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Integration of design for disassembly method using recycled mahogany material in modular furniture

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ABSTRACT: This paper explores the Design for Disassembly (DfD) methodological approach in the furniture design process. Design for Disassembly is a product design strategy that enables a product to be disassembled for easier maintenance allowing cost-effective recovery of reusable components and materials, which are important for optimizing products for reuse and recycling at the end of their life cycle. The modular concept further enhances this approach by allowing for interchangeable parts enabling customers to repair and upgrade their furniture without needing a complete replacement. Furthermore, this paper provides an overview of Design for Disassembly approaches on furniture development as an effective tool for significant reduction for new raw materials using recycled mahogany material that result from adopting these practices. The main aim of this research is to support the current and future development in the field of disassembly, promoting a more sustainable utilization of resources, contributing to a circular economy and minimizing the environmental impact of furniture manufacturing.

Keywords: Design for disassembly, Sustainable waste management, Modular furniture

Modüler mobilyalarda geri dönüştürülmüş maun malzemesi kullanılarak sökme yöntemi için tasarımın entegrasyonu

ÖZ: Bu çalışma, mobilya tasarım sürecinde Demontaj İçin Tasarım (DiT) metodolojik yaklaşımını incelemektedir. Demontaj İçin Tasarım, ürünün daha kolay bakım için demonte edilmesini sağlayan ve yeniden kullanılabilir bileşenlerin ve malzemelerin maliyet etkin bir şekilde geri kazanılmasını sağlayan bir ürün tasarım stratejisidir; bu bileşenler, yaşam döngülerinin sonunda yeniden kullanım ve geri dönüşüm için ürünleri optimize etmek için önemlidir. Modüler konsept, değiştirilebilir parçalara izin vererek bu yaklaşımı daha da geliştirir ve müşterilerin mobilyalarını tamamen değiştirmeye gerek kalmadan onarmalarını ve yükseltmelerini sağlar. Ayrıca, bu çalışma, bu uygulamaları benimsemekten kaynaklanan geri dönüştürülmüş maun malzemesini kullanarak yeni hammaddeler için önemli bir azalma sağlayan etkili bir araç olarak mobilya geliştirmede Demontaj İçin Tasarım yaklaşımlarına genel bir bakış sunmaktadır. Bu çalışmanın temel amacı, demontaj alanındaki mevcut ve gelecekteki gelişmeleri desteklemek, kaynakların daha sürdürülebilir bir şekilde kullanılmasını teşvik etmek, döngüsel ekonomiye katkıda bulunmak ve mobilya üretiminin çevresel etkisini en aza indirmektir.

Anahtar Kelimeler: Demonte tasarım, Sürdürülebilir atık yönetimi, Modüler mobilya

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1 Introduction

The Indonesian Stock Exchange reports that the Indonesian furniture industry is experiencing growth in the First semester of 2024, furniture industry products contributing 1,1% towards GDP, with export performance of over 1,02 billion US dollar. As the Data Statista Market Insight projects, the 2028 Indonesian furniture market will reach 4,24 billion US dollar. The largest segment in this market is living room furniture, followed by home décor and bedroom products. Besides the market analysis, increasing population growth in Indonesian metropolitan cities demands an ever-increasing amount of space, leading to the creation of limited residential space. As a solution to limited land, an apartment is considered the best option for urban communities to live in the city. This condition causes a problem for residents to create comfort and functionality in a limited space. One way to solve this problem is by creating multifunctional and flexible furniture, so that the room can be used to its full potential without compromising any daily activities. As time goes by, innovation in furniture products is growing and developing along with the needs of users, one of which is the innovation is furniture with modular features. Modular design involves creating products by arranging sub-assemblies and components as separated building blocks known as modules, which can be configured and integrated to meet a various user needs and technical requirements. (Tseng et al., 2018). Modularity in product design, as described by Ulrich and Tung (1991) defined in two terms: (1) alignment between the physical structure and its functional elements, and (2) reducing incidental interactions among physical components. Ulrich (1995) also states that modular products or subassemblies have a one-to-one mapping between functional elements in the function structure and physical components of the product, ensuring that all components from various modules are separated. In other words, a module is a component with the same shape and a configuration according to the needs of its users.

A design process is essential when creating a product; the importance of the design process in a product will determine the success of the product. Design is concerned with creating items that people want. This process involves thought and execution in the design. Modern product design is a systematic, methodical, and directional creative activity. The design practice refers to the progression of the design and the sequence in which design tasks are completed. This process represents an integrated approach to identifying, analysing, and solving problems (Cheng, 2018). A good design must follow a plan that includes objectives concerning cost, performance, effort, chance of success and even aesthetics. The design process must take a closely evaluated path, starting from the statement of needs that are considered important until the functionality is achieved. Therefore, design requires a methodological approach. Methods involve the totality of approaches that can be employed to accomplish specific objectives across various fields. When people want to understand and change the world, they must participate in a range of cognitive and practical activities. The diverse techniques in these activities are collectively referred to as methods. No matter the task at hand, it is essential to have appropriate methods, as the effectiveness or disadvantages of these methods directly influence the success or failure of the work (Cheng, 2018).

Design for Disassembly is one of the design methods used in the manufacturing industry. Mule (2012) states that Design for Disassembly is a method that allows products to be diassembled for easier maintenance, repair, and the recovery and reuse of components and materials. This method aims to reduce the environmental impacts while maximizing the end-of-life value of the product. Rios et al., (2015) define DfD as a method that aims to ease deconstruction processes through planning and design. Deconstruction is the process of dismantling a product recover the functionality of the disassembled materials so that it can be

reused. The deconstruction technique essentially changes the conventional waste management process. The Design for Disassembly process is a crucial strategy for conserving new raw materials in order to reduce waste, extend the life of materials, and optimise their use.

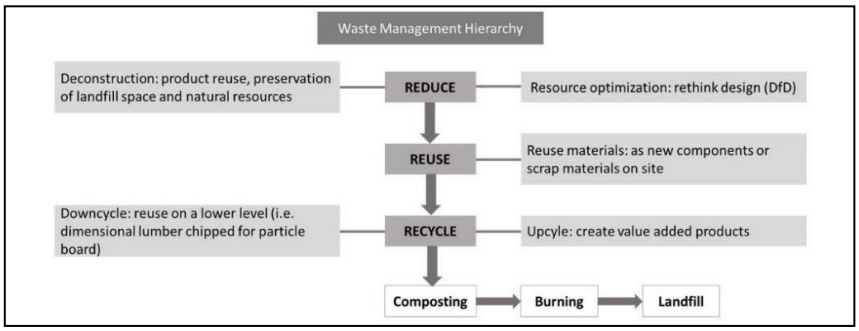

Figure 1. Waste Management Hierarchy (Rios et al., 2015)

Design for Disassembly functions as Reduce, Reuse, and Recycle (3R) process with the goal of eliminating the urgency of composting, burning, and waste disposal.

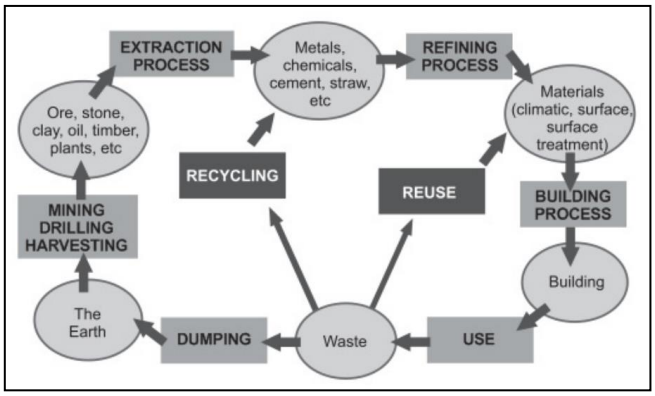

Figure 2. Closed Loop Material (Rios et al., 2015)

Design for Disassembly is an important concept in the effort to create a closed loop material system. The Closed Loop approach is similar to natural biologic metabolical processes where "waste" is transformed into "nutrients". The continuous cycle is referred to as technical metabolism, enabling waste to be recycled and reused into new nutrients, which can be new materials or uses to creating other products. (Rios et al., 2015). As will be discussed in this paper, the focus is on designing furniture by implementing the Design for Disassembly method. Research on the application of this method remains quite limited; therefore, this study aims to contribute to the existing literature, validate the effectiveness of this approach in the furniture products design process, and create a positive impact on both users and the environment.

2 Material and Method

This study utilizes a qualitative research methodology. Qualitative research systematically collects and analyzes a variety of empirical materials such as observation, interview, case studies, and document analysis and is used as an approach to uncover perceptions and events realistically and comprehensively in a natural environment. (Denzin & Lincoln, 2008).

Corbin and Strauss (2008) In Bowen (2009) defines document analysis as a systematic approach to reviewing or evaluating documents. Similar to other qualitative research methods, it involves analyzing and interpreting data to extract meaning, improve understanding, and

build empirical knowledge. Document search was applied in the analysis of the data in terms of Design for Disassembly approach, guidelines, framework and strategy. The findings from this analysis were then applied to the furniture production process based on Design for Disassembly principles.

3 Applying design for disassembly method in furniture design process

In Escoto-Munoz (2020), Mule (2012), Galantucci et al., (2004), and Dowie-Brahma (2001), there are three essential factors that designers should consider to applying disassembly method

- Material Selection.
- Fasteners and Connectors.
- Product Structure and Component design.

3.1 Material selection

Material selection is a crucial element in product design. In the Design for Disassembly method, the selection of materials must not compromise the structural requirements of the design, especially when using a variety of materials. Mule (2012) states several guidelines for material selection, explained as follows:

- Select materials that reduce pollution during extraction, processing, installation, recycling, and disposal.
- Limit the variety of materials in each component.
- Decrease the total number of various materials in product.
- Ensure that materials can be easily recycled during disassembly whenever possible.
- Design parts for remanufacturing and reuse after disassembly.
- Facilitate classification of material.
- Select materials that are compatible with one another.
- Reduce the overall diversity of materials.
- Optimize the use of all materials.
- Avoid contaminant material.

In this study, researchers utilized mahogany wood waste sourced from the INPI House, a local MSME (Micro, small and medium enterprises) producing and specializes in creating signage and displays for commercial spaces, such as cafés, restaurants, hotels, gallery rooms, offices, clinics and the other sector within the hospitality industry.

Figure 3. INPI House Workshop

Using mahogany as the main material, INPI House uses 3 m^3 of mahogany every month, which is equivalent to 180 mahogany tree trunks. This results in 10% of the wood not being used due to faulty tree trunks and materials that do not meet production quality standards.

Figure 4. INPI House Wood Waste

3.1.1 Waste management

The production process creates waste in the form of large pieces, small pieces and sawdust with different sizes. Waste management was categorized according to four waste types in Table 1.

Table 1. INPI House Waste Management

Waste source	Waste product	Waste size	Waste management
Deformed Mahogany Wood Material received from the supplier	Wooden Planks	15 cm x 1m to 15 cm x 2 m	N/A
Wood Processing Residues	Sawdust	N/A	Utilized for tofu factory furnace combusion
Production Process	Small sized pieces of wood	1 cm x 2 cm to 20 cm x 15 cm	Utilized for dowels, joints, moulds, and other wood working supportive equipments
Finished Products that fail the required qualification	Finished Wood Products	5 cm x 5 cm to 20 cm x 30 cm	N/A

As a result, INPI House continues to underutilize its potential for waste disposal; in other words, INPI House does not have any effective waste management practices. In this case, a significant portion of the wood waste can be recycled to create new products.

Rios (2015) describes Design for Disassembly as an essential concept for closing material loops and transforming waste into new materials. Recycled mahogany material was implemented to furniture design process using deformed wood and production process waste with the aim to reduce the use of new material and emphasize a closed-loop system.

3.2 The Selection and use of connector and fastener

Connectors and fasteners play a crucial role in joining components and sub-assemblies in designs intended for manual disassembly. Although different methods can be used to minimize the time needed for disassembling parts, designers need to consider several factors:

- Minimize the number of fasteners and connections in an assembly.
- Choose fasteners and connections that allow quick and easy disassembly.
- Limit the variety of fasteners used within an assembly.
- Utilize snap fit fasteners whenever possible.
- Use standardized fasteners.
- Design assemblies to accommodate common hand tools for disassembly.
- Avoid using incompatible adhesives that can negatively impact material recyclability.
- Prioritize fasteners and connectors over hard wired connectors.
- Aim to minimize both the quantity and diversity of fasteners.

By prioritizing sustainable and environmentally friendly principles, this furniture design deliberately avoids conventional fasteners and connectors such as bolts, screws, locks, nails, or other commonly used connectors in the furniture industry. To enhance this approach, the design utilizes joints that serve as connectors between components or sub-assemblies.

3.2.1 Joints

Joints are a crucial connection between two or more components of wood, essential to create a strong and functional structure. In this particular design, the sliding dovetail joint is applied, which is a specific type of wood joint used to connect two components of wood. This joint consists of two parts, with one part of wood having a prominent dovetail shaped projection and the other part of wood featuring channels or slots that imitate the shape of the projection.

Figure 5. Dovetail Joint

To enhance quick and easy disassembly, sliding dovetails are utilized to connect modules in various configurations. In traditional timber construction, a dovetail joint is used to connect stuctural components in the longitudinal direction to extend the length of timber tension. These joints are also employed to join two elements at right angles or nearly so. It is also used as a corner joint in carpentry and joinery. The specific geometry of the dovetail joint allows it to withstand both compression and tension forces along the longitudinal axis of the element. The precise fit of the dovetail joints keep maintain the alignment of the elements without the use of screws, nails, or other fasteners. (Dounas & Spaeth, 2014).

3.3 Product structure and component design

Product structure and component design that allow easy disassembly for maintenance will also enhance the recycling process initiated by the designer. Some applicable principles include:

- Facilitate quick and cost-effective disassembly of the product.
- Reduce the number of assembly operations required.
- Establish an appropriate service life for product.
- Design modular product that allows modules to be disassembly for maintenance or use.
- Decrease the number of parts involved in an assembly.
- Standardize the materials used for component assembly.
- Limit the variety of materials used in an assembly.
- Construct sub-assemblies in configurations without affecting the function of the component.
- Reduce the number of fragile parts to allow reuse and reassembly.
- Avoid the use of laminates that necessitate separation before reuse.

In alignment with the principles of the Design for Disassembly approach, this design uses modular concepts with the aim of simplifying assembly and disassembly processes. According to Tseng et al., (2018), modular design refers to structuring product design by arranging sub-assemblies and components as separate modules which can be integrated in various configurations to address diverse user needs and technical requirements.

3.3.1 The benefits of modularity

Sosale et al., (1997) in Gerhenson et al., (2003) highlight two main benefits of modular product functionality: reconfigurability and product variety. Reconfigurability allows products to be arranged and enhanced through the addition of new modules. Product variation and customization enable customers to choose from different models through the arrangement of optional modules. To integrate flexible features, it is essential to ensure that modules can be easily interchanged and reused. For optimal reusability requires designing products with separate functional modules instead of combining all functions into a single unit (one-to-one form-function mapping). Products with a modular concept offer better reusability compared to non-modular products. Successful module reusability also depends on the ease of assembly and disassembly.

Sosale et al., (1997) also discuss the impact of modularity during its life cycle. Two significant life cycle benefits and their associated design goals are as follows:

1. Maintenance: Faulty products can be easily detected and replaced by simplifying the analysis of product errors and maintenance processes.
2. Recycling, reuse, and disposal: Modular design allows components to be arranged into easily removable modules. This design approach enhances the ease of reusing, recycling, and disposing of components.

4 Result and Discussion

Design for Disassembly methodological approach, which is generally used in automotive in electronic manufacturing, presents a valuable opportunity for the furniture industry as well. This approach can be used as a sustainable strategy and an effective tool for product development and recovering disposal products and materials.

DfD techniques, which create a closed loop for a product, play an important role in reducing waste and optimizing the product manufacturing process. The implementation of the DfD method can lead to a significant reduction in production costs and provide greater flexibility during product development. This method is also essential for adapting to changing market demands and consumer preferences, which in turn leads to a cost-efficient development.

4.1 Design practice

This section describes the Design for Disassembly approach applied to furniture utilizing recycled mahogany wood waste sourced from the INPI House workshop. The project involves reusing wood pieces measuring between 10 cm by 15 cm and 15 cm by 30 cm. To be modular furniture, this product shaped as separates modules (one-to-one mapping) by combining wood pieces to create panels measuring 40 cm in height, 40 cm in width, and 3 cm in thickness.

The execution of the design process begins with 3D CAD (Computer-Aided Design) in Autodesk Fusion to precisely visualize product development, improve material selection, joint design, modular technique and specification. It allows precise measurements and adjustments to simulate how the product will perform before it is manufactured.

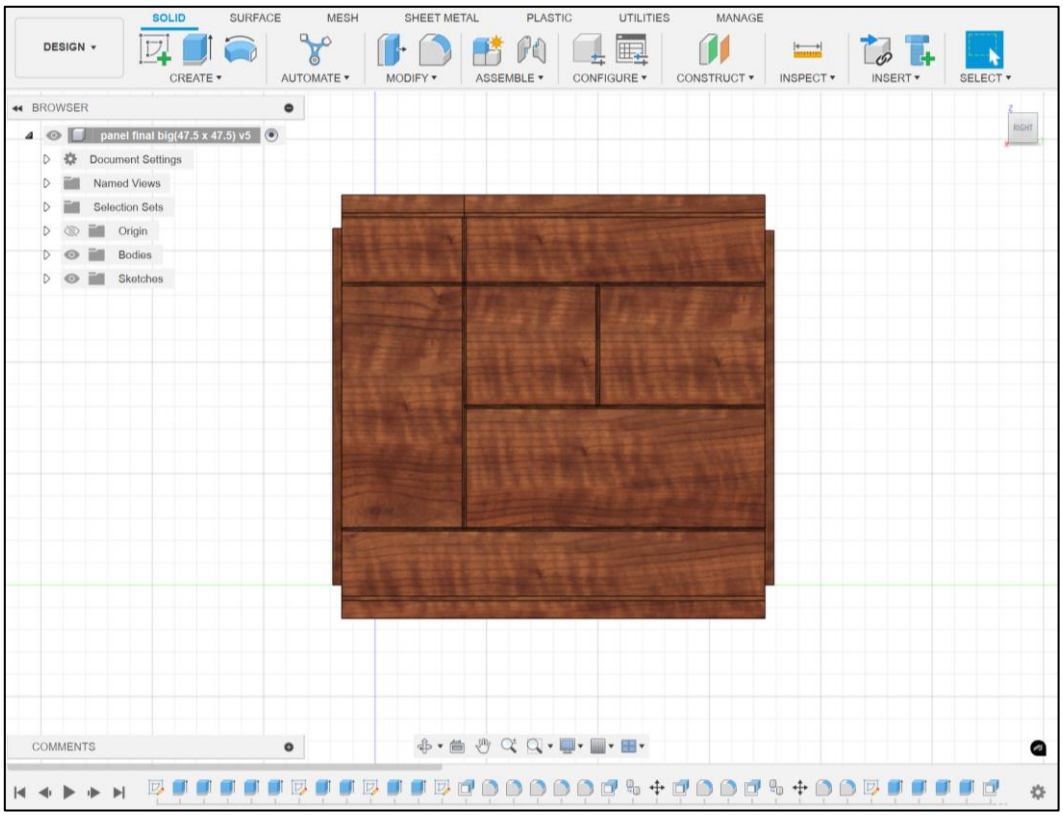

Figure 6. Wood Panel visualization in 3D CAD

Grouping modules with a dovetail joint allows easy assembly and disassembly. The dovetail joint is integrated into the panels and consists of two parts: one part features a male dovetail shape, and the other part of wood has slots that mimic the male dovetail, serving as the female joint. To allow modularity, the dovetail joint includes two male joints on one side and two female joints on the opposite side.

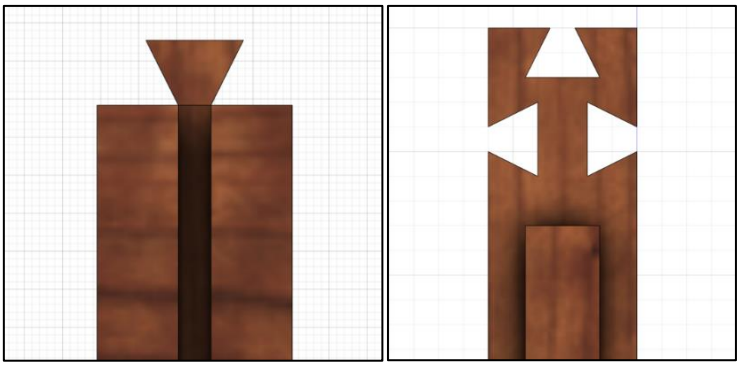

Figure 7. Male and Female Dovetail Joint

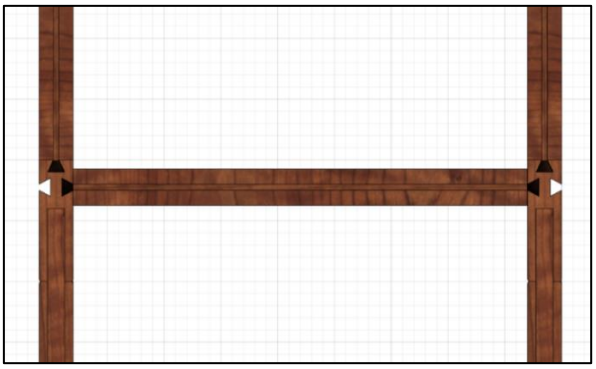

Figure. 8. Vertical and Horizontal Joint

Functioning as both horizontal and vertical connectors (Figure 8), this design allows easy assembly for connecting joints. This flexibility not only simplifies the assembly process but also allows for the configuration of modules into different shapes (Figure 9). By providing different arrangements and connections, user can customize the modules' layout to fulfil their specific needs. Whether creating a compact setup or an expansive arrangement, it is suitable for various applications and environments.

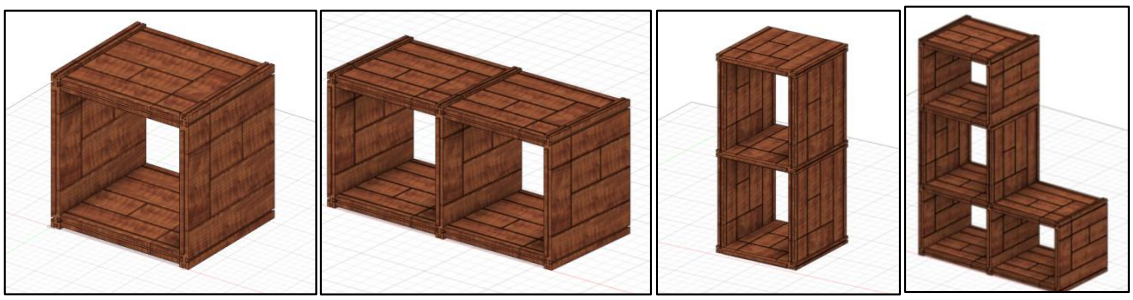

Figure 9. Module Configuration

4.2 Method Impact on Furniture Design

Implementing Design for Disassembly into the product design process allows a product and its components to be optimized for reuse and recycling once they have reached their end of life. The table presented below aims to summarize how the methods discussed in the study illustrating how they can be used as an effective tool for furniture design. This method not only decrease the demand for new materials but also contributes to a more sustainable approach to manufacturing by reducing the environmental impact. The numbers given in the table represent the impact on the effectiveness and potential benefits of these methods.

Table 2. DfD Impact on Furniture Design

DfD Principals	Applications	Reusability	Recyclability	Cost Efficiency	Manufacture Efficiency	Maintenance Efficiency
Material Selection	Mahogany Wood Waste	3	3	3	1	2
Fasteners and connectors	Integrated Dovetail Joint	3	1	3	1	1
Product Structure and Component Design	Modular Concept	3	3	3	1	3

1 = Poor impact 2 = Good impact 3 = Big impact

When a product is designed with disassembly, it becomes significantly easier to repair and maintain, resulting longer product life. Ease of maintenance not only benefits consumers by providing longer-lasting products but also promotes a more sustainable approach. By facilitating repairs and reuse, Design for Disassembly contributes to a reduction in the environmental footprint of the furniture industry and opens a way to a more sustainable industry.

5 Conclusion

- Design for Disassembly is a method that focuses on creating products that makes them easy to disassemble. The goal of DfD is to enhance resource efficiency and manufacturing sustainability.
- The primary aim of this paper is to support the current and future development in the area of disassembly.
- Design decisions concerning materials and connection methods directly influence the product structure and component design.
- Not every aspect of DfD principles can be applied to every design. Each principle may present challenges that require a flexible solution, e.g. the production of furniture modules that require to use wood adhesive.
- Implementing DfD in furniture optimizes products for reuse and recycling at the end of their life cycle.
- It is beneficial to limit the number of components and component types used in the design process. Simplifying the assembly and disassembly of furniture enhances the efficiency and ease of recycling.
- This approach significantly reduces the demand for new raw materials, promoting a more sustainable use of resources.
- Using this method can lead to lower production costs and increased efficiency, benefiting manufacturers financially.

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Author Contributions
Nurnajman Assyiraq Ibrahim: Conceptualization, Data Curation, Formal Analysis, Resources, Investigation, Methodology, Validation, Visualization, Writing - original draft, **Sheila Andita Putri:** Methodology, Project Administration, Supervision, Validation, Writing – original draft, Writing – review and editing.

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Conflict of interest statement
The authors declare no conflict of interest.

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