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Natalia Hartono
Department of Industrial Engineering, Universitas Pelita Harapan, Tangerang 15811, Indonesia, natalia.hartono@uph.edu

Agustina Christiani
Department of Industrial Engineering, Universitas Pelita Harapan, Tangerang 15811, Indonesia

Candida Keshia Larasati
Department of Industrial Engineering, Universitas Pelita Harapan, Tangerang 15811, Indonesia

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MODULAR FURNITURE MADE FROM CORRUGATED BOX WASTE USING DESIGN FOR ENVIRONMENT GUIDELINES

Natalia Hartono*, Agustina Christiani, and Candida Keshia Larasati
Department of Industrial Engineering, Universitas Pelita Harapan, Tangerang 15811, Indonesia

*Corresponding author: e-mail: natalia.hartono@uph.edu

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Abstract
Solid wastes at PT Pertamina in Jakarta were dominated by the corrugated box, so this research aims to utilize PT Pertamina's corrugated box waste into furniture using Design for Environment (DfE) guidelines. Stages in this research use the design and development product theory of Ulrich & Eppinger, consisting of Phase 0 of Product Planning along with step 1 of the DfE guidelines. Phase 1 Concept Development is concurrent with stage 2 DfE guideline Identification of Potential Environmental Impacts and Selection of DfE guidelines. Phase 2 System-Level Design works in conjunction with the 3rd stage of the DfE Guide to Initial Design Guidelines. The selected design is modular with a sectional-modular architecture type that can be arranged into three functions—table, shelf, and chair—so the product was named Mersi, which in the Indonesian language is an abbreviation of table, chair, and shelf (*meja, kursi, lemari*). The Phase 3 Detail Design added ergonomic aspects into the product design. In this phase, an alpha prototype is created, and the impacts on the environment are measured by the DfE phase 4 guideline, and the four factors measured show that the value of the DfE fraction is close to 1, meaning the prototype is environmentally friendly. Phase 4 Testing and Evaluation of Alpha Prototype with high-performance rating results for four dimensions were measured. The final product's DfE fraction value is close to 1, meaning that the product is environmentally friendly even if there is a component of the product that is not environmentally friendly. This product was registered to have Industrial Design, Intellectual Property Rights on March 2, 2018.

Keywords: corrugated box; design for environment; modular furniture; waste utilization

1. Introduction

PT Pertamina is an Indonesian state-owned oil and natural gas corporation. PT Pertamina has a Corporate Social Responsibility (CSR) program in which they committed to do several CSR activities carried out by all units for the purpose of people, the planet, and profit (PT Pertamina, 2017). Based on the feasibility study of office waste processing at the Head Office of PT Pertamina in Jakarta in 2012, it was found that the three most dominant solid waste categories in PT Pertamina's office building area were paper (40%), organic waste (food waste) (30%), and plastic (approximately 14%) (Anggreni, 2012).

Waste from corrugated boxes is considered dangerous to the environment due to landfill. According to a report on the life cycle assessment of average U.S. corrugated product by the National Council for Air and Stream Improvement (NCASI, 2017), end-of-life of corrugated products contribute significantly to global warming with a value of 0.532 kg of CO_2 eq FU.

The NCASI used the Life Cycle Impact Assessment (LCIA) from cradle-to-grave with U.S data of which the corrugated product is 89.5% recycled, 2% combusted with energy recovery, and 8.5% landfilled (NCASI, 2017). Observation and study at PT Pertamina show the corrugated box is treated as waste, and if we compare it with the NCASI research where it is only 8.5% landfilled, the LCIA impact to the environment from end-of-life of the corrugated box will be greater if we use the same model at PT Pertamina because it is 100% landfilled.

This research used the Design for Environment (DfE) Guidelines and not the LCIA software because DfE is suitable in the early design stage (Ulrich & Eppinger, 2016). LCIA in new product design is difficult, time-consuming, expensive (Kuo, Smith, Smith, & Huang, 2016). Another reason is the LCIA software database is mainly subject to foreign circumstance (Yang, Liu, & Han, 2010). At the design stage, a lot of design information is not known for certain (Mutingi, Dube, & Mbohwa, 2017) so the best choice is to use integrated DfE Guidelines into product design steps.

In an effort to utilize the waste, this research uses the corrugated box as the main part and uses a minimum number of parts. The research teams brainstormed an idea to use the corrugated box in part of a product that has economic value. We were interested in Taman Kardus (Corrugated Garden), a café in Bandung, Indonesia, which uses furniture made from corrugated boxes. The furniture is made by Dusdukduk, a company founded in 2013 that started as a student project at Sepuluh Nopember Institute of Technology (ITS), a public university in Surabaya, East Java, Indonesia (Dusdukduk, 2013). They use a special substance to make the product water repellent and have a lifespan of 1–2 years (Bekraf, 2014).

We saw the potential benefit of furniture products made from corrugated boxes because reusing it will reduce the environmental impact to global warming. This research aims to utilize the waste from corrugated boxes into ergonomic furniture using a DfE guideline.

2. Methods

The study consisted of three major steps. First, the research team brainstormed an idea to utilize the waste from the corrugated box, and the team decided to make furniture because it has an economic benefit by adding value to the waste. The research team also decided to use the corrugated box as the major components and as few parts as possible, which makes the disassembly easier, and focus on using the corrugated box only.

The second step is to research the theory of DfE in Product Design. The theory shows that considering environmental impact in product design is not a new idea. The early 1980s was when the technical aspects in design to lower the environmental impact of products was considered, and in the 1990s, this became a new approach to product design, known as DfE, Green Design, Environmentally Conscious Design, and EcoDesign, which meant that during the design phase, there is a priority objective to reduce environmental impact (Giudice, Rosa, & Risitano, 2006). There are several DfE guideline and Telenko, Orourke, Seepersad, & Webber (2016) compiled the most complete guidelines that resulted in six principles for DfE guidelines (Ulrich & Eppinger, 2016). Manufacturing firms have initiated DfE; however, few have used DfE as central to its corporate strategy as Herman Miller (Giudice et al., 2006). Herman Miller is a U.S. furniture company founded as Michigan Star Furniture Company in 1905 and was bought by Herman Miller for his son-in-law, D.J. De Pree, in 1923 (Hermanmiller, 2017). In 1999, Herman Miller created a DfE team with support from

McDonough Braungart Design Chemistry, and they introduced a DfE method that focuses on material chemistry, disassembly, and recyclability (Giudice et al., 2006). They have added LCIA as key areas in new product design, and they called it DfE protocol (Hermanmiller, 2017). Rossi, Germani, & Zamagni (2016) said that several researchers have reported limitations of LCIA in the design context, especially in the first stage when the size, composition of materials, and the construction of the product are still not known. As Hoffman's study found in 1997, the LCIA dependence on historical data and the conclusions may be influenced mostly by energy. According to Sheng et al. (1998), this can lead to a decrease in the importance of another issue such as toxicity and design for assembly.

The third step is deciding the DfE will be used in the research. The LCIA approach is considered too complex for the design, and Telenko et al. (2016) DfE guidelines are an extensive list that is not suitable for this research; therefore, we decided to use the DfE protocol from Herman Miller. The product design and development used steps from Ulrich & Eppinger (2016), with modification in the DfE process depicted in Figure 1. The research consists of phase 0 to phase 5 with the integration of five steps of DfE that were modified from Ulrich & Eppinger (2016) framework. Modification was needed to fit the research to create a simple and applicable approach.

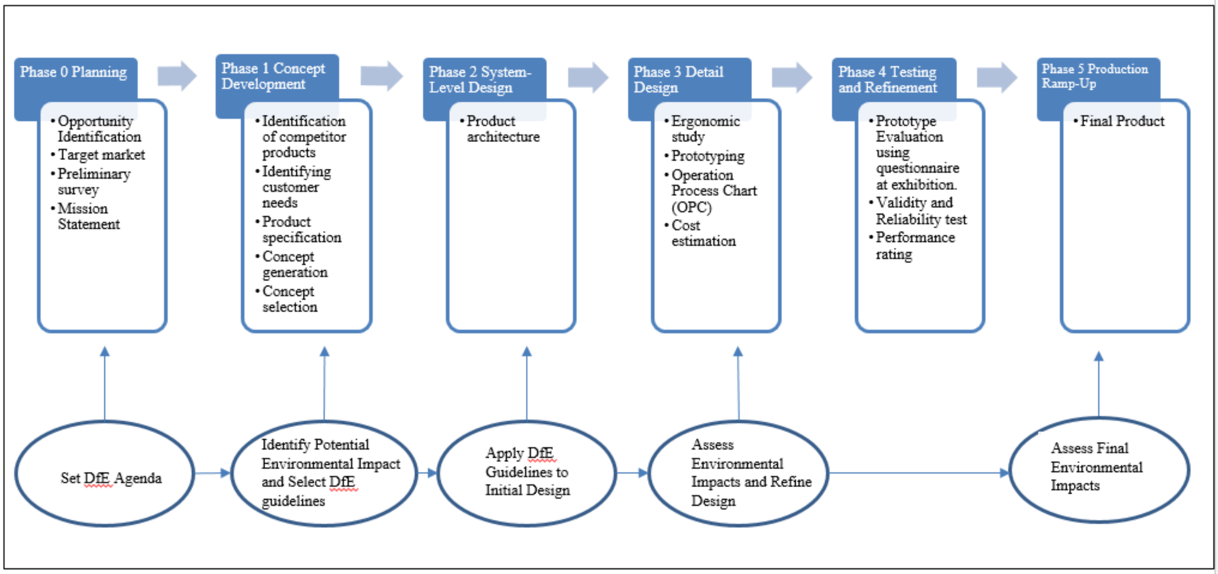

Figure 1. DfE in the Product Design and Development Framework
(Source: Ulrich & Eppinger, 2016)

3. Results and Discussion

The detailed steps in this research are presented according to the framework from Figure 1. The results of the product design are systematically presented from phase 0 to phase 5.

3.1 Phase 0 Product Planning and DfE stage 1

The opportunity identification started with cardboard furniture made by Dusdukduk that was used by a café in Bandung, Indonesia, which indicated there is an economic opportunity to sell furniture made from cardboard. Furniture made from cardboard is not new, and from an intensive web search, we found that there are several ways to make furniture from the corrugated box. The first furniture made from corrugated boxes was patented in 1971 by Frank O. Gehry, with the description that the furniture was made by forming a block of cross-laminated corrugated cardboard sheets in which the sheets are cut in the same shape and placed parallel to each other to form the furniture with an invented apparatus, ”Article of furniture or the like” (US Patent, 1978). Another method to make furniture from cardboard looks like origami, and the cardboard is folded to form the furniture, like Dusdukduk in Indonesia and Chairigami in the United States (Dusdukduk, 2013; Chairigami, 2013). Patent searches on the website of the Director-General of Intellectual Property Rights (DJKI, 2017) were conducted to find if there are similar patented products.

The target market for this product is college students who need affordable furniture around the Universitas Pelita Harapan, Tangerang. The preliminary survey used 20 college students to capture their opinions about furniture made from a corrugated box. The results varied: 40% wanted a table, 30% wanted a shelf, 20% wanted a chair and 10% wanted a laptop holder. Because of this, the researcher decided to design a product that can transform into a table, shelf, and chair. The DfE in phase 0 is to set the DfE agenda, which is the identification of the driver of DfE. The driver for this research is operational safety by reducing toxic material and using the end-of-life of corrugated box to decrease the material going into the landfill. The mission statement is the same as the aim of this research: utilizing the waste from the corrugated box into ergonomic furniture with DfE guidelines.

3.2 Phase 1 Concept Development and DfE stage 2

Phase 1 is Concept Development, which consists of the identification of competitor products, identification of customer needs, product specification, concept generation, concept selection, and concept testing. The main competitor product is Dus Duk Duk made in Surabaya, Indonesia, which uses a folding technique to made the corrugated furniture and sells for about IDR 500 thousand (USD 33.74) for the single chair to IDR 3.255 million (USD 219.65) for a set of table and two chairs. Conversion from IDR to USD is based on currency in September 2018 (1 USD = 14,819 IDR). Other competitors are outside Indonesia, thus the products sold are around USD 68, which is expensive for a product made from a corrugated box. Identification of customer needs is conducted through face-to-face interviews with 30 respondents who are the target market of the product, and the results are interpreted into need statements that are shown in Table 1.

The need statements were then distributed to 100 respondents using an online survey to give a rating scale from 1 to 5 where 1 = not important and 5 = very important. The results were averaged for every need statement and converted to customer weight as input in HOQ 1 with a conversion for an average 3–3.49 equaling customer weight 1, followed by 3.5–4.29 equaling 3 and 4.3–5 equaling 9.

Product specification is determined using Quality Function Deployment, that is, House of Quality (HOQ) 1 and 2 where HOQ 1 is a relationship of customer requirement and engineering metrics and HOQ 2 is a relationship of engineering metrics with part characteristics. The HOQ 1 and 2 are depicted in Figure 2. The HOQ 1 shows that the highest importance for the customer is in the load test, while HOQ 2 shows the most important parts are the size of the product and shelf size. This will be the researcher’s concern at the product design stage to accommodate the most important customer needs in the design.

Table 1. Need statement

No.	Factors	Customer Statement	Need Statement
1.	Strength	Can hold heavy items (chair, table, shelf)	Strong with max weight 90 kg
2.	Durability	Not easily damaged, especially if exposed to water	Minimum 3 years lifetime
3.	Capacity	Can load many books (shelf)	20 books per shelf
4.	Design	Simple and not using too much space	Simple, appealing, and compact
5.	Ease of Use	Easy to assemble and use	Easy to assemble
6.	Comfortable	Comfortable to use	Ergonomic
7.	Color	Black, white, or brown	Neutral color
8.	Price	Affordable price	Around IDR 150 thousand (USD 10.18)

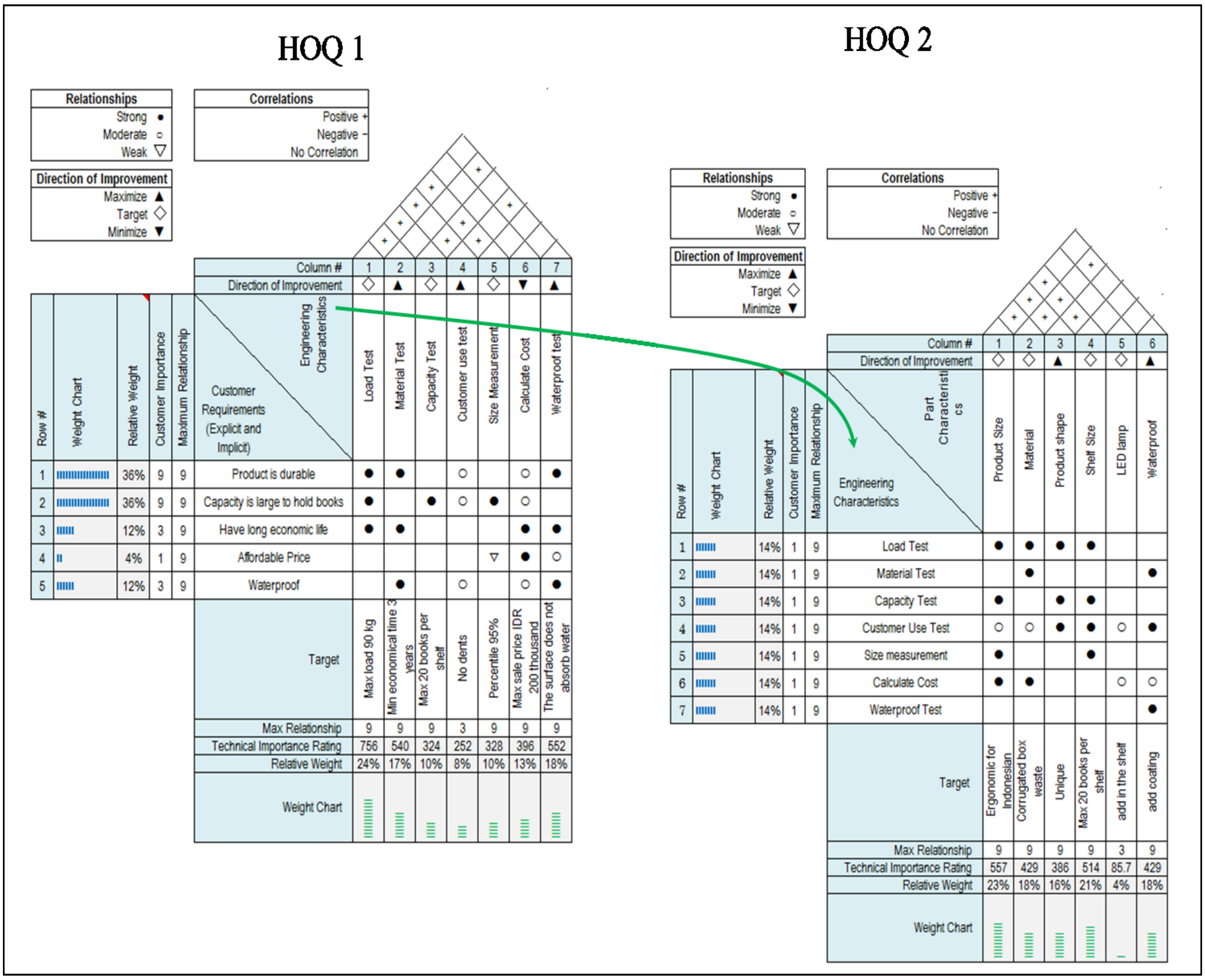

Figure 2. House of quality 1 and 2

The concept generation consists of details of product shape and design, how the products work and product technology. The details are illustrated in the form of a sketch drawing and the results of the concept generation are three alternative concepts shown in Figure 3. The general idea is to use the modular form because product modularity is a key concept for the application of environmental strategies (Giudice et al., 2006) and the preliminary data show the need of a table, chair, and shelf, thus it was decided to use sectional-modular architecture type so one product can be used for three different functions. Modular product design (MPD) has the advantage to escalate manufacturing efficiency, decrease inventory cost and logistics (Chiu & Okudan, 2014; Ma & Kremer, 2015). The product is named Mersi, which is an abbreviation of the table, chair, and shelf in the Indonesian language (*meja, kursi, lemari*). The research teams experimented with several sketches and decided to make the product using Gehry methods. The advantage is this method could give a creative shape that a folding technique cannot compete with, while the disadvantage of this method is it requires more material than the folding technique. However, the advantage outweighs the disadvantage since it can give a more appealing look.

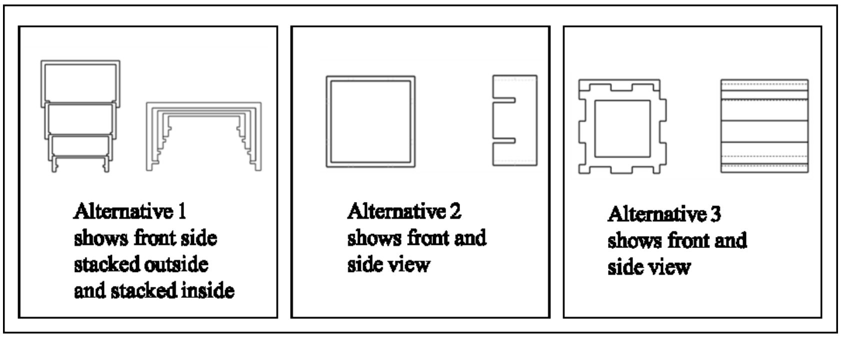

Figure 3. Alternative designs

The concept selection using concept screening for the three alternatives is depicted in Table 2. The selection process uses alternative one as a reference and compares the other alternatives and given a minus in every criterion if the research teams consider it is worse than the reference; it is given a plus if considered better than the reference and given a zero if it is the same as the reference. The pluses, equals, and minuses were counted for every alternative and then the net was calculated from pluses and minuses. We ranked the alternatives to decide which alternative will be developed and the team decided on concept 3.

This phase is carried out simultaneously with steps 2 of DfE, which are potential environmental impact identification and selection of DfE guidelines. In stage 2 DfE, potential environmental impacts are identified at each stage of the life cycle, which consists of materials, production, use, and recovery by making any environmental impact questions that may arise at each stage. The DfE guidance for this research decided to use the original Herman Miller's DfE protocol. The potential impact at the design stage is useful for teams in considering environmental impact at the concept stage when there is little or no specific data available yet (Ulrich & Eppinger, 2016).

This research uses qualitative life cycle assessment using a chart that is shown in Figure 4 that was adapted from Life Cycle Design Strategy Wheel created by Brezet and Van Hemel in 1997 (Brezet & Hemel, 1997) and EcoDesign Web (Bhamra & Lofthouse, 2016). The advantage of this qualitative tool is that it is quick, and the disadvantage is that it is subjective (Wever & Vogtländer, 2014). Bersano, Fayemi, Schoefer, & Spreafico (2017) also support the qualitative tool for SMEs (Small Medium Enterprises) due to the reduced time for the assessment. The chart created from the team's judgment from each list of the potential environmental impacts in each life cycle stage. The height of each bar in each life cycle stage shows the magnitude of overall potential environmental impact based on the team's judgment (using Likert scale from 1 to 10) and should be considered in the DfE effort. The emissions of distribution and recovery can be counted if the product is already sold in the market, so in this design phase, it is excluded and only on the material, production, and use, then the distribution and recovery stage is not discussed any further.

Table 2. Concept screening matrix

Selection Criteria	Concept Variants		
	2	3	Ref (1)
Product strength	-	+	0
Capacity	0	+	0
Life time	0	0	0
Price	0	-	0
Waterproof	0	0	0
Pluses	0	2	0
Sames	4	2	0
Minuses	1	1	0
Net	-1	1	0
Rank	2	1	3
Continue?	No	Yes	No

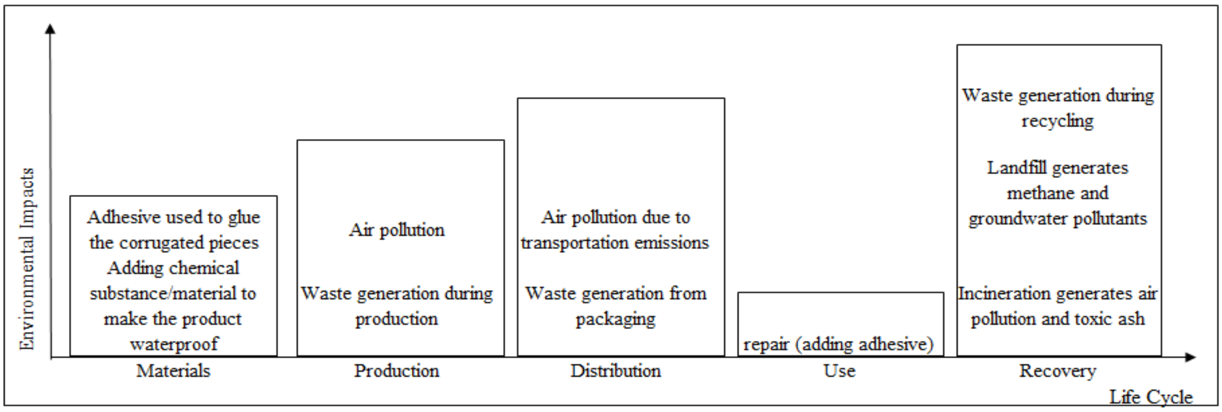

Figure 4. The qualitative life cycle assessment of Mersi

3.3 Phase 2 System-Level Design and DfE stage 3

Phase 2 is System-Level Design and the product architecture is explained in this stage. Mersi is designed with a Lego-like shape and is modular, which means it can be arranged according to the user wants, including a coffee table, chair, and shelf. One module of Mersi consists of a top and cube module. The DfE guideline in this phase is the application of DfE in the initial product design. Since the material has been set up in the beginning, the research teams sketched several dimensions to find the right size that maximizes the material used and reduces the material waste at the production phase.

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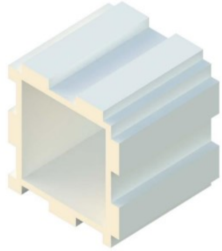
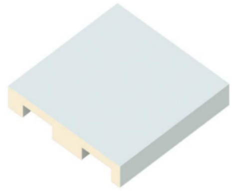
3.4 Phase 3 Detail Design and DfE stage 4

Detail design is phase 3, which consists of the ergonomic study, prototyping, Operation Process Chart (OPC), and cost estimation. The size of the cube and top module of Mersi refers to the anthropometric size of an Indonesian female using the smallest size as a consideration for the convenience of using Mersi. The anthropometric data is obtained from Antropometri Indonesia (2017). There are three anthropometric data taken as a reference, that is the popliteal length, hip-width and popliteal height that are 41.66 cm (5th percentile), 34.99 cm (95th percentile), 38.99 cm (50th percentile) respectively. Based on that, the dimension of one module of Mersi is 41 x 41 x 41 cm with specifications as in Table 3.

Table 3. Mersi specification

Parts	Function	Material	Dimension	Sketch
Cube Module	Store items and to serve as table or chair when combined with the top	Double layered corrugated cardboard	41 x 41 x 41 cm	
Top Module	Being a sitting mat or table surface	Double layered corrugated cardboard	41 x 41 x 5 cm	

The alpha prototype is made based on this specification where the prototype is used to test the function, design, and geometric shape. The alpha prototype is depicted in Figure 5. The alpha prototype was evaluated by research team and several college students were interviewed. It was suggested to add something that is visually appealing. The shape is unique and the respondents liked the model, therefore, the research teams decided to add an LED lamp inside the cube module to add attractiveness to Mersi. The Operating Process Chart (OPC) is made based on the making of the alpha prototype, which consists of 322 operations and 2 inspection with a total time of 24,841 second (6.9 hours) and the cost production of IDR 432 thousand (USD 29), with the highest cost in making the knife for cutting since the material is from waste.

Figure 5. The alpha prototype

The DfE in the detail design phase is a measurement of environmental impact using the Herman Miller DfE Protocol (Ulrich & Eppinger, 2016). There are four factors used to measure each product component as can be seen in Table 4. The four factors are assessed based on the fraction value; if the fraction value is close to 1, it means that it is environmentally friendly. Data on the prototype are as follows:

a. Total prototype weight = 5000 grams.
b. The weight of corrugated cardboard material = 4800 grams.
c. LED lamp weight = 15 grams.

Table 4. Environmental impact measurement of the alpha prototype

Assessment Factors	Fraction
Material chemicals	0.997
Recycled Content	0.96
Disassembly	1
Recyclability	0.963

The calculation for every assessment factor for the alpha prototype, as follows:

a. Material chemicals. The material consisting of chemicals from the alpha prototype are only X4 crossbond glue. However, as explained above, the glue used is environmentally friendly, so it does not cause toxicity. Based on this, the material chemical factor fraction was obtained by reducing the total weight of the alpha prototype with the weight of the LED light and dividing it by the total weight of the alpha prototype, so that the results of 0.997 showed that the prototype was environmentally friendly because the chemicals in the product were few.
b. Recycled content in the prototype alpha is a corrugated box. This makes the fraction calculation for the recycling factor obtained by dividing the weight of the cardboard with the total weight of the alpha prototype so that it is obtained 0.96. The fraction results are close to 1, which indicates that the prototype is environmentally friendly because most prototype components consist of recycled content.
c. Disassembly. All components in the alpha prototype can be disassembled, resulting in a fraction equal to 1 and indicating that the prototype can be completely dismantled.
d. Recyclability. The material in the alpha prototype that can be recycled is cardboard and LED lights, so the fraction calculation is obtained by adding the weight of the cardboard and LED lights then dividing the total weight of the prototype alpha, and the results are 0.963. Based on the results of the fraction, the prototype is environmentally friendly because most of the components in the prototype can be recycled.

Overall, the fraction for every assessment factor is close to 1, meaning that this alpha prototype is environmentally friendly.

3.5 Phase 4 Testing and Refinement

Phase 4 testing and refinement is a prototype evaluation using a questionnaire, validity and reliability test, and performance rating. The questionnaire was prepared based on five categories as a quantitative measure to assess the quality of Industrial Design (Ulrich &

Eppinger, 2016), which will result in the performance rating of the product. The prototype test was conducted on December 6, 2017, in an exhibition at the University of Pelita Harapan, Tangerang, Indonesia from 10 a.m. to 4 p.m. The future customer or the primary target of Mersi were testing the product and filled out the questionnaire afterward. There were 54 respondents, but only 48 that could be processed due to inconsistency in answering the filter question. The validity and reliability test was conducted and the results show the questionnaire is valid and reliable. The performance rating was calculated based on the questionnaire results, and it shows that Mersi has a high value in all five categories, that is quality of the user interface 4.29, emotional appeal 4.28, ability to maintain and repair the product 3.969, appropriate use of resources 4.448, and product differentiation 4.6, with an overall 4.32 from the scale of 5. The questionnaire also asked what price the respondents would be willing to pay and the results are around IDR 200 to 250 thousand (USD 13.5-16.9) for one module.

3.6 Phase 4 Testing and Refinement

The last phase is phase 5, production ramp-up, where the final product is made. The alpha prototype is not yet waterproof, thus in this phase, coating made from vinylon and PVC board was added to Mersi. Although the two coating materials are not environmentally friendly, the use in the product is small compared to the whole product. The DfE calculation for the final product is summarized in Table 5. The same calculation with DfE protocol in the alpha prototype with differences because the vinylon and PVC board is included in the calculation where the weight is 15 grams and 800 grams, respectively. Figure 6 shows the final product. After calculating the production cost, the selling price of a set of modules establishes at IDR 225 thousand (USD 15.18).

Table 5. Environmental impact measurement of the final product

Assessment Factors	Fraction
Material chemicals	0.997
Recycled Content	0.825
Disassembly	1
Recyclability	0.828

Even with adding vinylon and PVC board, overall, the fraction for every assessment factor is still close to 1, meaning that this product is environmentally friendly.

Figure 5. Final product

3.7 Discussion of the Steps in Product Design

The questionnaire results show that this product has a high-performance rating and it shows that this product will be liked by the target market. The steps in the product design show a simple calculation and a simple approach to make an environmentally friendly product. The framework shows a simple approach at the design stage until finalizing the product with integration of DfE guidelines compared to other research that uses the LCIA approach.

4. Conclusion

The waste utilization of corrugated box was successfully carried out in this research in the form of environmentally friendly and ergonomic furniture using the integration of product design from Ulrich & Eppinger (2016) with the DfE. DfE is important in product design in our effort to save our planet. This research has shown how a product can be made from waste with DfE guidelines in the steps of the design process. The DfE protocol from Herman Miller is suitable at the design stage of the product with a simple approach and a simple calculation of the impact to the environment where usually the designer does not yet know the process and material that will be used for the product. A Small Medium Company and individual who may not have knowledge about DfE can use this approach to design an environmentally conscious product without having to buy expensive LCIA software.

Further research will calculate the economic analysis for commercialization-ready. This research used the qualitative life cycle approach, which is appropriate in the design phase. The quantitative life cycle approach should be used after the product is ready for commercialization and also to measure the impact on the environment.

Acknowledgments

Universitas Pelita Harapan fully supports the registration of industrial design rights and Mersi was registered on March 2nd, 2018 with registration number IDD000051221 (https://pdki-indonesia.dgip.go.id/index.php/di/Q09selJyQlZuMklZQkpqQjZnSVZuZz09?q=mersi&type=1) and support from PT Pertamina that gave the corrugated box waste for this research.

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