Green Product Design to Reduce Environmental Impacts on Product Life Cycle: A Case Study

Tham Sook Chan
Politeknik Port Dickson, Negeri Sembilan
sookchan@polipd.edu.my

Shajahan Maidin
Universiti Teknikal Malaysia Melaka, Melaka
shajahan@utem.edu.my

Muhammad Syakiran Lokman
Dormakaba Production Malaysia Sdn Bhd, Melaka
muhammadsyakiran.lokman@dormakaba.com

Muhammad Afiq Mohd Hashim
Dormakaba Production Malaysia Sdn Bhd, Melaka
muhammadafiq.mohdhashim@dormakaba.com

Abstract
Sustainable design is an advanced manufacturing technique that takes into account the environment's impact and resource efficiency and is seen as driving the modern manufacturing process. It is a method of developing products and services that take into account environmental, social, and economic factors from the beginning to its end-of-life. However, the current state of global furniture production, including technology and development strategies, has not been thoroughly examined. In addition, a comprehensive furniture industry sustainable manufacturing system is lacking. This paper discussed a systematic literature review on the sustainable design concept for furniture. It is based on an initial review of works of literature on the manufacturing process and implications of life cycle assessment in furniture and consists of data identification, initial screening, eligibility determination, and final inclusion. This study will serve as a guide for implementing life cycle assessment to improve environmental design, particularly for furniture manufacturing. It will also use the Design for Assembly (DFA) and Design for X (DFX) methodologies to reduce environmental impacts throughout its life cycle. In addition, it serves as a resource for global furniture companies to aid in sustainable furniture development.

Keywords: Furniture, Sustainable Design, Design for Environment (DFE), Design for Assembly (DFA)

1.0 Introduction

This research reviews the existing literature and examines the available literature on sustainable product design and production principles, specifically for the furniture sector, by considering environmental factors during the life-cycle development process. The four steps of the Life Cycle Assessment (LCA) are introduced and discussed. Following that, the notion of furniture sustainability is identified. The current body of knowledge regarding various LCA approaches to the furniture business is explored through academic publications from various nations. Most studies encompass and use a cradle-to-grave approach to product life, starting with raw material supply and ending with product disposal (Tamoor et al. 2022; Aydin, 2018). This part also includes an overview of the literature on DFA, DFE, and sustainability and their definitions. As a result, product designers must pay close attention at an early stage to ensure that sustainable design becomes one of the alternative methods for decreasing environmental damage. The goal of the review was to provide insight into the possibilities of applying sustainability in the furniture industry and encourage discussion about the relationship between the concept of sustainable product design and environmental design aspects during the furniture industry's lifecycle development process. A few methods and concepts of sustainable design can be highlighted from the case studies analyzed, which could help the furniture business development while reducing its environmental impact.

Previous studies showed that materials used in chair production are poor are not good in quality (Al-Hinai et al., 2018; Luthfini Lubis & Vivi Putri, 2020). Complaints from customers have been received that they are not satisfied specifically with the quality of the student chair. The steel legs of the chair are easy to bend, and the plastic seat is too rough and not comfortable to sit on. The production cost for the previous student chair is relatively cheap, which is why all the parts are low in quality material. Customers are not satisfied with the previous chair because it could not last long and it is not lasting durable. So, to overcome this, it can be suggested to use high-quality materials at affordable prices. According to this scenario, the drive for green product design, production, and technology that can safeguard the planet from harm—whether it comes from humans or any activities that follow—is currently in full swing. Engineers or product designers now must think about how to design products that can incorporate all the ideas associated with sustainability and the green environment. Thus, the objectives of this paper are:

i. To propose a sustainable design method that may be implemented to reduce environmental impacts during the product life cycle of selected furniture.
ii. To establish and share the concepts, principles, and techniques of product design on environmental legislation, materials conservation and environmental management.

2.0 Literature Review

The practical features of sustainable product design include minimal material use, better material selection, design for product reuse and disassembly ease, low energy consumption, manufacturing without producing hazardous wastes, and use of clean technology (Xiong et al., 2020). Additionally, Design for Manufacture and Assembly (DFMA) supports Design for Environment (DFE) in its implementation, particularly during product recycling and recovery stages. By applying DFMA early in the design process and streamlining the design, in addition to supporting DFE, DFMA decreases costs and product development time by decreasing the number of design adjustments at the manufacturing stage (Antony and Subbaiah, 2020; Subbaiah & Antony, 2021; Thajudeen et al., 2022). Hence, the literature has been reviewed from the perspectives of DFMA, DFE, and Life Cycle Assessment (LCA).

2.1 Design for Manufacture and Assembly (DFMA)

In the early 1970s, Dr. G. Boothroyd and Dr. P. Dewhurst were the first to work on DFMA, and Boothroyd Dewhurst Inc. was started in 1982. They created software to apply DFMA, which is used in various sectors to improve assembly and manufacturing processes. As a result, Design for Manufacturing and Assembly combines DFM and DFA. It can be described as how simple it is to make and construct a thing. Early in the design process, challenges in assembly and manufacturing that potentially affect the final outputs are investigated. The extra time spent in the initial stages of design could result in a significant reduction in the product's cost. The limits of the manufacturing process are recognized early in the design process in DFM. DFA is used in the next phase. DFA is a design methodology in which the designer analyses, estimates, plans, and simulates the product to make the assembly process easier in terms of time and cost. The design could be revised multiple times during DFA until the assembly process is satisfied without harming the product's operation (Boothroyd, Dewhurst, and Knight 2011; Schmidt 1998). Several studies have discovered that beginning in 2015, they have used the DFMA principle in developing the product. Sudin et al. (2016), for example, used DFMA approaches to redesign a dry iron. In the redesigned dry iron, the number of parts was reduced from 20 to 16. As a result, the assembly time was reduced by 23.75% and the design efficiency increased from 8.82% to 10.34 %.

The DFMA method was used by Ferryanto et al. (2017) to improve the design of a prosthetic knee. As a result, the number of parts and assembly time was reduced. The assembly time was cut by 36.5%, but the DFA index was raised by 78%. The structural integrity of the new prosthetic knee was next examined. According to the simulation results, the improved design could safely manage the applied load without failing. Naiju, Jayakrishnan, and Warrier (2017) used DFMA to rebuild the pedestal fan without sacrificing quality. The overall assembly time was decreased by 15.17% and the total cost of the fan was cut by 7% which proved to be a significant financial profit for the manufacturer for mass manufacturing. Suresh, Ramabalan, and Natarajan (2015) designed the engine bracket using the DFMA approach to reduce the component's part count and weight. By eliminating unneeded fasteners, the number of parts in the revised one was reduced by 33.33%. As a result, the product's total weight was lowered by 39.13%. Similar to Zivkovic and Curcic (2017), they demonstrated the automatic implementation of DFMA concepts in designing a wind tunnel for the Military Technical Institute. In the design of a raincoat with thermal protection, Pinheiro et al. (2018) used DFMA and computer simulation methodologies. Because of the shorter lead time and lower resource utilization, DFMA provided a better solution, which resulted in higher production. It also resulted in lower part numbers, part standardization (staples were replaced with seam and thread), and ease of assembly (Styrofoam mosaic was replaced by granules in the raincoat).

Samsudin et al. (2018) used the DFMA approach to analyze the design of the XPB42-688 compact washing machine. There were thirty-seven parts in the modified tiny washing machine, compared to 43 in the original design. As a result, the part count reduction is 13.95%. This resulted in a 14.5% increase in design efficiency. Rahman et al. (2019) studied the design of a baby stroller (Sweet Cherry SCR8 Series). The assembly time was decreased by 452.29s when DFMA was implemented, which is 23% less than the original design. From 179 to 149, the total number of parts was reduced. The DFA index rose from 9.6 to 12.6 because of this. The use of DFMA for redesigning prefabricated bridge elements was investigated by Safaa, Hatmoko, and Purwanggono (2019). It was possible to obtain a design efficiency of 28.83%, an 8.71% reduction in the number of components, and a 25% reduction in the ease of handling. In addition, assembly time efficiency improved by 51.53%, and the cost of the rebuilt bridge decreased by 23.39%.

The DFMA technique was used by Mangera et al. (2019) to design a pediatric prosthetic knee. A finite element analysis tool was used to verify the modified model. Assembly efficiency increased by 13.6%, resulting in lower production and labor costs. Thus, it is noted that the DFMA technique is successfully utilized in the product design process to meet its objectives. Due to time constraints, this research only focuses on the DFA approach as a starting point in the redesign effort.

2.2 Sustainability and Design for Environment (DFE)

In the context of product design, sustainability refers to the creation of goods that have a minimal environmental effect, a high economic growth rate, and societal advantages. Industries must strive to create items that can be reused, recycled, and disposed of securely. They must also seek to reduce the number of materials, energy, and emissions used.

Over the last two decades, a change in the product design method has been witnessed. Green design was a term used to describe a product design strategy that included environmental considerations. Later, names like eco-design (environmentally friendly design, as used in Europe) and DFE (Design for Environment, as used in the United States) were applied. Both eco-design and the DFE are limited to decreasing environmental consequences. DFE included environmental concerns in one of the stages of a product's life cycle, but eco-design's scope spans the entire life cycle of a product.

The term "sustainable design" is now widely used and approved worldwide. Sustainable design considers environmental, economic, and societal factors when developing and designing products (He et al., 2020). There is a range of eco-design tools available, ranging from simple to complex, quantitative, and time-consuming. Several of them do extensive computations to evaluate the sustainability and make recommendations for improving the product's sustainability performance (Campos-Guzmán et al. 2019).

Primary qualitative analysis is conducted with simple techniques from which ideas are derived to improve the product's design (Ahmad et al., 2018). Several authors assigned different classifications to these eco-design tools. Frameworks, checklists, recommendations grading and ranking approaches, analytical tools, software, expert systems, and organizing methodologies were all classified as eco-design tools by Varžinskas et al. (2020). Kim and Moon (2017) divided them into four categories: guidelines/standards, checklists, comparison tools, and analytical approaches. More information on the tools described in this section can be found in the appropriate sources, as they are outside the scope of this paper. Several authors have worked on incorporating sustainability into product design. Lacasa et al. (2015) used sustainability factors in developing solar trackers with minimal power requirements and airbrushes for precision work. The amount of material used, the amount of energy used, and the amount of time it took to process the material were all lowered. As a result, energy consumption and global warming are reduced. In the situations of solar tracker and airbrush design, a decrease of 20% in eco-design indicators was achieved by reducing the total mass of the product by 40%. Suresh, Ramabalan, and Natarajan (2015) designed a connecting rod with the sustainability principle. The environmental effect was lowered by 25% by reducing the product's weight by 35%. Suresh, Ramabalan, and Natarajan (2016) used the sustainable concept to develop a single component, the pulley, with a low environmental impact. Using a sustainable design approach, the environmental effect was decreased by 45%.

2.3 Design for X (DFX)

The design stage is especially important because many decisions are made at this stage that affects downstream development activities and product costs. In cases wherein a widespread business product needs to pass through all the stages comprising its existence, and wherein design strongly impacts the product`s overall performance in every phase, there has currently been developing an interest in a brand-new methodological method known as Design for X (DFX) (Fabio et al., 2019).

Design for X (DFX) is a set of targeted design methodologies that help product developers solve specific engineering challenges, such as manufacturability, assimilability, maintainability, sustainability, and recyclability (Favi et al., 2022). These days, DFX has become a design system comprised of tools and methods that help make decisions, perform diverse types of analysis, and quantify the effectiveness of design options with the help of appropriate metrics. These tools can take many forms, ranging from instruction sets to detailed procedures using analytical models, sometimes implemented in programs (Fabio et al., 2019).

Each tool in the DFX system should provide designers with a structured way to make the most effective use of a set of product-specific information the tool will examine. Thus, DFX can be understood as a system of knowledge in which knowledge of how the individual properties of the engineering system have been acquired during the design process has been (or can be) collected and organized into appropriate forms. Technical system properties acquired during the design process, which are the expression of product requirements, become objective properties of various DFX tools, taking their name. Numerous design concepts/methods for DFX have been developed over the years to increase design efficiency and reduce overall product costs and development lead times.

According to Fabio et al. (2019), some critical objective attributes as shown in Figure 1 (and thus the corresponding tools and techniques of the DFX system) can be grouped by the stage of the product life cycle where they are most precisely applied. DFX techniques consist of three (3) phases, which are:

Manufacturing phase:

- Design for Productivity / Manufacturability — Design components and build systems based on machining.

- Design for Assembly — Designed to facilitate assembly, reducing assembly time and error potential
- Design for Variety — Design for product diversity, achieved by defining and optimizing base models, to provide flexible product architectures that ensure variety to match market needs
- Design for Durability/Quality — Component design reduces product susceptibility to uncontrolled disturbances (machining errors and unforeseen operating conditions) and product quality assurance.

Use phase:

- Design for Reliability - Design components and systems to improve the reliability of repair and maintenance contractors, to promote repair or intervention to eliminate the possibility of failure (e.g., replacement of worn parts).
- Design for Safety - Design aimed at controlling safety standards and preventing malfunctions during use.

Product end-life phases:

- Design for Product disposal - Design toward strategic planning for disposal and recovery at the end of the product's life.

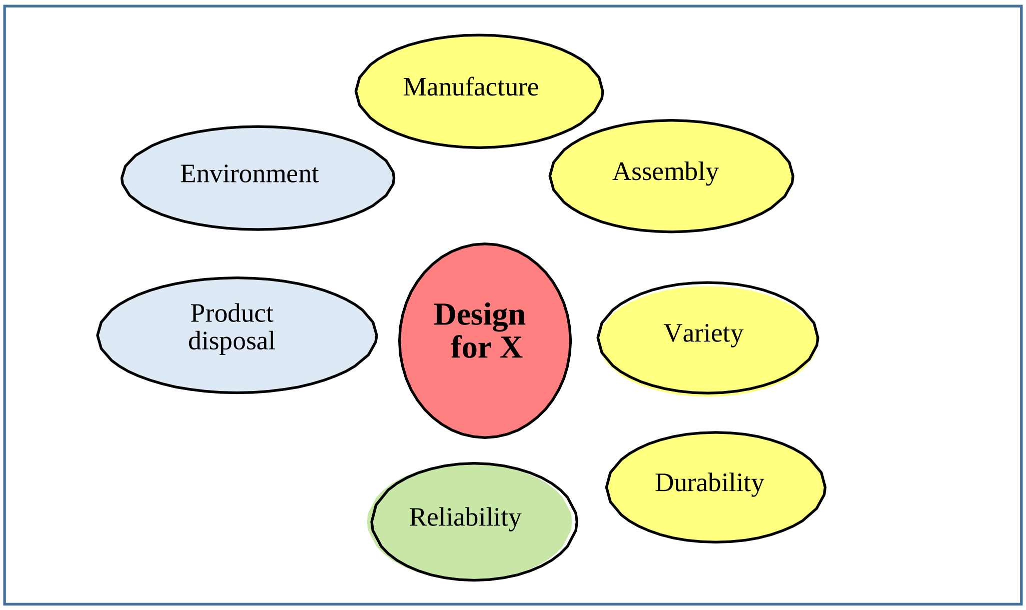

Figure 1: DFX product requirement (Fabio et al., 2019)

2.4 Life Cycle Assessment (LCA)

LCA is one of the numerous environmental management strategies that can be used as part of a much larger decision-making process, which ISO 14040 defines as "the collection and evaluation of all inputs, outputs, and potential environmental consequences of a product system throughout its life cycle" (ISO, 2006). LCA is a technique for examining a product's, processes, or service's cradle-to-grave environmental implications and making environmentally responsible decisions. LCA includes four phases, goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation.

2.4.1 Product life cycle in product development process

Gaining knowledge of the product's life cycle is a key stage in systematic environmental improvement. Product life thinking is the term for this activity. Product life thinking entails a methodical and active mapping of each stage of a product's life cycle and the many stakeholders and scenarios the product is likely to encounter. The product life cycle stages (PLC) begin with its development and launch and progress through its withdrawal or final demise, and it must follow its life cycle procedure. Early in the project, this comprehensive approach to product development provides the company with valuable knowledge about life cycle stages, such as the product's use stage. When the product life cycle is presented to the product creator, environmental issues and potential solutions for the entire life cycle can be identified. Product life thinking can ensure that a company's environmental responsibility is integrated into the manufacturing processes, logistics, and actual use of products introduced onto the market as environmental demands on a company's operations and products expand.

Figures 2 and 3 depict product life cycles used in some of the scholarly studies included in this review. In most studies, the complete supply chain was studied, from the cradle to the grave, including the phases of raw material supply, manufacture, distribution, usage, and disposal of the product, where the product creation process begins before the product is delivered to the consumer.

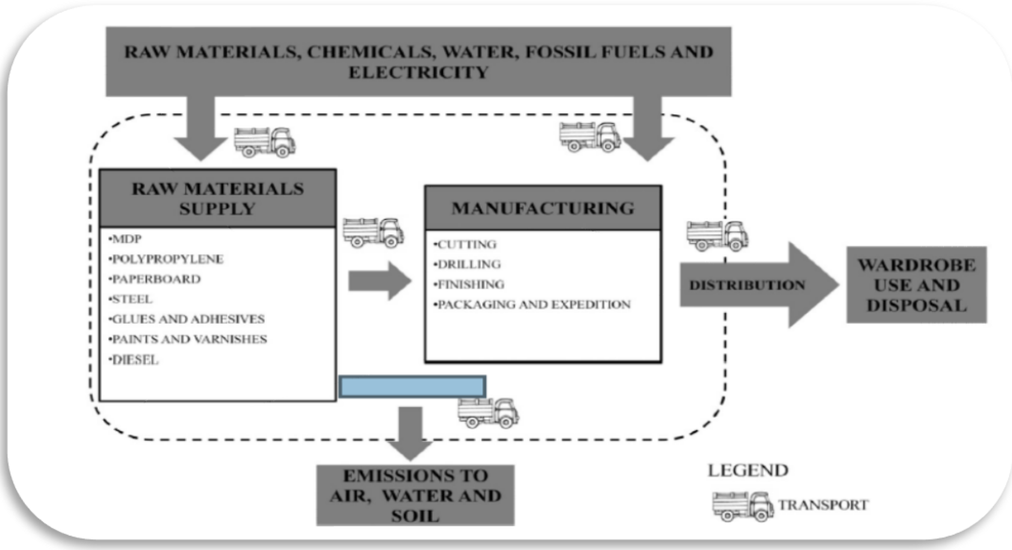

Figure 2: Product system of the production of the wardrobe includes its life cycle (Iritani et al., 2015)

From a cradle-to-gate perspective, it has three primary stages, as shown in Figure 2: raw materials supply, manufacturing, and product distribution. However, the product's use and end-of-life phases are not considered inside the product system's bounds. Figure 3, on the other hand, as eco-design objects that consider the product's entire life cycle, depicts the production phases and critical players in both the conventional and sustainable design processes. The figure's continuous lines represent the traditional design process, while the dashed lines depict how actors should be involved in a long-term process. The dotted line depicts the influence on society and the environment due to the primary impact.

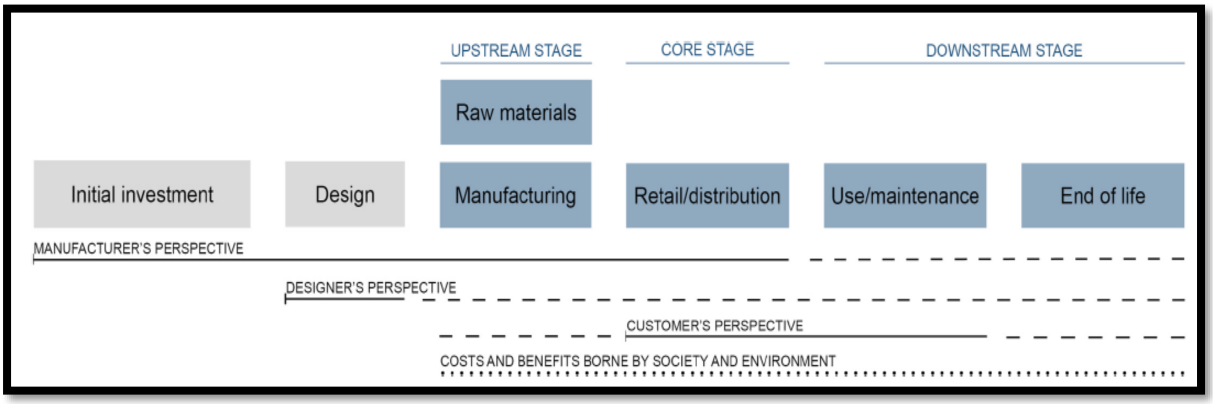

Figure 3: Life cycle of a piece of furniture and the main actors involved in the process (Bianco et al., 2021)

3.0 Methodology

In this section, the proposed project for product design can integrate all the values related to the green environment and the sustainability of products. The chair study is chosen – a popular product with a different design, materials, quality, production process, and prices. Using the DFA methods can contribute to reduce environmental impacts during the product life cycle.

3.1 Product Design Study (Current Design)

For students to feel more at ease and be able to focus while studying, a classroom chair is critical. Because of this, the engineering and design of a chair are considered particularly significant from the viewpoints of the student’s comfort and usability (Al-Hinai et al., 2018). The current chair design, as shown in Figure 4, is thought not to have any substantial adverse effects on the environment from an environmental standpoint. Most of the materials and resources employed in the chair's construction must be eco-friendly. Raw materials and harmful chemicals that can harm environment shouldn't be used, such as paint and glue. Table 1 and Figure 4 depict the type of materials and physical look of typical student chair used in a classroom. It can see that obviously metal and plastic are used to fabricate and produce furniture. However, this material is not so suitable because it is hardened and expensive to manufacture, yet these materials possibly generate various emissions and toxic that contribute to pollution to the environment thru its product life cycle.

Table 1: Student chair components with quantity

No.	Component	Material	Quantity
1	Chair leg frame	Steel	1
2	Backrest frame	Steel	1
3	Seat	Polypropylene (PP)	1
4	Backrest	Polypropylene (PP)	1
5	Rivet	Aluminium	6
		Total	10

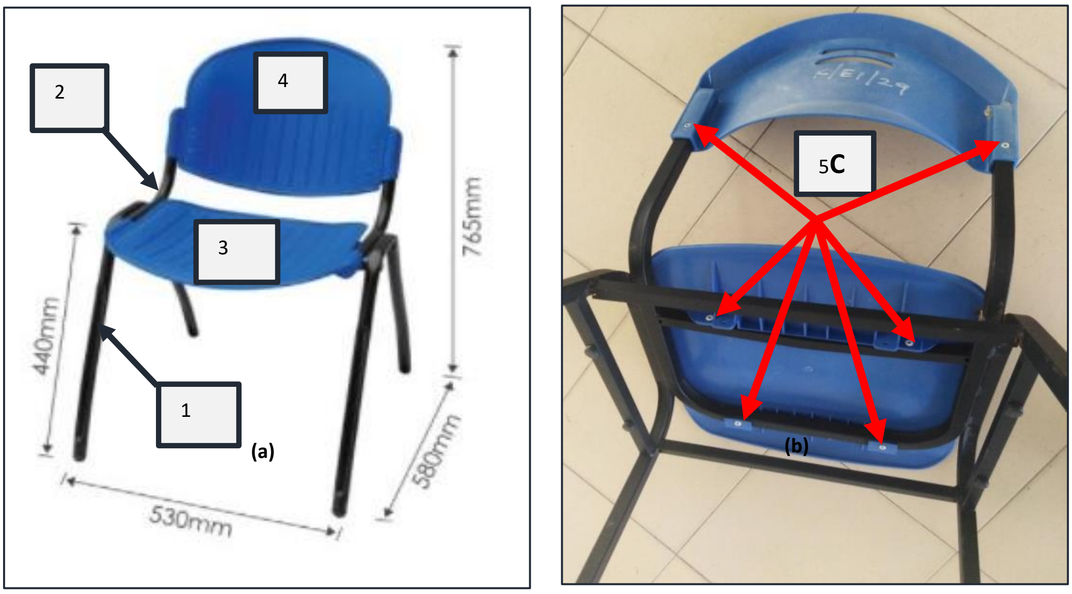

Figure 4: Student chair current design (a) Front view of the chair with item label. (b) Rivet's position at the current student chair.

3.2 DFA Methodology

The implementation of this methodology gives four interesting indicators: product assembly time, product assembly cost, the minimum number of components, and design efficiency (Ezpeleta et al., 2019). DFA analysis is to evaluate the efficiency of an assembly, unleash creativity to improve the assembly and compare alternate design approaches (Bill Devenish et al., 2016). The aim of this methodology for product design improvement is to reduce the number of parts, combine two or more parts into one, reduce or eliminate adjustments, simplify assembly operations, design for parts handling, select fasteners for ease of assembly, and minimize parts tangling.

All four stages of the product design process, particularly the embodiment stage, should consider Design for Assembly (DFA). Without a methodology to quantify an engineering product design, it can be challenging to examine and compare design solutions in a methodical manner. Boothroyd and Dewhurst developed a system to quantify a design using straightforward hand assembly procedures to solve this problem. The classification system that Boothroyd and Dewhurst developed systematically quantifies features' impact on the manual handling of the item during assembly. They separated the categorization and assembling techniques into two primary groups. By allotting time for each action, manual handling and manual insertion were assessed according to how challenging they were to handle and insert. Complete classification and definition can be found in their book - "Product design for manufacture and assembly" (Boothroyd Dewhurst Inc 1999).

4.0 Result and Finding

Based on this study's method, the DFA method will describe the total cost and time for assembly for the product design (Ezpeleta et al., 2021). Table 2 shows that the entire assembly cost is 114.814 cents, while the design efficiency for this current product design is 12.53%. Based on the result from the DFA method, it is not only can use to justify the cost and assembly time of the product, but for the future design proposal, it also works to propose improvement by reducing the material, the number of parts, combining the two-part become single part and can simplify assembly operation for project improvement to reduce environmental impact.

Table 2: Current Product Result

No.	Part Name	Number of Parts	Theoretical Part Count	Estimate Insertion Time (sec per item)	Estimate Handling Time (sec per item)	Assembly Time, (sec)	Assembly Cost, (cents)
1	Chair leg frame	1	1	1.5	1.95	3.45	4.7955
2	Backrest frame	1	0	12	1.95	13.95	19.3905
3	Seat	1	1	1.5	1.95	3.45	4.7955
4	Backrest	1	1	7	1.95	8.95	12.4405
5	Rivet	6	0	7	1.8	52.8	73.392
TOTAL		10	3	TOTAL		82.6	114.814

Labour rate:

RM/hour = 50 (assumption)
Cents/second = 1.39
Design Eff, E_{ma} = $N_{min} \times t_a / t_{ma}$
= 0.1253 = 12.53%

Design efficiency with a value between 10 – 20% indicates that the product design can be designed better, giving room for improvement. Items 5 and 2 from Table 2, which displayed a high number in assembly time and assembly cost, could eliminate the part or with a better replacement for the parts, as will be discussed further in the next section.

4.1 Proposed Project Improvement

Based on the current product design, chair improvement can be made by reducing the material, and the number of parts, combining the two-part become a single part and simplifying assembly operation for project improvement for future chair design to reduce environmental impact.

4.1.1 New design

As shown in Figure 5, the proposed design eliminates the fastener (for this case, rivets were applied in the current design) by applying a slot in the design for the backrest and seat. This suggestion will help to reduce the assembly time to 28.7 sec per product, as shown in Table 3. Reducing assembly time means reducing the number of operations too.

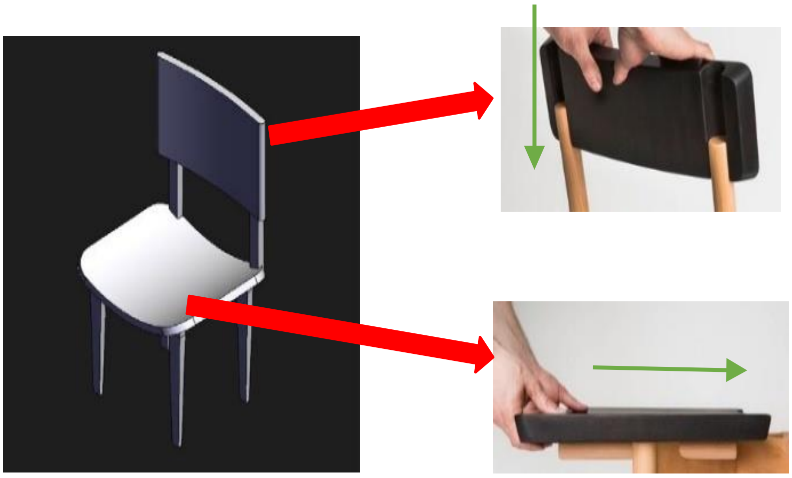

Figure 5: Proposed Design for Improvement

4.1.2 DFA Methodology

Based on the design proposed for improvement, the result in Table 3 shows the improvement in design efficiency from 12.53% to 57.49%. This design proposal also manages to eliminate and combine parts from 10 parts (current design) to become 3 parts (new design) after design improvement was performed through Boothroyd and Dewhurst DFA methodology. Again, assembly time was success reduced from 82.6 seconds to 28.7 seconds.

Table 3: Product Improvement Result

No.	Part Name	Number of Parts	Theoretical Part Count	Estimate Insertion Time (sec per item)	Estimate Handling Time (sec per item)	Assembly Time, (sec)	Assembly Cost, (cents)
1	Chair leg frame	1	1	1.5	4	5.5	7.645
2	Seat	1	1	6	5.6	11.6	16.124
3	Backrest	1	1	6	5.6	11.6	16.124
Total		3	3	Total		28.7	39.893

Labour rate:

RM/hour = 50

Cents/second = 1.39

Design Eff, E_{ma} = $N_{min} \times t_a / t_{ma}$

= 0.5749

= 57.5%

4.1.3 Life cycle phase improvement for material

Based on the LCP, improvements can be made to reduce the environmental impact by using a low-impact material on the environment and planning material recycling at end of use. Product material of student chair seat and backrest - Polypropylene can be replaced by using fiber composite material such as natural fiber composites. In the past 10 years, there has been a significant increase in interest in utilizing natural fibers with polymer matrices made from nonrenewable and renewable resources to create polymer composites that are competitive with synthetic composites (Karimah et al., 2021). Due to their advantages over synthetic fibers, such as reduced weight, recyclability with low cost, less damage to processing machinery, the improved surface quality of composite molded components, good mechanical properties, and widespread availability, natural fibers are more effective materials (Shahruzzaman et al., 2019).

From plastic waste, polypropylene material can be recycled to become raw material for the 3D printing process (Mikula et al., 2021) and as another alternative to make new product furniture. The recycling process of 3D printing materials is shown in Figure 6 and Figure 7 shows products printed with recycled material.

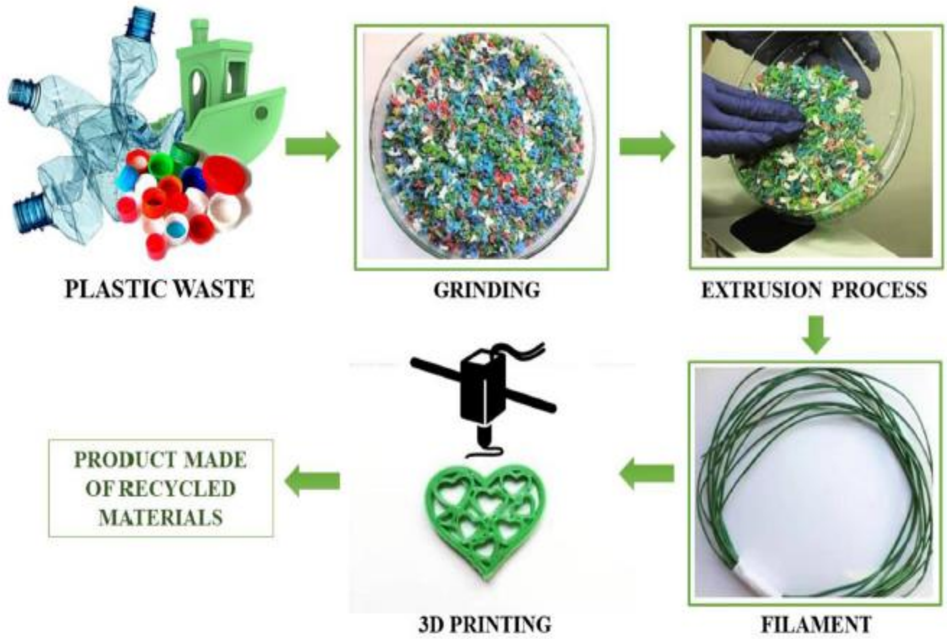

Figure 6: Recycling Process (Mikula et al., 2021)

Figure 7: New Product from recycled material (Sheth, 2021)

Due to their improved formability, renewability, cost-effectiveness, and growing environmental awareness, natural fiber composite materials or eco-friendly composites have recently attracted much attention in research and development. Composites constructed of bamboo, wood, straw, sawdust, rice hulls, and other natural fibers are some examples of natural fiber-based composites (Shahruzzaman et al., 2019). These materials are emerging significantly as prospective materials for key industry participants, including the furniture industry. Due to the limitation of the study, the proposed materials can be further analyzed in future research. Validation of the design efficiency of `improved products can be enhanced through the aid of DFMA software and various analysis thru well-established CAD software such as Solid Work, Catia, etc.

5.0 Conclusion

Based on the DFA approach, it shows that the number of parts can be redesigned and reduced from 10 parts to 3 parts only (approximately 70% of reduction). With the reduction of parts, this study also simplifies and reduces the assembly operation time from 82.6 seconds to 28.7 seconds (approximately 65.25% of reduction). The assembly cost is reduced from 114.81 to 39.89 cents (approximately 65.26% of savings). In line with the stated objectives, the environmental impacts can be reduced by reducing the number of parts needed to produce the chair. DFA is a cost-saving tool that focuses on lowering the cost of product assembly by minimizing the number of parts, the number of assembly processes required to manufacture the part and by making these assembly activities as simple and error-proof as feasible. Any assembly activity has fewer chances to fail, thanks to DFA. This inevitably results in higher-quality designs, production processes, and significant cost savings. The DFA method found it worked here for this case study by increasing the design efficiency much better as compared to its old design.

References

Ahmad, S., Wong, K. Y., Tseng, M. L. and Wong, W. P. (2018). Sustainable product design and development: A review of tools, applications and research prospects. *Resources, Conservation and Recycling* 132, 49–61. doi:10.1016/j.resconrec.2018.01.020.

Al-Hinai, N. & Al Kindi, M. & Shamsuzzoha, A. (2018). An Ergonomic Student Chair Design and Engineering for Classroom Environment. *International Journal of Mechanical Engineering and Robotics Research*, 7 (5). 534-543. 10.18178/ijmerr.7.5.534-543.

Antony, K. M., and Subbaiah, A. (2020). DFMA and sustainability in product design. *IOP Conference Series: Journal of Physics: Conference Series 1455: 012028*. doi:10.1088/1742-6596/1455/1/012028.

Aydin, E. G. 2018. Designing for sustainability: A comparative analysis of steel and wood based furniture. Master Thesis. LUT School of Energy Systems, Lappenranta University of Technology.

Azri, N. M., Effendi, M. S. M. and Rosli, M. F. (2018). Preliminary studies on DFMA and sustainable design approach: A case study on a cordless drill. *AIP Conference Proceedings 2030 (1): 020069*. doi:10.1063/1.5066710.

Bianco, I., Thiébat, F., Carbonaro, C., Pagliolico, S., Blengini, G. A., & Comino, E. (2021). Life Cycle Assessment (LCA)-based tools for the eco-design of wooden furniture. *Journal of Cleaner Production,* 324, 129249. https://doi.org/10.1016/J.JCLEPRO.2021.129249

Bill Devenish. (2016). *Conducting a Step-By-Step DFA Analysis*. Melbourne: L3Harris Technologies.

Boothroyd, G., Dewhurst, P., & Knight, W. A. (2011). *Product design for Manufacture and Assembly*. London: CRC Press.

Campos-Guzmán, V., García-Cáscales, M. S., Espinosa, N., & Urbina, A. (2019). Life Cycle Analysis with Multi-Criteria Decision Making: A review of approaches for the sustainability evaluation of renewable energy technologies. *Renewable and Sustainable Energy Reviews*, 104, 343-366.

Chowdary, B. V., Richards, M. and Gokool, T. (2019). An integrated approach of sustainable product design: Concurrent application of DFMA, DFE and CAD/CAE principles and tools. *Latin American Journal of Management for Sustainable Development,* 4 (4): 259 –275.

Deepak, B. B. V. L., Parhi, D. R. K. and Jena, P. C. (2019). Select proceedings of First International Conference on Innovative product design and intelligent manufacturing systems. In *Lecture Notes in Mechanical Engineering*, 1–1049. Singapore: Springer. doi: 10.1007/978-981-15-2696-1.

Ezpeleta, I., Justel, D., Bereau, U., & Zubelzu, J. (2019). DFA-SPDP, a new DFA method to improve the assembly during all the product development phases. *ProcediaCIRP,* 84, 673 – 679.

Ezpeleta, I., Pujana, U., Isasa, I., Ayerbe, J., & Justel, D. (2021). New design for assembly (DfA) methodology for large and heavy parts assembled on site. *ProcediaCIRP*, 100, 145–150.

Fabio, G., Rosa, G.L., and Risitano, A. (2019). *Product Design for the Environment*. CRC Press, Taylor & Francis Group.

Fatima, S. B. A. Effendi, M. S. M. and Rosli, M. F. (2018). An integration between sustainability and design for manufacturing and assembly (DFMA) analysis for angle grinder. *AIP Conference Proceedings 2030 (1): 020073*. doi:10.1063/1.5066714.

Favi, C., Campi, F., Germani, M., & Mandolini, M. (2022). Engineering knowledge formalization and proposition for informatics development towards a CAD-integrated DfX system for product design. *Advanced Engineering Informatics,* 51, 101537. https://doi.org/10.1016/j.aei.2022.101537

Ferryanto, F., Muhammad, K. A., Rubiyanto, T., Mihradi, S. and Mahyuddin, A. I. (2017). Design Modification of an Affordable Prosthetic Knee Based on DFMA and Static Analysis. *5th International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME) Bandung*. doi:10.1109/ICICI-BME.2017. 8537726.

He, B., Li, F., Cao, X., and Li, T. (2020). Product Sustainable Design: A Review from the Environmental, Economic, and Social Aspects. *ASME. Journal of Computing and Information Science in Engineering*, 20(4): 040801. https://doi.org/10.1115/1.4045408

Iritani, D. R., Silva, D. A. L., Saavedra, Y. M. B., Grael, P. F. F., and Ometto, A. R. (2015). Sustainable Strategies Analysis Through Life Cycle Assessment: A Case Study in A Furniture Industry. *Journal of Cleaner Production,* 96, 308–318. https://doi.org/10.1016/j.jclepro.2014.05.029

ISO, I. (2006). 14040: Environmental management–life cycle assessment–principles and framework. London: British Standards Institution. https://www.iso.org/standard/37456.html

ISO 14040. (2006). Environmental Management – Life Cycle Assessment – Principles and Framework. International Organization for Standardization (ISO), Geneva.

ISO 14044. (2006). Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Organization for Standardization (ISO), Geneva.

Karimah, A., Ridho, M. R., Munawar, S. S., Adi, D. S., Damayanti, R., Subiyanto, B. & Fudholi, A. (2021). A review on natural fibers for development of eco-friendly bio-composite: Characteristics, and utilizations. *Journal of Materials Research and Technology*, 13, 2442-2458.

Kim, S., and Moon, S. K. (2017). Sustainable platform identification for product family design. *Journal of Cleaner Production,* 143, 567–581. doi:10.1016/j.jclepro.2016.12.073.

Lacasa, E., Santolaya, J. L., Fuentes, L. and Majarena. A. C. (2015). Implementing sustainability criteria in product development. *Procedia Engineering,* 132: 1029–1036. doi:10.1016/j.proeng.2015.12.592.

Luthfini Lubis, A. and Vivi Putri, M. (2020). Designing Ergonomic Study Chair Using Quality Function Deployment Method with Anthropometry Approach. in International Conference on Logistic and Business Innovation, *KnE Life Sciences*, 14--34. DOI 10.18502/kls.v5i3.6557

Mangera, T., Kienhofer, F., Carlson, K., Conning, M., Pukis, T. and Govender, G. (2019). Design for Manufacture and Assembly of a polycentric paediatric prosthetic knee. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture,* 233 (14), 2566–2576. doi:10.1177/0954405419840555.

Mikula, K., Skrzypczak, D., Izydorczyk, G., Warchoł, J., Moustakas, K., Chojnacka, K. & Witek-Krowiak, A. (2021). 3D printing filament as a second life of waste plastics-a review. *Environmental Science and Pollution Research International*, 28, 12321–12333.

Naiju, C. D., Jayakrishnan, V. and Warrier, P. V. (2017). DFMA for early cost estimation of pedestal fan: A case study. *Journal of Industrial and Intelligent Information,* 1–4. doi:10.18178/jiii.5.1.

Pinheiro, N. M. G., Ordonez, R. E. C., Barbosa,G. L. L. and Dedini. F. G. (2018). Computational simulation applied in choosing the best solution in product development using Design for Manufacturing and Assembly approach. *Brazilian Journal of Operations and Production Management,* 15 (4): 618–628. doi:10.14488/BJOPM.2018.v15.n4.a 15.

Rahman, M. H. A., Maidin, N. A., Ahmad, M. N., Osman, M. H., Wahid, M. K. and Ruslan, A. N.M. (2019). Design for Manufacture and Assembly analysis of baby stroller. *Journal of Advanced Manufacturing Technology*, 61–67. eISSN: 2289- 8107; Special Issue iDECON 2016.

Safaa, Y. P., Hatmoko, J. U. D. and Purwanggono. B. (2019). Evaluation of the use of prefabricated bridge elements with Design for Manufacture and Assembly (DFMA) criteria. *MATEC Web of Conferences 270: 05006.* doi:10.1051/matecconf/ 201927005006.

Samsudin, H. A., Rosli, M. F., Effendi, M. S. M. and Abdullah, M. H. (2018). DFMA: Analysis on mini washing machine XPB42-688. *AIP Conference Proceedings 2030 (1): 020138*. doi:10.1063/1.5066779.

Schmidt, S. (1998). Preventive Optimisation of Costs and Quality for the Total Life Cycle - Design for Manufacture, Assembly, Service, Environment (DFMA). *Total Life Cycle Conference Proceedings, SAE International, Geneva*, 1–9. doi:10.4271/982166.

Sharma, J. K., Rajeshkannan, A., Sharma, A.A., and Seenivasagam, D. R. (2019). Some aspects on the sustainable process design in a timber mill using the design for manufacturability/sustainability. *International*

Journal of Sustainable Engineering. doi:10.1080/19397038.2019.1674941.

Shahruzzaman, M. & Biswas, S. & Islam, Md & Islam, Md.S. & Rahman, Md. (2019). Furniture: Eco-Friendly Polymer Composites Applications. **In** *Encyclopedia of Polymer Applications*,1517-1547. Taylor and Francis Group: CRC Press.

Sheth, S. (2021). These Designers Are Using 3D-Printing Robots to Turn the City's Plastic Waste into Beautiful Public Furniture. Retrieved from https://www.yankodesign.com/2021/11/23/these-designers-are-using-3d-printing-robots-to-turn-the-citys-plastic-waste-into-beautiful-public-furniture/[Accessed 13 November 2021]

Subbaiah, A. & Antony, K.M. (2021). Integration of DFMA and sustainability - A case study, *International Journal of Sustainable Engineering,* 14 (3), 343-356. DOI:10.1080/19397038. 2020.1871443

Sudin, M. N., Chin, N. S., Shamsudin, S. A. and Yusuff. M. A. (2016). Design efficiency analysis towards product improvement for Eco-friendly using DFMA method. *The Open Mechanical Engineering Journal,* 10 (1), 173–181. doi:10.2174/1874155X01610010173.

Suresh, P., Ramabalan, S. and Natarajan, U. (2015). Product development in automotive component using Design for Manufacturing and Assembly. *International Journal of Sustainable Engineering 355 (DFMA).* In Advanced Engineering Research and Applications, 183–191. Research India Publications.

Suresh, P., Ramabalan, S. and Natarajan, U. (2016). Integration of DFE and DFMA for the sustainable development of an automotive component. *International Journal of Sustainable Engineering,* 9 (2), 107–118. doi:10.1080/19397038.2015.1096313.

Tamoor, M., Samak, N. A., Yang, M., & Xing, J. (2022). The Cradle-to-Cradle Life Cycle Assessment of Polyethylene terephthalate: Environmental Perspective. *Molecules,* 27 (5), 1599.

Thajudeen. S., Elgh. F., & Lennartsson. M. (2022). Applying a DFMA Approach in the Redesign of SteelBracket - A Case Study in Post and Beam System. *Proceedings of the 30th Annual Conference of the International Group for Lean Construction (IGLC30*), 564–575. doi.org/10.24928/2022/0161

Vezzoli C. A. (2018). *Design for Environmental Sustainability: Life Cycle Design of Products*. London: Springer.

Varžinskas, V., Kazulytė, I., Grigolaitė, V. & Suskevice, V. & Markevičiūtė, Z. (2020). Eco-design Methods and Tools: An Overview and Applicability to Packaging. *Environmental Research, Engineering and Management*,76. 32-45. 10.5755/j01.erem.76.4.27448

Xiong, X., Ma, Q., Yuan, Y., Wu, Z., & Zhang, M. (2020). Current situation and key manufacturing considerations of green furniture in China: A review. *Journal of Cleaner Production*, 267, 121957.

Zhafri, Z. M., Effendi, M. S. M. and Rosli, M. F. (2018). Optimization of assembly process and environment impact using DFMA and sustainable design analysis: Case study of drone. *AIP Conference Proceedings 2030: 020074*. doi:10.1063/1.5066715

Zivkovic, S., and Curcic. (2017). Applying the DFMA techniques in the design and manufacture of wind tunnel models. *International Journal of Advanced Quality, 45*, 35–40. doi:10.25137/IJAQ.n1. v45.y2017.