Eco-friendly for product design: A literature review

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Abstract. This study focused on the research of the concept and implementation of eco-friendly design-based products over the years. Pertinent literature was reviewed in order to develop a comprehensive table of the empirical studies that pointed to the numerous findings which are linked to this investigation. The summary from 23 previous studies identified some variables, including design product, concept, and results. From the data, pro-environmental design concepts that were kept hidden in eco-friendly goals were used in various fields such as education, health, and engineering. In addition to the discussion of findings and contributions of the previous research, this study identified the gaps in the featured literature and suggested potential topics for eco-friendly product design research. Thus, this study aimed to provide a brief review of how the variables in this research could encourage the implementation of eco-friendly concepts and practical values.

1. Introduction

Although many articles have examined the eco-friendly product design concept and its effect on consumer attitude [1], the term eco-friendly is still a serious topic. The combination of design and environment for special products has become a complex issue in the human mindset. Although studies tended to focus on the adoption of environmentally friendly lifestyles, such as recycle, ozone-friendly, reusable, and renewable concepts [2], the eco-friendly context has also been applied in various productions around the world, such as in furniture in Turkey [3], in fashion in Indonesia [4], and in architecture [5]. The eco-friendly concept can be attributed to a few things. First, it can be attributed to local materials such as bamboo, wood, and green consumerism that reflect people’s awareness of environmental issues. Furthermore, the environmental impact is rooted in real-life situations. This can be seen from Indonesia, which loses natural resources due to poor governance, poverty, and increasing population [6]. Finally, considering the local materials and environmental impact, eco-friendly product design should be developed to encourage environmental protection as well. While previous studies found that life cycle phases, namely development, manufacturing, and usage, were concluded, this research suggested one step further by applying green consumption. Green consumption is a simple step towards the environmentally friendly concept. It forces humans to consume only the selected advertised products.

However, some eco-friendly concepts are just temporary design concepts. The environmentally safe quality of a product remains debatable because of the credibility of the information, consumer behavior, consumer education, green consumer, and product certification [7]. Green consumers are more conscious of environmental issues and live an environmentally friendly lifestyle to reduce
environmental problems [8]. Furthermore, the eco-friendly concept might be sensitive to environmental effects. Thus, the consideration of the environmental effects on product design and environmental sustainability is effective in reducing the gap.

This study examined 23 papers in total published in the last several decades. These papers were organized according to the publication year and were investigated based on three different attributes, namely product design, concept, and results as listed based on the year of publication. This study surveyed eco-friendly products on various topics, such as architecture, tourism, customer behavior, green consumers, and household. All selected papers were based on the concept and product implementation model. The papers explained in this study reflected the outline of what has been published so far. However, this study is not a complete review of all the papers in product design results. The selected papers were based on the similarity of product design concept, method, and result. Selected papers reviewed in this study were provided below.

2. Papers in review
The papers reviewed in this study were explained based on the publication year. The papers were selected from reputable journals and conference proceedings. The papers were categorized into three groups that not only represent decades of the year of publication but also the change of research area. There were only four papers selected for the 1990 to 2000 group due to a lack of studies related to the designated topic. The total number of papers reviewed in this study was 23 and was divided into three groups as follows:

- 1990 to 2000: 3 papers
- 2000 to 2010: 10 papers
- 2010 to 2021: 10 papers

2.1. Studies in 1990 to 2000 (3 papers)
First, Mildenberger & Khare [9] have applied environment-friendly cars to change company responsibility in technical and environmental performance. This research investigated three aspects of available tools for balancing ecological, technological, and economic production. The product was known as the German automobile industry, SMART from MCC AG. The smart concept resulted in high recyclable contents in the vehicle interior, exterior, and technical complex sections. Technical complex sections like the cockpit had more than 10% recyclable proportion. In addition, the module replaced 20 conventionally designed components that claimed could save additional resources.

Study from Kriwet et al. [10] analyzed the incorporation of recycling in product design. There were four fundamental networks for recycling, namely designers, consumers, recyclers, and suppliers. It utilized a case study that allowed the industry to take responsibility for the life cycle. The result showed that its networks could be used to consider the inclusion of the recycling process in the product design. The company needed to adopt a recycling approach because combining innovative technologies might turn the recycling activities to be profitable.

Storen’s study [11] investigated extruded aluminum which was appropriate to be used in environment-friendly products. There were four principles in improving eco-efficiency, namely better, cleaner, faster, and cheaper products and services. The improvement in efficiency could encourage the life cycle to be a part of the infrastructure of the society and natural ecosystem. They applied a regulation in which competition should be adapted among industries, universities, educators, and governmental organizations. Thus, it became a way to increase eco-efficiency in society.

2.2. Studies in 2000 to 2010 (10 papers)
Turner [12] assessed education technology for 6 practical learnings. These were strongly focused on helping students to solve problems in the eco-design contexts. It was also trying to solve the problem in how to encourage brainstorming, brainwriting, metaphoric thinking, outrageous thinking, mind mapping, problem-solving, and SCAMPER. An advanced and smart technology based on eco-friendly strategy entitled ASIT (Advanced Systematic Inventive Thinking) was used. Based on the concept, the
goals or mandatory concept identified by researchers regarding world business council for sustainable development can be seen in table 1.

| Identification | World Business Council for Sustainable Development |
|----------------|-------------------------------------------------|
| Seven goals    | Diminish material intensity in both service and goods |
|                | Lessen energy intensity in both service and goods |
|                | Minimize toxic depression |
|                | Increase recyclable material |
|                | Increase sustainable use of renewable resources |
|                | Minimize material durability |
|                | Gain service intensity of both service and goods |

It was suggested that only a limited number of eco-design concepts that focus on problem-solving design have been taught at the school level mainly due to educators who lacked knowledge about these designs. Unfortunately, teachers were traditionally focusing on problem-solving instead of the final product as a fundamental output at practical learning.

Clark et al., [13] used incremental and radical innovation with one eco-design concept for sustainability in several aspects including social, economic, and environmental aspects. It was mentioned that sustainable innovation and design were highlighting the decrease in negative environmental and social impacts rather than focusing on creating new technologies. Developed countries have been targeted for sustainability design (D4S) as stated in the study. In addition, integration with industrial sectors was needed because sustainable production could not guarantee environmental benefits. Thus, further action for an unlimited environmental movement was recommended.

Another study published from 2000 to 2010 was carried out by Ilgin & Gupta [14]. It explored a deep background regarding why research on eco-friendly in manufacturing and product recovery (ECMPRO) should be conducted. The study stated that environmental awareness and recycling regulations had been applied to various manufactures and consumers. The phenomena were started by indicating and forcing consumers and manufactures to produce in an environmentally responsible manner. Unfortunately, ECMPRO was commonly established in its infancy in the last two decades. It received attention from the government and other community members due to concern about the global warming issue. However, there was a lack of environmental impacts from creating an eco-friendly concept for product design. The study formulated general conclusions from a literature review method as follows. The tendency of their studies on an eco-friendly concept for product design can be seen in the table 2.

Prakash, Bhojwani & Srivastava [15] studied plant tissue culture as a prospective element for a bioactive compound. Because it was proven effective to eliminate key pests, this study focused on the awareness of environmentally friendly and non-toxic pesticides. This study stated that plant cell culture had a prospect to be a substitute element for producing the Azadirachtin system. Azadirachtin was extracted from seeds of naturally grown whole plants which required meticulous work with uncertain geographical and climatic factors.

Demirbilek & Sener [16] explored some theoretical issues in ergonomics related to the emotional content and semantics of design. The basic concept was to design a product that could trigger “happiness” in communication and evoke positive emotions. Using the literature review method, the study found that design was exceptional in creating emotional content including happy feelings, joy, senses, fun, familiarity, cuteness, color, and metonymy.
Table 2. Result of Ilgin and Gupta’s study

| Identification                                                                 | Conclusion on an eco-friendly concept for product design |
|--------------------------------------------------------------------------------|----------------------------------------------------------|
| Seven points                                                                  | Environmental issues for art product design gradually increased in several investigations. |
|                                                                                | Design products traditionally focused on various areas with special issues such as environment, consumer behavior, economics, education tools, and material requirements. |
|                                                                                | Reverse Logistics (RL) studies needed more development in unlimited areas. |
|                                                                                | Remanufacturing system studies on eco-friendly design also needed more realistic analysis and integrated methodology. |
|                                                                                | There was a disassembly regarding ergonomics studies. |
|                                                                                | The study was dominated by a quantitative study instead of neural networks and fuzzy systems. |
|                                                                                | There was high degree research in RL (Reverse Logistics). |

Zulfia & Arana [17] investigated an industrial cooked dish based on eco-friendly principal. The study used a pilot experiment to develop an agri-food product. A life cycle assessment (LCA) was used to identify environmental performance regarding the production and distribution of a dish that contained tuna that was mixed with tomatoes. The study emphasized that eco-design for a new agri-food product needed to be analyzed because both topics were rarely associated with each other.

Baumann, Boons, & Bragd [18] discussed engineering, policy, and business perspective related to the mapping of its green product development. More than 650 manuscripts were analyzed by identifying the process, various contexts of the company, the product chain as well as society. Even though the study identified many aspects related to the research development, understanding the connection between companies and public policies was challenging. Thus, considering many layers of research and practice especially companies and policies, further research was needed instead of focusing on the theory. In addition, research in green product development should adopt a more systematic perspective regarding the internal process of product development within the firm, the process of competition as well as its cooperation among economic actors in the product chain. Governmental policy programs needed to be linked to this development processed to provide fundamental stimuli and barriers to green product development.

In their study, Bouguerara & Combris [19] investigated a unique topic of combining consumer’s motives and the concept of eco-design labeled products that focused on environmental problems. They recruited the premium consumers who were willing to pay for eco-labeled products because their (consumer) motivation was known as a selfish act or altruistic reason. The product was bottled orange juice with a retail brand that had two labels: organic and agricultural techniques contributing to environmental protection. The 128 participants were randomly assigned to two different groups, 70 participants and 58 participants respectively. An incentive-compatible experiment was done through within-subject and between-subject designs to study the effect of stating the product as eco-friendly and financially free on the premium consumers. The assumption was consumers’ willingness to pay for eco-labeled products was not motivated by higher taste. The result confirmed that in the between-subject design, the information not only affected but also controlled the buying price for the eco-friendly.
product. Even though the result of the study was significant, the samples were not suitable for socio-demographic subsamples.

Bereketli, Genevois, & Ulukan [20] studied eco-friendly or green product designs for special mobile phones. The background talked about the issue of hazardous substance management in the production of green products. Green principles then were expended in many departments because there was legislation pressure on the environmental side. The result showed that Eco-QFD which was a customer-driven product development tool could provide a framework for designing eco-mobile phones by blending the life cycle analysis (LCA) into QFD throughout the entire product development process.

Lastly, Lischuk [21] investigated eco-friendly technology in leather manufacturing. The study used the fibrous structure of animal skin’s collagen as a research subject which was indistinguishable biological material. The result concluded that the semi-manufactured product structure was environmentally friendly because of the chrome-free tanning.

2.3. Studies in 2010 to 2021 (10 papers)
Dubihlela & Nkxukumeshe [22] studied customers who shopped in various grocery retail stores with a survey method. The study used a total of 400 questionnaires with a cross-sectional study by applying a random sample as well. This study claimed that native respondents have understood environment sustainability due to their behavior in Southern Gauteng. However, the accuracy of the sample was not appropriate for targeted consumers because imbalanced respondents could not be generalized with equal behavior. However, there was a glaring gap in the consumers’ age in which adult and young groups may behave differently in many ways. In addition, this study focused on eco-friendly behavior in consumers without classifying the type of retailers.

Yüksel, E., & Kiliç, M. [3] analyzed product materials of pieces of furniture for health. The study applied a strong concept based on natural and recyclable materials. However, an example of sample product design materials was not appropriate as the title because the paper only focussed on previous study cases instead of creating an eco-friendly practical design concept. Even though some samples were art-based designs, this study found a unique ecological material for future design approaches.

Pusporini, Abhary, & Luong [23] predicted the QFD method by identifying customers’ environmental requirements regarding a life cycle analysis. These involved raw material design, manufacture, distribution, and usage to secure customers satisfaction. The result identified the house quality as the main attribute to describe customers’ essential needs to determine the priority order of environmental indicators.

MacDonald & She J [24] applied review research on encouraging pro-environmental behavior in various fields. The results of the study were then used to establish recommendations for eco-design. The environmental aspects were also utilized to explore the cognitive concepts that induced the purchase and application of eco-products. The aspects were behavioral psychology, business, consumerism, environmental psychology, and social science. The researchers created seven fundamental concepts for a successful eco-design, such as trust, responsibility, motivation, cognitive dissonance, decision heuristics, altruism-sacrifice, and complex decision-making skills. It was stated that pro-environmental behavior (PEB) was highly applicable in improving the eco-products design. However, this concept was quite questionable because the significant influence on U.S. engineers was determined by the influence of public policy on engineering design decisions. In addition, the study had a direct validation of the recommendations regarding its specific design example. An irrelevant review design method was used instead of a test on designer efficacy even though some deficiencies bridged the gap between the abstract cognitive concept and the application in eco-design. The result suggested a new design method in achieving better change in humans’ behavior.

Bracke et al., [25] studied eco and sustainability-related decisions in the conceptual design phase of a subsequent product generation. Using an automotive engineering example, the study mentioned layers of product generation of A and B respectively to observe the usage of the product life cycle. Surprisingly, B as a second-hand product generation several more demanding redesigns to improve the product. From
the point of view of an eco-friendly design concept for automotive products, it was important to focus on the physical functions as well as the remanufacturing process to upgrade second-hand products.

Vlaeminck & Vranken [26] focused on an incentive-compatible frame especially in the field of experiment. The study investigated whether information of products’ environmental impact evoked the behavior in food consumption. Using online experiments, the study identified product attributes on food especially a food label that presented the grade of eco-friendliness. A graded label entitled think global, eat local was more significant to encourage consumers by 10%.

Raza et al. [27] in 2012 investigated green computing technology (ICT) for eco-friendly and sustainable IT. It was indisputable that IT was able to save human energy and cost. However, some researchers believed there were various impacts on the environment regarding computer’s production and disposal given a strong background in which computer hardware used thin-client architecture to encourage global benefit. This study used two green design methods whose materials should be recyclable, and the manufacturer should maintain materials due to environmental impact. Recycling electronic components and applying energy stars for energy efficiency became fundamental points. The research objective was to improve the concept of green computing-based energy for energy-hungry centers. However, the study could not identify a need for efficient implementation and model for computing service sustainability.

Soegoto [28] investigated customer satisfaction regarding product quality and its environmental concept. The study used a quantitative method while the analysis used multiple linear regressions. Classical Assumption Test was used for the statistical aspects with the result of testing hypothesis at a significant level of 5%. 100 respondents were recruited randomly from modern market customers in Bandung. The result showed a positive relationship among variables that when the eco-friendly product quality was improved, customers’ satisfaction increased as well. Even though variables reached a significant level, the results were more understandable when the number of participants was bigger. In addition, the targeted modern market was correctly validated.

Singh, Sharma, & Malviya [29] used three basic eco-friendly materials related to their classification, uses, and benefits to summarize the future need for pharmaceutical packaging. Pharmaceutical referred to biological protection to protect for the product. It was designed against physical damage as well. Researchers claimed that their design could prevent any absorption and was marked as a global trend design. However, they cannot identify ways to reduce disposal that may cause problems for the environment.

Lastly, the study of Kumar & Anand [30] that focused on consumer behavior towards eco-friendly paper had a different result. The concept was to recycle to reduce harm to the environment. The study used questionnaires to collect primary data. The result showed that customers’ attitudes and personal norms had positive effects on purchase intention towards the eco-friendly paper. Eco-friendly use of paper could be seen from how people use it for printing, writing, documenting, and packaging in the paper industry. However, this study did not find a novelty because there were no differences from previous studies by Straughan & Ro [31].

3. Conclusion
This study surveyed the eco-friendly aspect in product design literature on various topics including education, engineering, health, biology, and art. Previous studies used different methods such as experiment, case study, Life Cycle Assessment, and survey, but literature review was the one used the most. This study also presented a review of listed literature published from 1990 to 2021. The conclusion can be drawn as follows:

- Eco-friendly product issues have an increasing fundamental concept among researchers. Hence, in recent years, there is a significant expansion in the number of studies on the green consumer as a strong reason to protect the life cycle for a sustainable environment.
- Eco-friendly product studies traditionally focus on multilayers eco-materials which allow for recycle method. However, collaboration with manufacturers and big industries regarding production is
limited. Thus, very eco-friendly designs which have direct-recycle innovations are been needed for further research.

- Eco-friendly literature is dominated by green customer behavior topics. It is commonly studied using sample cases from typically high-income countries. Thus, further research is needed especially on practical applications or software which is assessable online due to the Covid-19 pandemic especially those from developing countries.

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