INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 9 (2024) 209-217
https://publisher.uthm.edu.my/ojs/index.php/ijie

# Enhancing Fastener Standardization for Disassembly: A Path to Sustainable Laptop Design

**Y.M. Khan[1], T.F. Go[2,*], V.C. Tai[3], L.K. Moey[3], L.S. Ngow[4] , D.A. Wahab[5] and W.S. Yap[6]**

[1] *Faculty of Engineering, Built Environment & Information Technology, SEGi University, 47810 Petaling Jaya, Selangor, MALAYSIA*
[2] *Centre of Advanced Materials and Sustainable Manufacturing, Faculty of Engineering, Built Environment & Information Technology, SEGi University, 47810 Petaling Jaya, Selangor, MALAYSIA*
[3] *Centre for Modelling and Simulation, Faculty of Engineering, Built Environment & Information Technology, SEGi University, 47810 Petaling Jaya, Selangor, MALAYSIA*
[4] *Centre for Advanced Electrical and Electronic Systems, Faculty of Engineering, Built Environment & Information Technology, SEGi University, 47810 Petaling Jaya, Selangor, MALAYSIA*
[5] *Centre for Automotive Research, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, MALAYSIA*
[6] *Perunding PAC, Jalan Sentul, Sentul, 51100 Kuala Lumpur, MALAYSIA*

*Corresponding Author: gotzefong@segi.edu.my
DOI: https://doi.org/10.30880/ijie.2024.16.09.016

### Article Info

Received: 7 March 2024
Accepted: 14 November 2024
Available online: 16 December 2024

### Keywords

Design for disassembly, disassembly time, laptop design, standardized fasteners, sustainability

### Abstract

This project aims to design a laptop for easy of disassembly, thereby reducing disassembly time. The challenges associated with product disassembly include the complexity of replacing worn-out components, managing various types of fasteners, and finding solutions for end-of-life products. This paper focuses on the design for disassembly of laptops by standardizing fasteners to minimize disassembly time. A modified design is proposed to decrease the disassembly time of the laptop compared to the reference design. The laptop components and fasteners are designed using Autodesk Inventor, and the disassembly time is calculated accordingly. The comparison between the new design and the reference design reveals significant improvements in disassembly time for both the laptop screen and keyboard. Specifically, the disassembly time is reduced by a factor of 4 for the laptop screen and 4.5 for the keyboard. Furthermore, the number of required disassembly tools is reduced from three different screwdrivers to just one. The primary objective of the new laptop design is to ensure easy disassembly and reassembly. By making product components easily accessible for repair, replacement, recycling, and reuse, this design not only saves time and resources for manufacturing and recycling companies but also reduces labor costs. It enhances customer satisfaction and minimizes the time and effort required for quick disassembly during product repair and refurbishment. In conclusion, Design for Disassembly is an effective approach for creating sustainable products that can be easily disassembled, facilitating simpler maintenance, repair, recovery, and reuse of components and materials.

## 1. Introduction

The increasing disposal of products have caused negative environmental impacts and a loss of materials, resources, and energy invested in the product have raised the concerns of many people [1] [2]. This issue arises due to the absence of Design for Disassembly (DFD), which even compels companies to resort to landfilling their end-of-life products, causing both financial and environmental consequences [3]. The absence of a DFD contributes to landfilling by preventing or hindering the efficient and systematic disassembly of products, making it challenging to separate and recover valuable components or materials. Without a thoughtful design that facilitates disassembly, products are more likely to be discarded in their entirety, leading to increased waste in landfills and a missed opportunity for resource recovery. The incorporation of DFD in recovery strategies is a proactive approach to sustainable practices, as it enhances resource efficiency, reduces waste, and supports a circular economy by ensuring that products are designed with their end-of-life considerations in mind.

The recent EU Circular Economy action plan released in 2020 emphasizes the need to transition towards a circular economy to achieve new sustainable advantages [4]. This includes enhancing product durability, repairability, upgradability, and remanufacturing, aiming to boost the economy and address sustainability concerns. Remanufacturing involves the process of restoring used products to a like-new condition, incorporating upgrades and improvements. Besides, remanufacturing is an integral component of recovery strategies, fostering sustainability by conserving resources, reducing waste, promoting energy efficiency, and supporting the transition towards a circular economy. Therefore, remanufacturing is an effective strategy for promoting sustainability in the product industry due to the remanufacturing costs 40-60% less than creating new products [5], while utilizing 60% of energy and 70% of materials [6] [7].

Product designers are now concerned with designing products that can be easily disassembled to avoid destructive separation, minimizing waste and scrap at their end of life [8]. DFD simplifies disassembly and recycling by incorporating modular design, standardized connections, clear identification, minimal adhesives, accessibility considerations, appropriate material selection, reverse engineering foresight, and adherence to design guidelines. These principles collectively contribute to a more efficient and sustainable end-of-life process for products. This approach contributes to the development of eco-friendlier components, which, when disassembled from the main product, can be recycled, remanufactured, and reused for another product. By incorporating these DFD principles, the remanufacturing process becomes more efficient, cost-effective, and environmentally friendly. DFD not only streamlines the disassembly and refurbishment of components but also contributes to the overall goal of extending the product life cycle and reducing the environmental impact associated with manufacturing new products. Therefore, product disassembly becomes a major concern for sustainable product development. It is believed to be the future of industries, offering numerous advantages with negligible disadvantages. The utilization of the 3R concept, along with product disassembly, is poised to shape the future of manufacturing industries [4].

DFD is a targeted design method that provides guidelines to assist designers and engineers in the early stages of product design [2]. DFD contributes to the remanufacturing process via modular design, standardized connections, clear identification, minimized adhesives and welding, design for accessibility, reverse engineering considerations and material selection for durability. The primary objective of implementing DFD is to minimize the time required for product disassembly [2] [9]. The authors emphasized that disassembly is one of the most critical requirements for designing sustainable products [9]. One effective approach to promote DFD and enhance product sustainability is by improving fastener standardization. By implementing standardized fasteners throughout the product design, the disassembly process becomes more streamlined and efficient.

Sassanelli et al. mentioned that existing literature reviews provide design guidelines and proposed strategies to determine values such as product lifespan and disassembly time, or to enhance product characteristics for recycling and remanufacturing purposes [10]. Vanegas et al. proposed a robust method called "eDiM" (ease of Disassembly Metric) to calculate the disassembly time based on the Maynard operation sequence technique (MOST) [11]. They emphasized that the ease of disassembly can provide valuable support for the development of international standards. Frizziero et al. [12] indicated that standardizing fasteners can enhance the separability of components. Furthermore, enhanced fastener standardization enables component interchangeability, facilitating the replacement or upgrading of specific parts without the need for specialized tools or extensive technical knowledge [13]. This not only extends the product's lifespan but also reduces waste generation and promotes a more circular economy. In other words, the use of standardized fasteners allows for easier identification and removal, reducing the time and effort required for disassembly. This benefits not only manufacturers during production and assembly but also simplifies the process for repair technicians and end-users.

Standardized fasteners also facilitate the recycling and recovery of valuable materials from end-of-life (EOL) products. Dangal [14] standardized the fasteners and used eDiM to evaluate product disassembly time, finding that standardized fasteners contribute to reducing the disassembly time of EOL products. With clear identification and separation of components, recycling processes can be optimized, ensuring effective reuse, repurposing, and remanufacturing of materials while minimizing environmental impact. Therefore, determining the disassembly time to extract components can serve as the basis for evaluating the ease of disassembly for eco-design, supporting the enforcement of product requirements that facilitate lifetime extension strategies and improve EOL treatment [2].

This paper presents the implementation of Design for Disassembly (DFD) in a laptop, aiming to facilitate the removal of its parts through the standardization of fasteners. The objective of this paper is to contribute to the overarching goal of DFD, which is to create a more sustainable and environmentally friendly product. The remainder of the paper is organized as follows: Section 2 outlines the methodology of this project, followed by Section 3 describing the results of the disassembly process. Section 4 presents the discussions, and finally, Section 5 concludes the paper.

## 2. Methodology

This section is organized as follows: it starts with the explanation of the case study selection, then proceeds with the explanation of the implementation of DFD. Next, it provides a description of the standardization of fasteners, and finally, it concludes with the equation for the evaluation of disassembly.

### 2.1 Case Study

The chosen case study for this research is a laptop, which represents a significant area of future innovation in electronic products. Laptops are widely used in various settings such as offices, schools, and homes, making them an essential part of our daily lives. With increased product usage, proper maintenance becomes crucial. Laptops often require frequent upgrades to ensure optimal performance. Moreover, the electrical and electronic industry is one of Malaysia's leading industries which covers around 24.5% in manufacturing production sector [15]. Therefore, it is essential to consider disassembly and assembly during the design phase to avoid complex designs that can make disassembly and assembly challenging. By implementing the principles of DFD, the concept of disassembling various parts of the laptop can greatly enhance maintenance, repair, recovery, and component reuse.

### 2.2 Implementation of DFD

It is crucial to understand the disassembly steps designed for a product. A detailed disassembly design not only makes it easier for users but also facilitates the repair department in handling the product, investigating defective components, and disassembling the affected parts from the whole product. Using Autodesk Inventor, the detailed design of the product be generated. In Figure 1, the parts of the newly proposed laptop, including the lower case, upper case, laptop screen, keyboard, touchpad, and speakers, are displayed. The assembly and disassembly of these components are designed to be simple, avoiding the need for complicated disassembly tools and processes.

Additionally, the selection of environmentally friendly and recyclable materials for the product aligns with the objective of DFD, which aims to extend the end-of-life (EOL) of products. The main components of the new laptop design utilize low-impact materials such as aluminum alloy, stainless steel, and natural rubber, enabling most of the materials in the laptop to be recycled after their entire lifespan. The assembly drawing of the new laptop by Autodesk Inventor for all laptop parts is provided in Figure 3 in the results section.

The figure number and caption should be typed below the illustration in 10pt and centered. Artwork has no text along the side of it in the main body of the text. However, if two images fit next to each other, these may be placed next to each other to save space. For example, see Fig. 1. The figures and the number should be placed in the table. Then, the table border needs to be adjusted to no border.

### 2.3 Standardization of Fasteners

The second design criterion in this study is the standardization of fasteners. Standardized fasteners contribute to the reduction of time and energy required for product disassembly. In the datum design laptop, different types of fasteners are used for each part, resulting in the need for different screwdrivers during disassembly. This variation in screws across components increases disassembly time and requires additional tools. To address this, the concept of standardized fasteners is introduced in this study, aiming to minimize the number of tools needed for disassembly and avoid confusion in the workload.

The datum laptop consists of 11 types of screws with different dimensions for assembly, necessitating the use of 2 different screwdrivers for disassembly. In contrast, the proposed laptop design focuses on standardizing the screws, resulting in a reduced number of variants, and minimized tool requirements. The newly designed laptop utilizes only 2 types of screws: M2.5x25 for the laptop screen and M2.5x3 for the keyboard. Figure 2 illustrates the screws used in the proposed DFD laptop, M2.5x25 flat head screw for laptop screen while M2.5x3 flat head screw for keyboard.

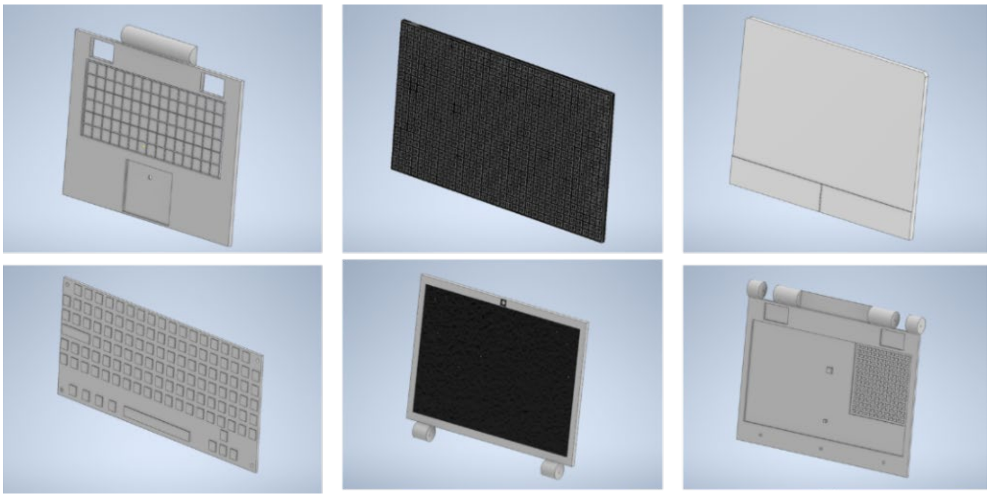
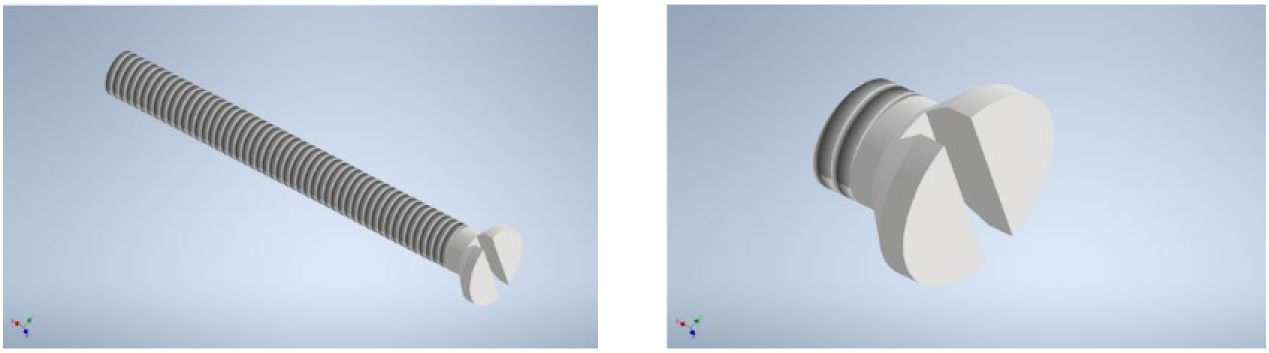


**Fig. 1** *Parts of proposed DFD laptop*



**(a)** **(b)**

**Fig. 2** *Standard fastener parts in the proposed laptop (a) M2.5x25 flat head screw; (b) M2.5x3 flat head screw*

## 2.4 Fasteners Used in the Proposed DFD Laptop

Disassembly time is chosen as the metric to evaluate the ease of disassembly in this study. A comparison of the disassembly time between the datum and proposed designs will be conducted to demonstrate how the proposed design meets the requirements for facilitating lifetime extension strategies and improving end-of-life (EOL) treatment. The determination of the effective disassembly time follows the approach outlined by Mandolini et al. [16], which involves referencing the standard disassembly time and applying a corrective factor based on the screw liaison type:

$$T_e = T_s \times CF_k \quad (1)$$

Where, $T_e$ and $T_s$ are the effective disassembly and standard disassembly times, respectively, while $CF_k$ denotes the corrective factor. The corrective factor for the screw liaison type can be found in the 5th column of Table 1.

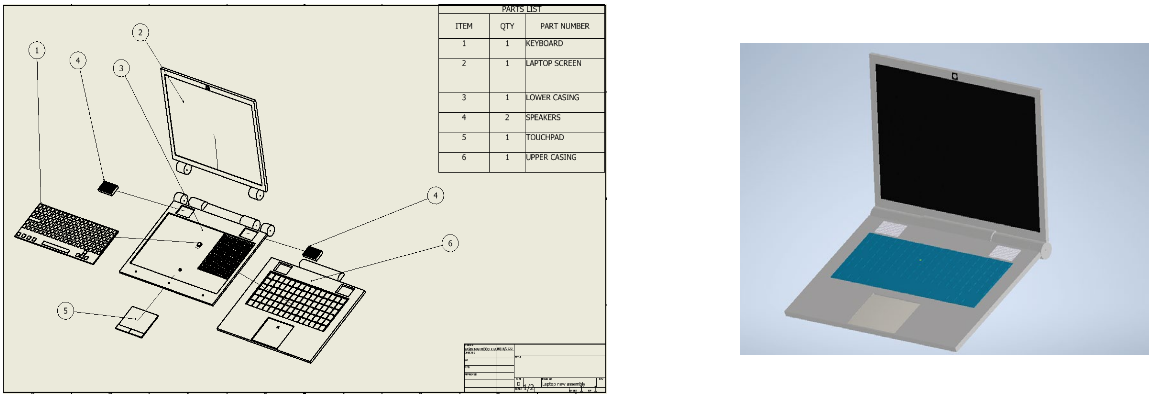
## 3. Results

This paper explores the path to designing a sustainable and environmentally friendly laptop by implementing Design for Disassembly (DFD), standardizing fasteners, and evaluating disassembly time. DFD contributes to product design simplicity in terms of geometry and assembly. In the case study of the laptop, a more impactful design was developed, enabling faster and more efficient disassembly compared to the datum design. Figure 3 shows the disassembly view of the proposed laptop with all the main components labelled alphabetically and isometric assembly view as well. The proposed design depicted in Figure 3, prioritizes disassembly time while maintaining or improving overall efficiency.

The proposed laptop design underwent a comparative analysis with a datum design available in the market, as detailed in Table 2. The table highlights the distinctions between the two designs, emphasizing the enhanced disassembly features and upgrade capabilities of the proposed laptop design. Specifically, the proposed design facilitates a smoother disassembly process for various components, streamlining the overall maintenance and allowing for convenient upgrades. In contrast to the datum design, the proposed laptop design excels in efficiency, significantly reducing the time required for disassembling specific components like the laptop screen, touchpad, and keyboard. This improvement underscores the design's efficacy in optimizing the disassembly process, contributing to increased operational efficiency and user-friendly maintenance practices.

**Table 1** *Corrective factor for screw liaison type [16]*

| Liaison class | Liaison type | Standard disassembly time (s) | Liaison property | Liaison corrective factor |
|---|---|---|---|---|
| Threaded | Screw | 4 | Wear | Completely worn/rusted = 2<br>Partially worn/ rusted = 1.3<br>Not worn/rusted = 1 |
| | | | Deformation | Deformed = 2<br>Not deformed = 1 |
| | | | Head type | Hexagonal = 1.2<br>Hexagonal with notch = 1<br>Flat = 1<br>Cylindrical = 1.2<br>Cylindrical with notch = 1<br>Cylindrical with hex notch =1.1 |
| | | | Length | L ≤ 20 mm = 1<br>20 mm < L ≤ 40 mm = 1.1<br>L > 40 mm = 1.2 |
| | | | Diameter | D ≤ 4 mm = 1.2<br>4 mm < D ≤ 12 mm = 1<br>D > 12 mm = 1.2 |
| | | | Tool | Screwdriver = 1.4<br>Spanner = 1.2<br>Screwdriver = 1.4 |

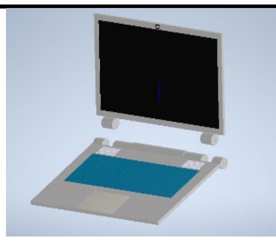
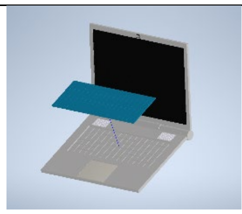
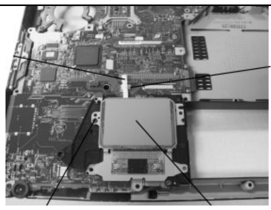
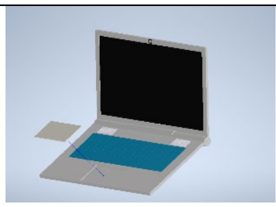



**(a)** **(b)**

**Fig. 3** *Newly designed laptop (a) explosion view; (b) 3D view*

Standardizing fasteners ensures that the entire system utilizes standardized fasteners, leading to a reduction in disassembly time and the number of tools required for product assembly. As shown in Table 3, the disassembly time for all screws appears comparable; a significant distinction emerges in the complexity of the process. The datum design introduces a total of 11 diverse screws, contributing to a more intricate disassembly procedure. Notably, this design mandates the use of three distinct screw types, each demanding a specific screwdriver. This multiplies the disassembly time and introduces the risk of damage if inappropriate tools are employed. The intricate screw arrangement in the datum design underscores the potential for operational inefficiency and heightened susceptibility to errors during disassembly.

**Table 2** *Comparison of design aspect between datum and proposed design*

| Datum design [17] | Proposed design |
|---|---|
| <br>The datum design has the screen attached to the laptop, making it hard to disassemble. | <br>The new design allows easy disassembly of laptop screen. |
| <br>The keyboard is attached piece by piece to the laptop making it inefficient and costly to disassemble. | <br>The keyboard is attached as a whole piece on upper case making it easy to disassemble using the flat head screwdriver. |
| <br>The touchpad is attached completely to the laptop which requires the whole laptop to be disassembled to repair the part. | <br>The touchpad is attached separately on the uppercase to easily remove it. |

In contrast, the proposed laptop design adopts standardized fasteners and disassembly tools, relying on only one type of screw, namely the M2.5, with varying lengths. This design choice ensures that the same screwdriver can be used to disassemble screws with the same screw head but different lengths. Consequently, the newly designed laptop only requires one type of screwdriver, while the datum laptop employs 3 types of screws, as depicted in Table 4. Overall, the proposed design offers a simpler disassembly process compared to the datum laptop.

## 4. Discussion

The design for disassembly aimed to reduce the disassembly time required for the laptop screen and keyboard. After considering the components and prioritizing disassembly time, the newly designed laptop showed significantly shorter disassembly times compared to the datum design. The datum design required approximately 60.48 seconds and 121 seconds for the disassembly of the laptop screen and keyboard, respectively. In contrast, the proposed design achieved disassembly times of around 14.78 seconds and 26.88 seconds for the laptop screen and keyboard, respectively. The proposed design not only achieved shorter disassembly times but also incorporated material choices that enhance the end-of-life (EOL) sustainability. The main components of the proposed design, such as aluminum alloy, natural rubber, and stainless steel, are environmentally friendly and can be recycled after the product's lifetime. This sustainability aspect makes the proposed design socially and environmentally impactful.

The standardization of fasteners in the proposed laptop design aimed to establish a more efficient and consistent system compared to the datum design. This was achieved by reducing the number of different screw types, thereby minimizing the need for multiple screwdrivers. The datum design utilized 11 different screw types, requiring the use of 3 screwdrivers for disassembly. Although all the screws had the same disassembly time of 6.72 seconds, the number of tools used was significantly higher compared to the newly designed laptop. The proposed design, on the other hand, utilized only 2 variations of screws and required only 1 type of screwdriver for disassembly. This successfully standardized the screws used throughout the system and reduced the number of tools necessary for component disassembly.

**Table 3** *Comparison of disassembly time aspect between datum and proposed design*

| Laptop component | Datum design | Proposed design |
|---|---|---|
| **Laptop screen** | Standard disassembly time ($T_s$) = 4 seconds<br>Wear: Not worn/rusted; $CF_1$= 1<br>Deformation: Not deformed; $CF_2$= 1<br>Head type: Flat; $CF_3$= 1<br>Length: L ≤ 20 mm; $CF_4$= 1<br>Diameter: D ≤ 4 mm; $CF_5$= 1.2<br>Tool: Screwdriver; $CF_6$= 1.4<br>Using Equation (1),<br>$T_e = T_s \times CF_k$<br>$T_e = T_s \times CF_1 \times CF_2 \times CF_3 \times CF_4 \times CF_5 \times CF_6$<br>$T_e = 4 \times 1 \times 1 \times 1 \times 1 \times 1.2 \times 1.4$<br>$T_e = 6.72$<br>The datum laptop screen is connected to 9 M2x4 flat screws,<br>Disassembly time for laptop screen= 9×6.72=60.48s. | Standard disassembly time ($T_s$) = 4 seconds<br>Wear: Not worn/rusted; $CF_1$= 1<br>Deformation: Not deformed; $CF_2$= 1<br>Head type: Flat; $CF_3$= 1<br>Length: L ≤ 20 mm; $CF_4$= 1.1<br>Diameter: D ≤ 4 mm; $CF_5$= 1.2<br>Tool: Screwdriver; $CF_6$= 1.4<br>Using Equation (1),<br>$T_e = T_s \times CF_k$<br>$T_e = T_s \times CF_1 \times CF_2 \times CF_3 \times CF_4 \times CF_5 \times CF_6$<br>$T_e = 4 \times 1 \times 1 \times 1 \times 1.1 \times 1.2 \times 1.4$<br>$T_e = 7.39$ s<br>The proposed design laptop screen is connected to 2 M2.5x25 flat screws,<br>Disassembly time for laptop screen = 2 × 7.39 = 14.78 s. |
| **Keyboard** | Standard disassembly time ($T_s$) = 4 seconds<br>Wear: Not worn/rusted; $CF_1$= 1<br>Deformation: Not deformed; $CF_2$= 1<br>Head type: Flat; $CF_3$= 1<br>Length: L ≤ 20 mm; $CF_4$= 1<br>Diameter: D ≤ 4 mm; $CF_5$= 1.2<br>Tool: Screwdriver; $CF_6$= 1.4<br>Using Equation (1),<br>$T_e = T_s \times CF_k$<br>$T_e = T_s \times CF_1 \times CF_2 \times CF_3 \times CF_4 \times CF_5 \times CF_6$<br>$T_e = 4 \times 1 \times 1 \times 1 \times 1 \times 1.2 \times 1.4$<br>$T_e = 6.72$ s<br>The datum keyboard is connected with 18 screws of different types having the same corrective factors,<br>Therefore,<br>Disassembly time for keyboard = 18 × 6.72 = 121s. | Standard disassembly time ($T_s$) = 4 seconds<br>Wear: Not worn/rusted; $CF_1$= 1<br>Deformation: Not deformed; $CF_2$= 1<br>Head type: Flat; $CF_3$= 1<br>Length: L ≤ 20 mm; $CF_4$= 1<br>Diameter: D ≤ 4 mm; $CF_5$= 1.2<br>Tool: Screwdriver; $CF_6$= 1.4<br>Using Equation (1),<br>$T_e = T_s \times CF_k$<br>$T_e = T_s \times CF_1 \times CF_2 \times CF_3 \times CF_4 \times CF_5 \times CF_6$<br>$T_e = 4 \times 1 \times 1 \times 1 \times 1 \times 1.2 \times 1.4$<br>$T_e = 6.72$ s<br>The proposed design laptop keyboard is connected with 4 M2.5x3 flat screws Therefore,<br>Disassembly time for keyboard = 4 × 6.72 = 26.88 s. |
| **Total disassembly time** | **181.48 seconds** | **41.66s** |

**Table 4** *Comparison of disassembly time aspect between datum and proposed design*

| DFD design aspect | Datum design | Proposed design |
|---|---|---|
| **Number of fasteners type** | 11 | 2 |
| **Number of disassembly tool required** | 3 | 1 |

As presented in the results section, the implementation of DFD in the laptop design effectively reduced its disassembly time, ensuring ease of disassembly in the proposed design. Table 2 highlights the modifications made to the laptop's main components, focusing on ease of disassembly, standardization of fasteners, and disassembly tools. The proposed design achieved shorter disassembly times, as demonstrated in Table 3. This involved understanding the necessary changes in each laptop component and how they could be modified to provide better usability for customers. The laptop screen, keyboard, and touchpad were specifically considered and individually modified according to the main design principles of DFD, fastener standardization, and disassembly time. Consequently, the evaluation of the proposed laptop design demonstrated improved disassembly times compared to the datum laptop available in the current market. The proposed laptop design offers greater sustainability and facilitates lifetime extension strategies and improved EOL treatment, as stated by Shahhoseini et al. (2023).

New phones, tablets, and laptops flood the market daily, leading to a significant expansion in the laptop market size. This growth can be attributed to advancements in technology and evolving customer demands. Unfortunately, the inevitable consequence of this technological turnover is the escalating e-waste stream, which has become the fastest-growing waste stream globally. To address this issue, implementing a DFD can enhance recovery strategies, while modular design stands out as a promising alternative. Modular design offers several advantages, including design flexibility, augmentation capabilities, and cost reduction. By organizing components into distinct modules, designers gain the ability to modify specific modules without overhauling the entire system. This approach enables easy upgrades by adding new functions through plug-and-play modules, catering to the dynamic needs of the laptop industry. However, the downside of modular design lies in its limitation of configurations. Some parameters remain fixed by default, hampering efficiency and hindering technical growth for organizations. This restriction extends to both design and manufacturing aspects, impacting strategic advantages in manufacturing and intellectual property generation. This poses a significant barrier to the implementation of modular design in laptops. In conclusion, while DFD proves to be a more suitable approach for sustainable practices in laptops, it is crucial to weigh the advantages and disadvantages of modular design carefully. Finding a balance between adaptability and efficiency is essential for fostering sustainable and technologically progressive practices in the electronic industry.

## 5. Conclusions

This study presented the design of a sustainable laptop through the implementation of Design for Disassembly (DFD) and the standardization of fasteners. The focus of the DFD implementation in this study was to reduce the disassembly time for both the laptop screen and keyboard. A comparison between the proposed laptop design and the datum design revealed that the proposed design exhibited better disassembly efficiency, requiring less disassembly time compared to the datum design. The standardization of fasteners was an essential aspect of the proposed design, aiming to have a consistent set of fasteners and reduce the number of tools required for disassembly. The proposed laptop design was specifically developed to have standardized fasteners, enabling the entire device to be disassembled using a single type of tool. This approach significantly simplified the disassembly process compared to the datum design, facilitating potential end-of-life (EOL) treatment. In conclusion, the implementation of DFD as a design approach in this study successfully created a sustainable product that can be easily disassembled, promoting simpler maintenance, repair, recovery, and reuse of components and materials. The combination of DFD and standardized fasteners contributes to the overall goal of creating environmentally friendly and easily disassembled products.

## Acknowledgement

The authors would like to acknowledge SEGi University for providing financial assistance under project SEGiIRF/2021-06/FOEBEIT-05/110. They would also like to express their gratitude for the partial support received from Universiti Kebangsaan Malaysia.

## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Mr. Khan, Dr. Go, Mr. Yap;* ***data collection:*** *Mr. Khan, Dr. Moey;* ***analysis and interpretation of results:*** *Mr. Tai, Ms. Ngow, Dr. Go, Prof. Wahab;* ***draft manuscript preparation:*** *Dr. Go, Mr. Tai, Mr. Yap. All authors reviewed the results and approved the final version of the manuscript.*

## References

[1] Jaykumar Yoga Mule (2012) Design for disassembly approaches on product development, *International Journal of Scientific & Engineering Research, 3(6)*, 996-1000.

[2] Ahad Shahhoseini, Sara Heydari & Siamak Pedrammehr (2023) Manufacturing and assembly for the ease of product recycling: a review, *Designs, 7(2)*, 42, https://doi.org/10.3390/designs7020042

[3] Cutieru, A. (2020, July 10). A Guide to Design for Disassembly. ArchDaily. https://www.archdaily.com/943366/a-guide-to-design-for-disassembly
[4] Francesco De Fazio, Conny Bakker, Bas Flipsen & Ruud Balkenende (2021) The disassembly map: A new method to enhance design for product repairability, *Journal of Cleaner Production, 320*, 128552, https://doi.org/10.1016/j.jclepro.2021.128552
[5] Mansour Alyahya, Gomaa Agag, Meqbel Aliedan, Ziad Hassan Abdelmoety & Maya Mostafa Daher (2023) A sustainable step forward: understanding factors affecting customers' behaviour to purchase remanufactured products, *Journal of Retailing Consumer Services, 70*, 103172, https://doi.org/10.1016/j.jretconser.2022.10317
[6] Abu, M., Jamaluddin, K., & Zakaria, M (2016). Classification of crankshaft remanufacturing using Mahalanobis-Taguchi system, *International Journal of Automotive and Mechanical Engineering, 13(2),* 3413-3422, https://doi.org/10.15282/ijame.13.2.2016.10.0282
[7] Abu, M.Y., Jamaluddin, K.R., & Zakaria, M.A. (2017). Characterisation of activity based costing on remanufacturing crankshaft, *International Journal of Automotive and Mechanical Engineering, 14(2),* 4211-4224, https://doi.org/10.15282/ijame.14.2.2017.8.0337
[8] Hoda Abuzied, Hesham Senbel, Mohamed Awad & Ayman Abbas (2020) A review of advances in design for disassembly with active disassembly applications, *Engineering Science and Technology, an International Journal, 23(3),* 618-624, https://doi.org/10.1016/j.jestch.2019.07.003
[9] Go Tze Fong, Dzuraidah Abdul Wahab, & Hawa Hishamuddin (2016) Evaluation of eco-design strategies for development of multiple life-cycle products, *International Journal of Automotive and Mechanical Engineering, 13(3),* 3642-3656. https://doi.org/10.15282/ijame.13.3.2016.9.0299
[10] Claudio Sassanelli, Andrea Urbinati, Paolo Rosa, Davide Chiaroni & Sergio Terzi (2020) Addressing circular economy through design for X approaches: A systematic literature review, *Computer in Industry, 120,* 103245, https://doi.org/10.1016/j.compind.2020.103245
[11] Paul Vanegas, Jef R. Peeters, Dirk Cattrysse, Paolo Tecchio, Fulvio Ardente, Fabrice Mathieux, Wim Dewulf & Joost R. Duflou (2018) Ease of disassembly of products to support circular economy strategies, *Resource Conservation and Recycling, 135*, 323–334, https://doi.org/10.1016/j.resconrec.2017.06.022
[12] Leonardo Frizziero,,Alfredo Liverani, Gianni Caligiana,Giampiero Donnici & Luca Chinaglia (2019) Design for disassembly (DfD) and augmented reality (AR): Case study applied to a gearbox, *Machines, 7(2),* 29. https://doi.org/10.3390/machines7020029
[13] Thomas Jeandin & Christian Mascle (2016) A new model to select fasteners in design for disassembly, *Procedia CIRP, 40,* 425–430, https://doi.org/10.1016/j.procir.2016.01.084
[14] European Union's Horizon 2020 Research and Innovation Programme (2020, February 29). State-of-the-art of design strategies and design principles in relation to obsolescence, Horizon 2020, EU, 2020. https://prompt-project.eu/wp-content/uploads/2020/07/PROMPT_20200229_State-of-the-art-of-design-strategies-and-design-principles-in-relation-to-obsolescence.pdf
[15] Nurharyantie Nik Mohd Kamil, Sri Nur Areena Mohd Zaini & Mohd Yazid Abu (2021) Feasibility study on the implementation of Mahalanobis-Taguchi system and time driven activity-based costing in electronic industry, *International Journal Industrial Engineering and Management, 10,* 160-172, https://doi.org/10.15282/ijim.10.1.2021.5982
[16] Marco Mandolini, Claudio Favi, Michele Germani & Marco Marconi (2017) Time-based disassembly method: how to assess the best disassembly sequence and time of target components in complex products, *International Journal of Advanced Manufacturing and Technology, 90(1-4),* 409–430, https://doi.org/10.1007/s00170-017-1201-5
[17] Toshiba, (2023). *Toshiba Satellite A10 Series Field Replaceable Unit Documentation*. https://www.manualslib.com/manual/1672782/Toshiba-Satellite-A10-Series.html