Integration of design for environment principles and guidelines into study desk design

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Abstract. Design for Environment (DfE) Principles and Guidelines have been developed to guide designers in creating product concepts from the planning phase. This research integrated Telenko’s DfE Principles and Guidelines into Ulrich and Eppinger’s Product Design and Development to provide a simple structure to design a product with DfE for non-expert and small companies with the aim to design a marketable ergonomic study desk that uses environmentally friendly material and design. The study desk made from pinewood which is from ex-pallet wood. It is designed with dowel joints without nail and bolts which is in line with DfE guideline. After making two prototypes, the finished product evaluated and tested using a questionnaire. The results show that the desk has a high-performance rating of 4.78 out of 5. 77% of respondents choose big smile face, 15% choose smile face and 8% choose a neutral face for their feeling about the desk. It means that respondents like the desk, so it is expected that this desk will be liked in the market. The results also show that respondents think the appropriate selling price is 500 thousand rupiah or around $34.4. This study desk has been registered to have Industrial Design, Intellectual Property Rights on March 2, 2018.

Keywords – Design for Environment, Study Desk Design, Product Design and Development

1. Introduction
A product is something that the company sells to its customers and every product has an environmental impact [1]. The environmental impact of a product can be divided into two main categories namely energy and material. In the early 1980s emerging design practices were directed to regulate the use of energy and materials to create environmentally friendly products [2]. Sustainable product design and manufacturing has become an obligation to the environment and society itself [3]. Indonesia also concerns with environmental impact from production. Program Penilaian Peringkat Kinerja Perusahaan, abbreviated PROPER (The Corporate Performance Rating Assessment Program) is one of the efforts of the Indonesian State Ministry of Environment to encourage compliance with the company in environmental management through information instruments [4]. The PROPER not yet regulated from the design stage, but the design stage is crucial because of the impact to the environment in the form of material, production, and transportation. The choice of green design is inevitable because it can achieve the harmony of the environment, social and economic development [5].

Ecodesign approach had positive financial and non-financial impacts on companies and it is a promising strategy for improving a company’s profitability [6]. Design for Environment (DfE) methods has been proposed since the first half of 1980 and known also as Green Design (GD),...
Environmentally Conscious Design (ECD) and EcoDesign [2]. The term Green Design, EcoDesign, Sustainable Design, and DfE are more or less synonymous today [1] so the term DfE used throughout this research.

Design for Environment (DfE) Principles and Guidelines have been developed to guide designers in creating product concepts and shapes from the beginning of the product planning process and Telenko has compiled and suggested DfE principles and guideline in creating product concepts and layouts that can be implemented in the early conceptual and embodiment design stages when lack of time and detailed information prohibit a full Life Cycle Analysis [7]. Bovea and Perez-Belis categorized tools for DfE as Design Matrix, Quality Function Deployment (QFD), Value Analysis (VA), Failure Mode and Effect Analysis (FMEA), TRIZ and Kano Model [8]. Integration of DfE into Product Development has been done, yet many organizations not knowing how to do it effectively as Hallstedt et al and Ameknasi et al said [9,10]. Ameknasi et al use the electronic industry as an example to test the application of their integrated approach of design for environment (DfE) into Product Development Process [10].

As Bovea and Perez-Belis said that tools for DfE vary widely in their complexity, quality, and time required to apply them and no clear classification which of the tools is the most suitable approach for every application [8], then this research integrate Telenko’s DfE Principles and Guidelines into Ulrich and Eppinger’s Product Design and Development Steps to provide simple structure to design a product with DfE for non-expert and small companies. A study desk was chosen as a product to develop with a function for students to study comfortably. The target market for the study desk are students from junior high school to college students. Material that chosen for the study desk is from wood, because according to the calculation of the Environmental Priority Strategies (EPS) method, the wood material has Environmental Load Units (ELU) or the environmental damage value of a material is 0 which means the wood material does not have an adverse impact on the environment where EPS is a systematic approach to environmental impact calculations based on the product manufacturing process [11].

This research aims to design a marketable ergonomic study desk that uses environmentally friendly material and design using integration DfE Principles and Guideline into the Product Design and Development Process.

2. Methodology
Telenko’s DfE guideline consists of 6 guidelines from A to F where A is to maximize availability of resources, B is maximized healthy inputs and outputs, C is minimized use of resources in production and transportation phases, D is minimized consumption of resources during operation, E is maximized technical and aesthetic life of the product and components, and F is facilitate upgrading and reuse of components [7]. DfE Principles and Guidelines integrated throughout the design process. This research uses product design and development from Ulrich and Eppinger and the integration with DfE Principles was depicted in figure 1.
3. Product Development Phase
The product development phases were described in detail as follows.

3.1. Phase 0 Product Planning
This planning phase is called a zero phase because this stage is the initial stage of the project. The idea is to use end-of-life strategies which are recycling where the material is recycled to be a new product. The material chosen for the study desk is wood that already becomes waste and we found that expallet wood is plenty in Tangerang where the main source is from Merak Port, Serang.

Desk design in a modern world identical to the use of nails and bolts where the material is classified as materials that require a long and more difficult recycling process than woods. This guideline brings the research to find the suitable joints for the study desk and history show that Japanese already use a connection technique at woodworking called sashimono since the 17th century. Sashimono is a technique of combining two pieces of wood without the use of nails and bolts where the meaning of the word Sashi means insert [12]. Indonesia also has a long history of making a table using wooden pegs to connect parts of the table, especially a heavy table that uses material from *Samanea saman* or *Tectona grandis* tree. There are many types of joinery, but basic woodworking joints are butt joint, dado joint, dowel joint, lap joint, miter joint, mortise-and-tenon joint, through-dovetail joint, and tongue-and-groove joint [13]. The production is subcontracted to a local carpenter and due to the skill of the carpenter, it is decided to use basic joints, that is dowel joint, although if the joint more complicated, the stronger the joint.

The DfE guideline in this phase is guideline A and F which guideline A maximize availability of resources where the abundant and recyclable resources is found, minimize the variety of materials in the products and guideline F facilitate upgrading and reuse of components where minimize the number of tools required for disassembly/assembly, make component interfaces simply and reversibly separable [7]. After the planning, the mission statement for this research was formulated, that aim to make an environmentally friendly study desk, with college students as a primary target while junior and high school students become the secondary target. The key business goal of this research is that this desk can be produced in 2018 and the stakeholder of this research are future users and the design team.

3.2. Phase 1 Concept Development
This stage is the development of concepts consisting of several activities such as competitor analysis, customer needs identification, concept generation, selection, and concept testing. These stages are expected to build and deliver value-added products that will be created based on customer needs.

Competitor analysis is conducted to see the strengths and weaknesses of competitor products that have similar functions with products to be designed. There are two competitor products that were analyzed, Lisabo Table from IKEA and Vesar Table from India. The IKEA table product has a wedge dowel concept similar to a screw system and fitted by inserting and shifting the legs of the desk. This product still uses bolts for assembly but the number of bolts used is very minimal (just one for each leg) compare to other products. Vesar table (INDIA) in their advertising stated that they use less screw. However, the table parts consist of several large boards that make this study table less environmentally friendly because of overuse material usage. Both of the products have one position where users have to use the chair when using the desk.

After the competitor analysis, the next step is the process of identifying customer needs, which consists of collecting raw data from customers using questionnaire about the desired study desk, then
interpreting raw data into customer statements, followed by grouping customer statements as Voice of Customer (VOC). VOC was converted to House of Quality (HOQ) 1 to relate VOC with Engineering Metric and continued to HOQ 2 that link Engineering Metric with Part Characteristics. HOQ 1 is a method that transforms consumer needs into technical design quality based on the level of importance of each existing consumer voice. Technical Targets for each existing Engineering Metric are the objectives or technical targets to be achieved by conducting a survey, ergonomic test, product usage test and weight test, which is expected to be measurable and answer the needs of the target market, have the convenience, safe, environmentally friendly and fit the customer wants. HOQ 2 shows the most important part is bookends and desk boards indicated by importance percentage of 29% and 25% respectively.

The next step is concept generation of this product with the making of several alternative concepts that prioritize the important things of the HOQ that has been done. Before making several concepts, the steps are searching for a similar product using external and internal search. The external search is the search of the design patent to find out whether there is already a similar concept. The patent search was conducted in September 2017 at the website of the Directorate General of Intellectual Property [14]. Internal searching is done by brainstorming and looking at the desk designs in the shops and website. The design idea must consider the voice of the customer that has been translated to HOQ so that the designer knows which things are important to the customer. However, not all the things that the customer wants will be incorporated in the design. The designer has the freedom to choose from importance in the HOQ, which one will be included or excluded in the design. The DfE guideline in Concept Development phases is guideline C that minimizes the use of resources in production which is to minimize the total volume of material and minimizes the number of components. This process produces 3 alternative concept designs which depict in Figure 2.

![Figure 2. Three alternative concept designs](image)

The next step was concept selection, where the final decision of the concepts which will be used in the next stage. The process uses external decision using voting to 100 people and the results are 54% choose the third concept, so the third concept is continued to the next stage.

Here are some advantages of chosen concepts compared to competitors products that are has features such as custom wooden photo, bookends, stationary holder and book holder, affordable price (estimated sale price) 500 thousand rupiah or around $34.4 (IDR to USD in July 2018 = 14,500) which is cheaper than competitor (competitor price around $144), easy to assemble, easy to move, adjustable because user can use two positions (used while sitting in the chair and used when sitting on the floor or mattress).

3.3. Phase 2 System Level Design
This stage is the stage of making product architecture that discusses the definition of each product section. Products can be divided into functions and physical [1] where the study desk functional elements are “for study activities such as writing, reading and storing stationary and books” and physical elements are parts and components that have been defined in concept development.

3.4. Phase 3 Detail Design
In this stage, the design will be detailed using ergonomic studies, material selection, the design of each part of the desk, and build the prototypes, and made the operation process chart of production. The ergonomic study was conducted with anthropometric data accessed through the www.antropometriindonesia.org to obtain human body size data with age 12-25 years, Indonesian data, and in accordance with percentile concept [15]. This research use anthropometric of Indonesian people from website www.antropometriindonesia.org [16] and these are the measurement that used in the design:

1. The overall height of the study desk
   The elbow rest height (sitting) added to the popliteal height (sitting) using male and female data with 50% percentile so both genders can use the study desk comfortably. The results of Indonesian data is 70.02 cm. Optimal work surface height for reading or writing is 28-31 inch (71.12 – 78.74 cm) [17] so the results rounded to 75 cm as an allowance for the thickness of the top table since it still in acceptable range.

2. Study desk height for users that sit in the floor/bed
   The elbow rest height (sitting) from the previous data used, which is 27.76 cm and rounded to 35 cm due to traditional sitting will raise the height of elbow rest height.

3. The length of the study desk
   Data of Indonesian people are not available for functional arm reach, so the span of arm length and elbow with 50% percentile is 161.8 cm and 85.16 cm respectively. A functional arm reaches based on Roth, Ayoub and Halcomb study in 1977 that measure the direction of arms reach and the nature of the manual activity for male and female minimum 40 cm and maximum 90 cm [15]. Minimum length of the working area for top table work is 40 inch (101.6 cm) [17] It is decided to use the length 100 cm for the length of the study desk.

4. The width of the study desk
   The dimension of forearm reach with 50% percentile of Indonesian people is 70.84 cm. The minimum width of top table work is 20 inches (50.8 cm) [17]. The study desk is using 60 cm so the user can reach easily because the width of the desk is smaller than the length of arms reach.

   The edge of the study desk is designed with a slope so that there is no trace of pressure if the hands lean on the desk when doing writing or typing activity.

   The material study is a principle that emphasizes the selection of resources to be used as a basic step for designing environmentally friendly products which have been chosen in phase 0 but detailed more in this third phase. The material selection using Design for Environment (DfE) Principle A which are determine the material of the recycled product (end-of-life strategy), utilizing the unique properties of recycled materials, using similar materials throughout the product components, determine compatible materials for recycling, determine one type of material for the product and its subassemblies, determining non-composite materials, not mixed and no alloys. The materials for the study desk is only one material from ex-pallet wood from pinewood with no nails, bolts or screw.

   Principles and Guidelines Design For Environment B, C, D, E, and F are integrated into the specification stages of the product components. Principle B is a principle that takes into account the health and safety of users viewed on the basis of the materials used in the final product which is the result of the raw materials used. This research uses end-of-life strategies which use recycled materials to be used as new products. The study desk using wood as inputs that serve as raw materials as well as output is a desk made wholly from wood. The production process uses clear coating (water based varnish) to get the natural wood color as well as to protecting, preserving and beautifying the desk.
DfE Principle C is creating an environmentally friendly production process, that minimizes waste production, minimizes the stages of the production process, minimizes the number of components designed, determine the clean and efficient production process. Principle C encourages designers to think about how product attributes affect process efficiency. This stage provides direction in developing and measuring products to reduce material waste in production and reduce excessive use of materials. Components of the desk will be very minimal because only use wood materials without metal components.

Principle D is the product use, where the design has minimum volume, width and weight of the product, create features that prevent waste of materials by users, care of easy products, the product is designed by reducing energy use at the time of its use, and it has a unique aesthetic design. The desk uses an ergonomic scale to fit the right size of arm span so it has the right size. The varnish protects the desk surface for easy treatment by wiping the surface. This product also does not use any energy in its use because there is no source of electrical energy in the product. The design of this product is also made unique so that users could adjust the height and change the placement of bookends or photo at the desk.

Principle E ensures product durability designed to be used for long periods of time and durable for longer product life cycles. The desk was designed with a functional, aesthetic design and quality to be used in long-term. Principle F is the principle that governs the demolition stage of the product or when the product is damaged. The components of this desk could be replaced easily, the process of disassembly is very simple and could be done by hand, and all the parts can be cleaned easily with only use a piece of cloth and a small amount of water. All the parts of this desk can be recycled to another ex-wood form. Figure 3 shows the final design sketch of the chosen alternative.

![Figure 3. Final design sketch](image)

There were two prototypes made in this research. First is the Alpha prototype, which is made using wooden dowel material with diameter 10 mm and balsa wood board 100cm x 10cm x 1cm with scale 1:5. The leg and table were joint using glue and the sandpaper used to smooth the surface. The alpha prototype only shows the design and not its function due to the limitation of small size. The latter is preproduction prototype or also called pilot-production, which is supposed to be the first product produced using the actual production process. In this research, the production processes were at a wood workshop at Tangerang area and use a carpenter to produce one prototype. Because of the limited time and difficulty to find ready stock of environmentally friendly varnish, the prototype uses the existing varnish in carpenter’s workshop.

3.5. Phase 4 Evaluation and Improvement
At this phase, the pre-production prototype evaluated qualitatively and the improvement was made before the finished product was produced. The prototype was tested by 10 college students of the
Industrial Engineering University of Pelita Harapan and based on their suggestion the improvement was made. The first improvement was adding a hole with a distance of 15 cm from an initial position in front of the book holder which shorter distance for tablet and longer distance for book placement. The second improvement was made to the legs, by adding rubber to make the desk more stable. After the second improvement, the Operation Process Chart was made and there are 182 operations and 25 inspection and total production of approximately 3,746 minutes or 62.43 hours. Figure 4 shows the final product.

![Figure 4. Final product](image)

Assessing the quality of Industrial Design for a finished product is subjective, but Ulrich and Eppinger suggest to qualitatively evaluate the product use five categories [1]. This research uses these five categories and developed it as a quantitative measure in the questionnaire for the finished study desk. The questionnaire made in three parts. The first part was product assessment that uses Ulrich and Eppinger’s categories to assess the quality of study desk design. The dimensions to assess the quality of the design are quality of the user interface, emotional appeal, ability to maintain and repair the product, appropriate use of resources, and product differentiation.

The second part of the questionnaire asked the respondents to estimate the suitable selling price for the desk. And the third part was an overall feeling of respondents toward the desk. The questionnaire was distributed at a one-day exhibition that was conducted in University of Pelita Harapan at 6th December 2017. The visitors were asked to test the desk and fill out the questionnaire. There are 56 filled questionnaires, however, only 52 questionnaires can be used due to inconsistent answers in the filter question. Validity and reliability test shows valid and good reliability.

The respondents were college students where 63% are female. The first parts of the questionnaire translated to performance rating use calculation of the average value of each statement with a rating scale from 1 to 5 (low to high). The performance rating results that dimensions of quality of the user interface are 4.76, emotional appeal 4.84, ability to maintain and repair the product is 4.88, appropriate use of resources 4.57, and product differentiation is 4.88 with overall value is 4.78 from the scale of 5. This value shows that the desk has a high-performance rating. The second part results that the majority
of respondents (45%) gave an opinion that the desk should be sold at 500 thousand rupiah or approximately $34.4. The last part is the customer expression to determine the respondents feeling towards the desk. There were 77% of respondents choose the expression of a big smile, 15% choose a smile expression and only 8% give a flat or neutral expression. No respondent gave no smile expression so it is estimated that this desk will be liked in the market.
4. Conclusion and further research
This research runs a series of the design process and product development of study desk from ex-palette wood with DfE principles and guidelines. The study desk has a good value for commercialization based on high-performance rating and 77% choose the happy expression that shows customer feeling toward the desk. Further research will be conducted to prepare for commercialization of the desk by partnering with industry particularly small micro medium enterprises to boost the local economy.

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