them.

In some cases, modifications to designs are documented, usually noting what changes were made without detailing the rationale or context behind these decisions. While this provides a basic record, it falls short of preserving the reasoning behind design choices or capturing deeper insights that could be valuable for future projects. Participants noted that the maintenance of a knowledge database would be ideal, but such systems require ongoing effort and regular updates, which are challenging given the limited resources allocated for this purpose.

4. Discussion, outlook and limitations

The study addresses the research question by listing the used data, resources and support tools and by revealing that the selection process predominantly relies on personal and collective experience within the organization. This experiential approach has proven to be a valuable resource, allowing designers to quickly navigate decisions based on practical insights and lessons learned in the field. Engineers often turn to colleagues' expertise, which can be highly effective for making informed choices based on established methods and previously successful projects. One participant noted, *"I would struggle without my own production, there is a lot of knowledge"*, emphasizing the value of accumulated, practice-based knowledge within the company.

However, while experience serves as a solid foundation, it also has limitations, especially as products become more complex and new manufacturing methods emerge. The complexity of manufacturing process selection is compounded by the many factors that must be considered, including function, material, time, costs, tolerances, and surface quality. Given this multifactorial nature, empirical knowledge alone is insufficient to consistently meet the demands of modern design projects. One participant recounted a missed opportunity: *"Once we didn't have a manufacturing process on our radar because we thought it was too expensive for the quantities, but it was still cheap in China."* Such insights reveal that broadening the range of options through data-based tools could complement experience, ensuring that alternative processes are considered when appropriate and helping designers adapt to an evolving production landscape.

4.1. Leveraging colleagues' expertise with broader support

Colleague support is often instrumental in decision-making, as peer insights add value to the process. Nevertheless, advice from colleagues may reflect familiar methods rather than novel approaches, which may unintentionally limit innovation. As one participant noted, *"Colleagues don't know the project as well as you do"*, signalling that input, while beneficial, may not always align with specific project nuances. There is a strong need for comprehensive, data-based tools that can support design engineers by integrating diverse considerations in an objective manner. Some approaches in this area are providing support too late in the process (Hoefer & Frank, 2018; Z. Wang & Rosen, 2023; Yurdakul et al., 2014), as they require an established CAD model, which is often unavailable at the early stages when manufacturing decisions are typically made. Other methods fail to incorporate functional considerations (Buchert et al., 2019; Tlija & Al-Tamimi, 2023), despite function being identified as the most critical factor in decision-making according to the interview findings. Broadening support tools with objective, data-based elements could help engineers consider a wider array of options without replacing the collaborative value of team insights.

4.2. Risks of knowledge loss

The potential loss of valuable design knowledge when experienced engineers retire or leave the company remains a significant concern. Although some organizations attempt to document changes on drawings, the reasoning behind these adjustments is often not preserved. As one interviewee observed, *"Design knowledge is lived in processes, but not necessarily written down."* A more structured approach to retaining knowledge, such as through comprehensive knowledge-sharing systems or catalogues, could help capture essential expertise and transfer it to newer designers.

The development of structured knowledge-retention systems, such as design catalogues, decision trees, and other documentation methods, could offer a solution. However, maintaining and updating such resources requires dedicated time and resources. As one participant noted, *"Design catalogues are powerful if you actually use them; you have to maintain them and fill them with new knowledge."* Existing approaches, such as those proposed by Kadkhoda-Ahmadi et al. (2019) or Liu et al. (2020) offer methods for integrating such design heuristics into design processes, yet their adoption remains limited. Such tools could serve as a reference for new employees, reducing the learning curve and preserving the accumulated expertise within the company.

4.3. Overcoming manufacturing fixation

The study indicates that many design engineers may fixate on manufacturing processes, potentially limiting consideration of outside options or new technologies. This fixation is particularly evident in companies with extensive in-house expertise and production facilities, where reliance on internal capabilities sometimes discourages exploration of external suppliers or alternative processes. These findings coincide with those of Bracken Brennan et al. (2022). Participants acknowledged the value of a tool to counterbalance this bias: *"When you're entrenched, a tool can help open your mind, especially with in-house manufacturing."* Such support could help broaden designers' perspectives, encouraging more flexible decision-making that goes beyond internal limitations.

4.4. Tailoring support tools to industry requirements

The findings indicate that existing support tools developed in research are not widely utilized in practice. This highlights the need to investigate the underlying factors contributing to their limited adoption and to explore potential modifications that could improve their applicability and effectiveness in real-world settings. Effective decision support must consider the specific requirements and constraints of various industries. Factors such as production volume, material selection, and functional demands vary significantly across sectors, meaning that a one-size-fits-all tool is unlikely to meet the needs of every organization. Support tools that incorporate industry-specific parameters and leverage design knowledge from similar applications could offer practical solutions. This approach could also support design decisions for transfer designs, where a substantial amount of design information is already available and could be strategically applied to related projects. As one participant observed, *"You can't get carried away with every part; then you won't be able to keep up"*, emphasizing the importance of prioritizing areas for improvement.

4.5. Outlook: toward a systematic, data-driven approach

To mitigate the current limitations, there is strong potential for adopting data-driven tools that offer structured guidance without limiting creative freedom. In the future, companies may benefit from a dual approach to design knowledge management.

Firstly, by integrating data-based decision tools to support manufacturing process selection: These tools could assist engineers in exploring a wider range of manufacturing processes, comparing options across factors such as cost, scalability, and feasibility. Incorporating data-driven support into early stages of the design process could enhance flexibility and encourage the consideration of diverse manufacturing pathways. Support mechanisms should be implemented early in the development process and work with the data available at that point in time. For example, a support tool could facilitate the analysis of potential manufacturing processes based on functional schematics and spatial constraints, along with key requirements such as projected quantities and cost parameters.

And secondly, by establishing comprehensive knowledge-retention practices to capture and store the experience of seasoned engineers: *"There is a decision tree for fans, developed by an expert in our company; if everyone followed it, the expert would no longer be needed"*, said one participant, pointing to the potential for knowledge systems to make expert insights widely accessible. Large-language models offer the potential to make existing documented knowledge more accessible, reducing the need for designers to navigate extensive documentation to locate relevant insights efficiently. Such an approach would not only reinforce effective decision-making but also enhance adaptability to new manufacturing technologies, making it particularly relevant in fast-evolving industries. Additionally, systematic knowledge management practices, such as structured design catalogues and decision trees, could ensure that valuable insights from experienced designers remain accessible, fostering a culture of continuous improvement and knowledge sharing within engineering teams.

4.6. Limitations

This study is based on a rather small sample of engineers from a limited number of companies, which restricts the ability to generalize the findings. As a result, only a narrow range of influencing factors—such as company-specific practices, supply chain structures, and industry contexts—were captured, limiting the transferability of the results. Given that manufacturing process selection is shaped by numerous variables, including engineering discipline, product type, and organizational culture, a broader dataset is necessary to better represent industry-wide practices. Future research should therefore expand the scope across diverse industries to provide a more comprehensive understanding.

5. Conclusion

This study explored the intricacies of manufacturing process selection in design engineering, revealing that experience, contextual industry knowledge, and company-specific practices are central to decision-making. Our findings suggest that while experiential knowledge is a powerful and reliable resource, it is often complemented by intuition and practical heuristics. These strategies are well-suited to the high pace and complex requirements of engineering environments, especially where rapid decision-making is required. However, they also highlight areas where more systematic, data-driven tools could provide essential support, particularly in uncovering overlooked options and diversifying process strategies. One of the key challenges identified is the reliance on informal knowledge exchange among colleagues, which, while valuable, may not fully align with project-specific demands or capture evolving manufacturing options. Moreover, with limited formal documentation practices in place, critical knowledge risks being lost as experienced designers retire or leave, pointing to a clear need for enhanced knowledge-retention systems. Our study also illustrates that the presence of in-house production facilities impacts the selection process significantly, potentially encouraging a strong, though sometimes restrictive, focus on established internal capabilities. This underscores the potential of more flexible tools that can objectively evaluate both internal and external options.

Looking ahead, a balanced approach, integrating experiential insights with data-supported tools, could strengthen manufacturing process selection by expanding the range of viable options considered and supporting consistency across projects.

In summary, our research highlights that while experience-based decision-making remains indispensable, improving existing and introducing new structured tools and processes could enhance process selection practices, supporting engineers in navigating increasingly complex design requirements with greater confidence and adaptability.

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