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Integration of Design for Manufacture and Assembly with Product Design in Product Design Improvement: A Systematic Literature Review

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ABSTRACT

This paper aims to investigate and analyze some previous literature relevant to the Design for Manufacture and Assembly and Design for Safety methods in international journals. An extensive review and analysis of the body of literature was conducted to discuss the findings in a few chosen papers pertaining to the application of both methods, using a survey based on descriptive and qualitative surveys published in international journals with publication period limitations from 2011 to 2023 published in proceedings and electronic journals in English. So far, there has never been any research or literature review that discusses the Integration of Design for Manufacture and Assembly with Design for Safety.
Keyword: Design for Manufacture and Assembly, Design For Safety, Product Design

ABSTRAK

Penelitian ini bertujuan untuk menyelidiki dan menganalisis beberapa literatur sebelumnya yang relevan dengan metode *Design for Manufacture and Assembly* dan *Design for Safety* dalam jurnal internasional. Tinjauan dan analisis yang ekstensif terhadap badan literatur dilakukan untuk membahas temuan dalam beberapa jurnal yang dipilih, yang berkaitan dengan penerapan kedua metode tersebut, menggunakan survei berdasarkan survei deskriptif dan kualitatif yang diterbitkan dalam jurnal internasional dengan batasan periode publikasi dari tahun 2011 hingga 2023 yang diterbitkan dalam prosiding dan jurnal elektronik berbahasa Inggris. Sejauh ini, belum pernah ada penelitian atau tinjauan literatur yang membahas Integrasi *Design for Manufacture and Assembly* dengan *Design for Safety*.
Kata Kunci: Desain Produk, Design for Manufacture and Assembly, Design for Safety

1. Introduction

The Design for Manufacture and Assembly (DFMA) method was developed in the early 1980s and has since become widely used in both academia and industry for optimizing the manufacturing and assembly stages of product development. DFMA aims to simplify product structure, improve manufacturability and assembleability, and reduce production costs [1]. In recent years, there has been growing attention on incorporating safety considerations early into product design, as unsafe product designs can lead to occupational injuries and workplace accidents. In 2008, the Ministry of Labor and the Occupational Safety and Health Council published Design for Safety (DFS) guidelines to remove or mitigate foreseeable safety hazards in product designs [2].

While DFMA focuses on optimization for manufacturing and assembly, it does not explicitly address product safety. On the other hand, DFS provides a framework for identifying and assessing safety risks in designs, but does not offer specific guidelines for improving manufacturability or assembleability [3]. An integrated DFMA-DFS approach can lead to improved product designs that are optimized for both manufacture and safety [4]. However, research on the integration of DFMA and DFS methods in order to simultaneously improve the manufacturability, assembleability, and safety of product designs has been limited [5].

Therefore, the aim of this literature review is to examine the present status of research regarding the integration of DFMA with safety considerations during product design improvement. Specifically, this review aims to analyze existing studies on implementing integrated DFMA-DFS approaches for enhancing manufacturability, assembleability and safety in product redesigns. Key research gaps and future directions for advancing research and practice in integrated DFMA-DFS product design will also be discussed. Findings from this review can help promote safer and more efficient product designs across industrial sectors [6].

2. Design for Manufacture and Assembly

The Design for Manufacture and Assembly (DFMA) method was developed in the early 1980s by Boothroyd and Dewhurst as a structured approach for improving the manufacturability and assembleability of product designs [7]. DFMA seeks to streamline product designs and minimize costs by eliminating unnecessary parts and features [8]. Key principles of DFMA include analyzing part candidates for elimination, standardizing and interchangeable parts, design parts for ease of fabrication, design modules for clustering parts into assemblies, design parts for ease of assembly, and analyze product structure for minimum assembly steps [9]. By considering manufacturability and assembleability early in the design process, DFMA provides quantitative guidelines for reducing the number of components, simplifying component shapes, developing modular designs, and streamlining assembly processes [10]. This can lower production costs by reducing raw material usage, machining requirements, tooling needs and assembly times [11]. DFMA also has environmental implications through dematerialization and facilitating product end-of-life processes [12]. The quantified DFMA approach relies heavily on software tools for analyzing design efficiency and providing metrics to compare alternative product concepts [13]. Effective implementation of DFMA requires cross-functional coordination between design engineering, manufacturing engineering, and other stakeholders in a concurrent engineering environment [14].

3. Design for Safety

Design for Safety (DFS) provides a systematic approach for identifying, assessing, mitigating and controlling hazards and risks associated with product designs [15]. DFS emerged in the 1990s out of the field of safety engineering as a proactive method to "design out" dangers rather than relying solely on reactive approaches of warnings, instructions and training [16]. Key principles of DFS include incorporating safety considerations early in design conceptualization, taking a system-level view of potential hazards across the product lifecycle, employing risk assessment techniques to estimate and prioritize risks, and driving design decisions to reduce unacceptable risks to acceptable levels through the hierarchy of hazard controls [17]. This hierarchy involves first eliminating hazards through design selection, then implementing engineering controls such as safety features or safeguards, followed by administrative controls through procedures and policies, with personal protective equipment as a last resort [18]. Effective implementation of DFS requires coordination across design, safety engineering, risk management, and human factors domains. By considering safety early and throughout the design process, hazards can be eliminated or minimized in a cost-effective manner prior to a product being finalized and introduced into the workplace [19].

4. Integration of Design for Manufacture and Assembly with Design for Safety

Product improvement design using the integration of the DFMA (Design for Manufacture and Assembly) method with DFS (Design for Safety). The first step in the improvement process is the identification of design problems with QFD (Quality Function Deployment) analysis [20]. QFD analysis aims to collect consumer needs and expectations for the product to be improved. Integration with DFMA occurs in the design selection process (QFD Phase II), namely by using this method to find efficient design alternatives, minimize time and facilitate the production process and product installation [21]. Furthermore, in the design analysis stage, the DFS method will be used to find design improvement solutions that will minimize work accidents without reducing product quality [22]. The steps of product improvement using the integration of the Design for Manufacture and Assembly method with Design for Safety can be seen in the block diagram in Figure 1[23].

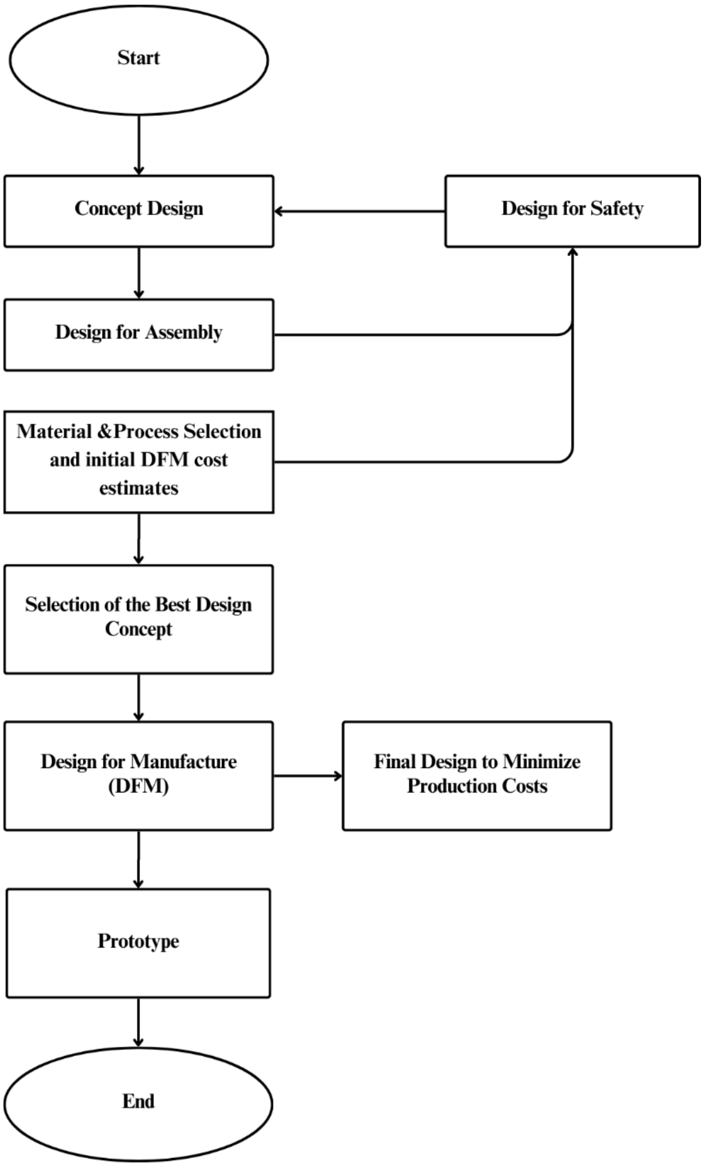

Figure 1. Steps for Integrating the Design for Manufacture and Assembly Method with Design for Safety

5. Research Methodology

In order to accomplish the goals outlined in this research, it was determined that employing a paper centered on case studies would be beneficial. Additionally, the utilization of a case study aligns with the aims of this project, aiming to diminish assembly time and costs through the Design for Manufacture and Assembly approach, as well as mitigating potential risks that could endanger the company and users via the Design for Safety methodology [24].

The methodology employed for this study encompasses five distinct phases, each serving a crucial role in the research process. The initial phase involves the definition of research questions, providing a clear framework for the investigation [25]. Following this, the second phase entails outlining the search process, specifying the parameters and criteria for identifying relevant articles [26]. The third phase is dedicated to defining the criteria for article selection, ensuring that only pertinent and high-quality sources are included in the review [27].

Moving forward, the fourth phase involves the execution of data extraction and classification. During this stage, information is systematically gathered from the selected articles, and a meticulous classification process is implemented to organize the data effectively [28]. Finally, the fifth phase involves the execution of the analysis, where the collected data is critically examined, patterns are identified, and insights are drawn to address the research questions [29].

This comprehensive approach is designed to ensure a rigorous and systematic review of the literature. Each phase plays a crucial role in the overall process, from formulating research questions to conducting a thorough analysis [30]. The following sections provide a detailed breakdown of each phase, shedding light on how the literature review was meticulously conducted to contribute to the understanding of the research topic [31].

6. Results and Discussion

Based on the information gathered, it is clear that the concept and practice of Design for Manufacture and Assembly does not only concern one component and cost, but all components and costs in the manufacture of a product to obtain effective and efficient product design improvements [13]. As shown in Table 1, there are many applications of the DFMA method in various industrial sectors.

Table 1. Application of DFMA Method in Various Industry Sectors

Year	Author	Discussion
2011	Williams et al [32]	System design revolves around three key elements: recognizing significant usage scenarios, pinpointing formwork systems, and identifying communication software components to streamline collaboration among expert users.
2014	Wang et al [33]	Incorporating 3D printing, Building Information Modeling (BIM), and augmented reality (AR) is essential for enhancing visualization throughout the product lifecycle.
2015	Bock and Linner [34]	The structural composition of the product and the information details it entails are vital for manufacturing technology to achieve its full potential.
2015	Yang and Zhao [35]	Conventional design theories and methodologies often fail to harness the enhanced design flexibility and expanded process options available. Adapting design for manufacture and assembly methodologies can empower designers to utilize products more effectively and efficiently.
2016	Wu et al [36]	BIM and 3D printing collaborate to introduce a novel approach to Design for Manufacture and Assembly (DFMA).
2016	Tang and Zhao [37]	Numerous design approaches at the product level cater to both functionality and assembly, reflecting various current design methodologies.
2016	Tang et al [37]	Establishing the groundwork for sustainable design involves integrating functionality and consolidating components. DFMA provides reduced-component designs and reduced material usage while maintaining functionality.
2016	Kim et al [38]	Interviews ascertain the acceptability of product components in accordance with DFMA criteria.

The pie chart in Figure 2 visually demonstrates a notable surge in research publications concerning Design for Manufacture and Assembly (DfMA) post-2018 compared to pre-2018. Prior to 2018, only 30% of DfMA-related research was published, whereas a substantially larger proportion, 70%, emerged thereafter. This depiction underscores the escalating interest, emphasis, and research endeavors directed towards DfMA concepts and principles in the realms of design, manufacturing, and construction in recent years. Such heightened attention likely stems from the perceived advantages of adopting DfMA practices, including enhanced efficiency, cost reduction, and superior quality control.

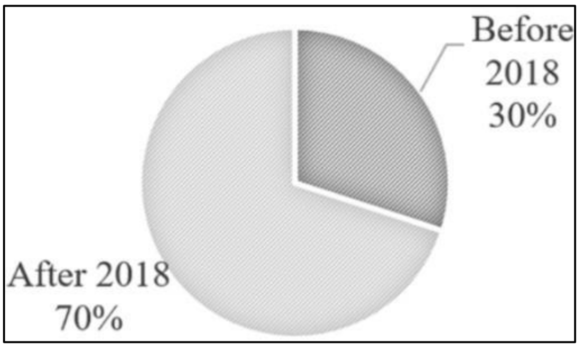

Figure 2. Diagram of The Number of Design for Manufacture and Assembly Relative Research Published Before 2018 by 30% and After 2018 by 70%.

From a human and cost perspective, safety is the most important consideration in product design. Safety during manufacturing, use and safety after product disposal are all important [39]. As shown in Table 2, there are many applications of the Design for Safety method in various industrial sectors.

Table 2. Application of DFS Method in Various Industry Sectors

Year	Author	Discussion
2015	Oney-Yazici and Dulaimi [40]	The demographic profile and safety culture of the organization significantly influenced their attitudes towards DFS. Conversely, experienced is essential to enhance designers' knowledge and comprehension of DFS.
2016	Goh and Chua [41]	Enhancing DFS knowledge and practice necessitates the implementation of additional DFS guidelines and training initiatives. Varied understandings between designers and clients can improve DFS's efficacy even more.
2016	Morrow et al [42]	It has been advised that there is a necessity for a shift in the perspectives and comprehension of many designers, and educators as well as professional bodies can play a crucial role in facilitating this change.
2016	Timvios and Gambatese [43]	Architects and engineers have highlighted economic, legal, and contractual obstacles that designers must consider when implementing DFS, whereas contractors have primarily identified economic barriers.
2017	Toh et al [44]	Three recommendations to enhance DFS implementation are as follows: 1. Enhance DFS training programs to provide comprehensive education and skill development for designers. 2. Establish DFS communities of practice to facilitate knowledge sharing, collaboration, and support among practitioners. 3. Develop DFS courses within higher education curricula to guarantee that future designers possess the required knowledge and skills to integrate DFS effectively into their work.
2018	Manu et al [45]	Although there is a strong awareness about DFS, engagement in its practices remains low. Encouraging the diffusion of DFS among design professionals will necessitate collective efforts from all key stakeholders.
2019	Manu et al [46]	High awareness of DFS does not translate into widespread practice, indicating a gap between awareness and implementation. Despite elevated interest in DFS training, engagement remains low. Notably, initiatives such as DFS awareness training, education programs, and design professional memberships have minimal impact on actual DFS practice.

Year	Author	Discussion
2020	Che Ibrahim and Belayutham [47]	Three recommendations were proposed to enhance DFS in the local context: external forces, industry dynamics, and operational organizational factors, indicating that DFS practices are still evolving.
2020	Abueisheh et al [48]	Although design professionals demonstrate a alertness and positive attitudes towards DFS, their engagement in DFS practices remains limited. Collaborative efforts among industry stakeholders are essential to enhance DFS implementation.
2021	Guo et al [49]	While existing legislation encourages collaboration on DFS and fosters a positive attitude towards it, there is room for improvement in understanding DFS. More comprehensive information regarding the description of DFS within the law, as well as the inclusion of good practice examples and case studies, could enhance knowledge and implementation of DFS.

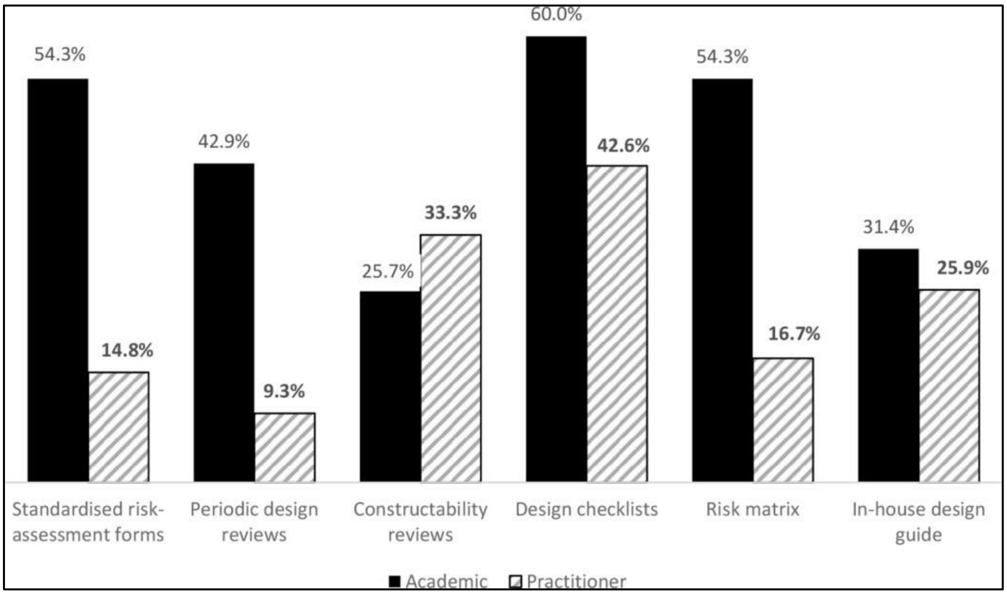

Figure 3. Tool and Resource Preferences for DFS Activities

The bar graph in Figure 3 illustrates that a majority of both academics (60.0%) and practitioners (54.3%) believe that design checklists are a key tool and resource for Design for Safety (DFS) activities. Design checklists can significantly contribute to DFS by identifying potential hazards early in the design process. Systematically, these checklists aid in recognizing and evaluating potential hazards associated with a design, preventing them from being overlooked or ignored. Furthermore, they ensure that all relevant safety considerations are addressed throughout the design process, thereby reducing the risk of accidents and injuries. The use of checklists also enhances communication and collaboration among designers, engineers, and other stakeholders involved in the design process, ensuring collective awareness of safety risks and fostering collaboration to mitigate these risks. Additionally, design checklists serve as a record of the design process, offering valuable documentation for future reference and demonstrating adherence to proper design processes. Despite the valuable role that design checklists play in DFS, it is crucial to emphasize that they are not a substitute for sound engineering judgment. Checklists should be employed in conjunction with other risk management practices such as hazard identification, risk assessment, and risk mitigation.

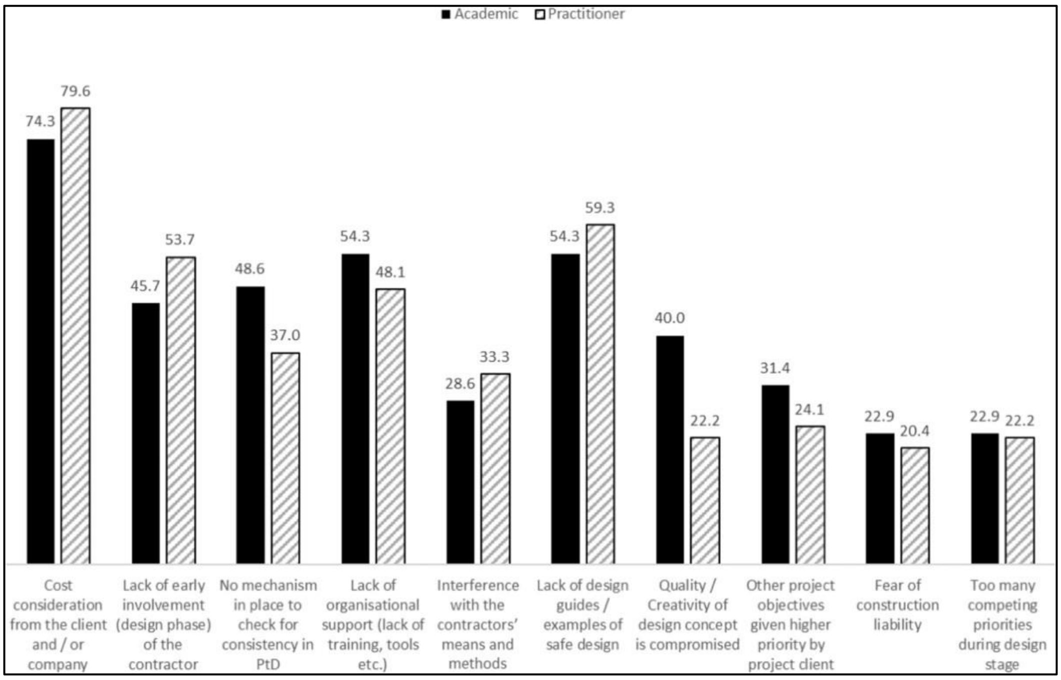

Figure 4. Anticipated Problems When Adopting DFS [47]

Figure 4, depicting results from Che Khairil Izam Che Ibrahim et al.'s 2022 survey on Design for Safety (DfS) in Malaysia, reveals a unanimous consensus among academics (60.0%) and practitioners (54.3%) regarding the pivotal role of "design checklists" as essential tools for DfS activities. Design checklists prove invaluable by systematically identifying and assessing potential hazards early in the design process, ensuring the comprehensive addressing of safety considerations, and fostering improved communication and collaboration among stakeholders. Serving as a documented record of the design process, these checklists are crucial for future reference and validation of adherence to proper design procedures. However, it is emphasized that while design checklists are valuable, they should complement, not replace, sound engineering judgment, necessitating integration with other risk management practices such as hazard identification, risk assessment, and risk mitigation.

7. Conclusion

In summary, the exploration of integrating Design for Manufacture and Assembly (DFMA) with Design for Safety (DFS) has brought to light both promising avenues and notable limitations in the existing body of literature. The identified research gaps underscore a critical need for more comprehensive investigations into the concurrent optimization of manufacturability, assembleability, and safety in product designs. While the outlined multifaceted benefits of DFMA and DFS applications across diverse industrial sectors highlight the potential impact of integrated approaches, the scarcity of specific studies addressing this integration reveals a notable weakness. The limited depth of exploration and case studies on simultaneously enhancing manufacturability, assembleability, and safety through integrated DFMA-DFS methods underscores the urgency for further empirical research. Recognizing these gaps is pivotal, emphasizing the need for future studies and practical applications to comprehensively understand the challenges and advantages associated with integrating DFMA and DFS. Therefore, the implications of this research underscore the pressing demand for more in-depth investigations to unlock the synergies between DFMA and DFS for more holistic and efficient product designs, while also recognizing and addressing the current limitations in the available literature.

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