Journal of Architectural Sciences and Applications
JASA 2023, 8 (2), 609-623
Research article
e-ISSN: 2548-0170
https://dergipark.org.tr/en/pub/mbud

A Multi-Dimensional Analysis of The Relationship Between Design and Material in Terms of Sustainability

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Abstract

The importance of sustainability issues has increased in every field. Industrial design is one of the important areas that will contribute to sustainability. In the article, it is focused on how to contribute to sustainability through design. The article focuses on the use of recyclable, environmentally friendly materials and reducing material consumption. Within the scope of the article, various studies have been carried out that examine the design-material-sustainability relationship. First, the importance of sustainability in industrial design was investigated. Secondly, the relationship between material and design in industrial designs has been examined in terms of sustainability. Thirdly, products focusing on sustainability have been designed by the students of the industrial design department. Fourthly, an experimental study focusing on sustainability in industrial design was conducted. The experimental study was carried out on metal furniture. Furniture design has been developed in a way that reduces the use of materials, the number of parts, and the number of processes in production and contributes to sustainability. Experimental study shows that design has a calculable impact on sustainability. All studies in the article show the effect of design on sustainability.

Keywords: *Sustainable design, material, energy sources, production process.*

Tasarım ve Malzeme İlişkisinin Sürdürülebilirlik Bakımından Çok Boyutlu İncelemesi

Öz

Sürdürülebilirlik konusunun önemi her alanda artmıştır. Endüstriyel tasarım sürdürülebilirliğe katkı sağlayacak önemli alanlardan biridir. Makalede tasarım yoluyla sürdürülebilirliğe nasıl katkı sağlanacağı üzerinde durulmaktadır. Makale, geri dönüştürülebilir, çevre dostu malzemelerin kullanımına ve malzeme sarfiyatını azaltmaya odaklanmıştır. Makale kapsamında tasarım malzeme sürdürülebilirlik ilişkisini inceleyen çeşitli çalışmalar yapılmıştır. İlk olarak endüstriyel tasarımda sürdürülebilirliğin önemi araştırılmıştır. İkinci olarak endüstriyel tasarımlardaki malzeme tasarım ilişkisi sürdürülebilirlik açısından incelenmiştir. Üçüncü olarak endüstriyel tasarım öğrencileri tarafından sürdürülebilirliğe odaklanan ürünler tasarlanmıştır. Dördüncü olarak endüstriyel tasarımda sürdürülebilirliğe odaklanan bir deneysel çalışma yapılmıştır. Deneysel çalışma metal bir mobilya üzerinde yapılmıştır. Mobilya tasarımı ürünün parça sayısını, üretimdeki işlem sayısını azaltacak ve sürdürülebilirliğe katkıda bulunacak şekilde geliştirilmiştir. Deneysel çalışma tasarımın sürdürülebilirlik üzerinde hesaplanabilir bir etkisi olduğunu göstermektedir. Makaledeki tüm çalışmalar tasarımın sürdürülebilirlik üzerindeki etkisini göstermektedir.

Anahtar kelimeler: *Sürdürülebilir tasarım, malzeme, enerji kaynakları, üretim süreci.*

Citation: Günal Ertaş, D. (2023). A multi-dimensional analysis of the relationship between design and material in terms of sustainability. *Journal of Architectural Sciences and Applications*, 8 (2), 609-623.
DOI: https://doi.org/10.30785/mbud.1309026

Received: *05/06/2023 –* ***Accepted:*** *16/08/2023*

1. Introduction

Nowadays, consumption is increasing gradually due to the growth of population and technological developments. The resources are getting decreased. Therefore, sustainability concept has become more important in every field. Industrial design is one of the important areas that will contribute to sustainability. Decisions taken during the design process are important in terms of sustainability. Industrial design includes the actions of designing, producing, using, and consuming. Industrial design is an area where materials, workforce, and energy are consumed. Thanks to the design, the consumption caused by the production processes can be reduced. There are several components that are effective in sustainable design. These components include the use of environmentally friendly materials and energy resources, energy-saving products, reducing material consumption, the number of processes in production and energy consumption, the use of natural and renewable energy resources, the shape, size, and number of parts of the product. Reducing the use of non-recyclable materials in industrial design can be beneficial for sustainability. Design is a creative field. The creative aspect of design can be beneficial for producing sustainable solutions. It is important to focus on sustainability in the design process. It is important to take decisions on design that contribute to sustainability. Thanks to industrialization, the production volumes of the products are very high. Sustainability becomes much more important in industrial design due to the high production volume. Industrial designs should be developed by paying attention to the environmental effects. Designers and manufacturers have to be conscious of sustainability.

In the article, it is discussed how product design can contribute to sustainability. Sustainability in industrial design is discussed in the article by focusing on the design-material relationship. In addition, the article focuses on the use of recyclable, long-lasting, eco-friendly materials and reducing material and energy consumption. Within the scope of the article, some examples of sustainable design are examined. In addition, some suggestions for developing sustainable designs are shared. A pilot experimental study has been performed to support these recommendations. Within the scope of the article, various studies have been carried out to show the effect of design on sustainability. First of all, a literature search was performed about sustainability in industrial design. Studies on sustainability in industrial design and product examples have been researched. Later on, material-design-sustainability relationships were examined in various examples of industrial design. It has been determined by what kind of factors these products contribute to sustainability. And also, new product design projects which focus on sustainability were developed. These projects have been developed by the students of industrial design dept. The project was carried out by the team which the author is in. In the projects, priority was given to the use of eco-friendly materials, the use of natural energy resources, and the limited use of energy. And also products that produce energy have been designed. Therefore, industrial designs contribute to sustainability using different features. In another section of the research, an experimental study was performed. This experimental study was executed on metal furniture. The results of the experimental study show the calculable impact of design on sustainability.

2. Material and Method

One of the methods used within the scope of the article is the literature scan. In recent years, various research and studies on sustainability have been carried out in Turkey and on international platforms. Studies on sustainability associate sustainable development with a political perspective, planning, environmental conditions, green cities, and green buildings. Studies on sustainability in direct product design are relatively less. Among these studies, there are projects carried out under the leadership of Politecnico di Milano. Manzini has performed studies and publications on sustainability. Also, some design firms and design schools work on sustainability. These companies produce sustainable products aimed at social support and intended for daily needs. In underdeveloped countries, many things such as energy resources, materials, budget, and production opportunities are limited. Therefore, products for the needs of people living in underdeveloped countries are important. In the research also the products and design approaches of different companies were examined in terms of sustainability.

During the research process, it has been observed that there has not been enough study on some issues in the field of sustainable design. Within the scope of sustainability, it has been observed that

there were fewer studies on topics such as material selection for the product, material savings, design with fewer parts, use of recyclable materials, and low-cost and sustainable production methods. For that reason, in the article, the studies carried out within the scope of sustainable design are directed to these indicated issues.

One of the methods used in the article for this purpose is the design. Within the scope of the project, the students designed different products in terms of sustainability. The students used eco-friendly materials and natural energy sources to provide their designs become sustainable. Also, products that produce their energy have been designed. Traditional and simple production techniques have been preferred in the production of some products. All of the products are user-friendly and eco-friendly products that will make the lives of the users easier. In addition to these, an original experimental study has been carried out in the laboratory by the author of the article. The experimental study has been carried out on a metal chair. The method of the study is to measure the amount of shape changes with strain gauges. In the experimental study, the strain gauges have been sticked to the critical points of the furniture. Deformations at these points have been measured. According to the measured amounts of shape changes, the tension values at different points of the furniture have been calculated. Computer-aided programs such as the "finite elements" method have been used to calculate the tensions. Based on the data of this experimental study, the furniture has been redesigned without decreasing its strength. The redesigned furniture has better features in terms of sustainability. The redesigned furniture is thinner. The furniture is produced with fewer materials and fewer parts, it is lighter, the production process is shorter, the workforce in production is less, and it is more economical. With this experimental study, it is being demonstrated the calculable effect of technical methods used in industrial designs, on sustainability.

3. Research Findings

3.1. Sustainability Concept and its Historical Background

Çınar's research indicates that the concept of sustainability has a long history of preserving nature (Çınar, 2014, p.231-240). According to this research, Hittites, one of the oldest cultures of Anatolia, regarded water resources and springs as sacred. This situation can be understood from the Hittite Monument in Eflatunpınar. Besides, it is indicated that having been an ancient culture, they protected forests, trees and they had a developed sense of nature protection. O'Riordan takes the idea of sustainability to very ancient histories, even to ancient Greek mythology, and states that this concept emerged in Gaia, the earth goddess in Greek mythology (O'Riordan, 1998, p.29-50). According to belief, the actions of the country's rulers must have been satisfactory to Gaia, and the country should live in peace and prosperity. The aim was that the activities should bring positive results (Bozloğan, 2004, p. 1011-1028).

According to a study by Kaplan quoted from Hermann Hill: "The concept of 'sustainable development' was first employed in the legislation issued to prevent the destruction of Karaorman in the Baden region in the Federal Republic of Germany in the late 18th and early 19th centuries. This legislation, it was aimed to ensure the sustainability of the forests in meeting the wood requirement, as well as to maintain their feature of wind prevention, their capability to meet the water requirement, and their characteristic of being recreation areas. Therefore, it was thought that to benefit from the forests, not only did they have to observe the requirements of the day, but also they had to reproduce them to serve the later generations" (Kaplan, 1999, p.160; Hill, 1993, p. 56).

"E.F. Schumacher was known for his *small and sustainable systems* for social and economic development. Within this context, in his book "Small is Beautiful", Schumacher tackled the human and environmental damage caused by the 'worship of the giant' and put forth the idea of 'localization' as a solution. As the 'most rational' method for economic life, he suggested that the form of production, consumption, and organization should be as local and small as possible. He also recommended the use of local resources for local needs" (Akkuş, 2011, p. 131-136). In his book entitled "Small is Beautiful" published in 1973, Schumacher argued: "... a great effort must be spent to overcome the present negative situation" and he tackled "economic sustainability". He stated: "the concept of sustainability" was not compatible with the present looting attitude which created a share of joy in the situation

where “the luxury for our predecessors has become a daily necessity for us” (Schumacher, 1995; Bozloğan, 2004, p. 1016).

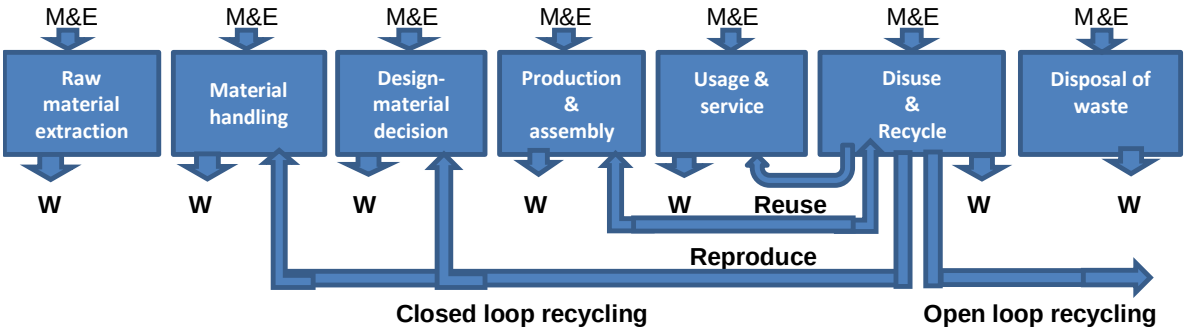
In the second half of the 1970s, debates began on the basic principles of sustainable development. In the spring of 1987, the World Commission on Environment and Development (WCED) published the Brundland Report. The report entitled “Our Common Future” coined the term “sustainable development”. By stating “A world in which poverty is endemic will always be prone to ecological and other catastrophes”, the report defined sustainable development in general terms as follows: “Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future” (Torunoğlu, 2023).

In 1992, at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, it was revealed that the application of unsustainable models of production and consumption, especially in industrialized countries, caused the natural cycle to become more and more distorted. On the other hand, using energy and resources in more efficient production processes, and developing and preferring cleaner production methods in all processes of the product life cycle, to minimize waste during production and after use were considered strategic objectives (United Nations Sustainable Development, 1992). Regarding this crucial issue, it is quite evident that the concept of sustainability would be at the center of the relationship between design and material based on product design.

The Kyoto Protocol which is linked to The United Nations Framework Convention on Climate Change could enter into effect only in 2005 when countries that accounted for a specific gas emission rate accepted it. The Intergovernmental Panel on Climate Change (IPCC) was held as part of the Towards 2020 - Kyoto-Type Climate Change Negotiations and scenarios of future changes in world order were developed Four main scenarios were drawn from the data. “B1 (A homogeneous and ecological world): Rapid economic growth will take place, but changes will shift toward a service and information economy. Instead of material intensity, clean technologies for resource efficiency will come into prominence Global solutions will be provided to economic, social, and environmental sustainability” (United Nations, 1998).

In the B1 scenario set by the IPCC, the shift of changes toward a service and information economy, and the prominence of clean technologies for resource efficiency have been pointing out the approach to the material in relation to product design, which is also noteworthy for this paper’s perspective.

Table 1. Product life cycle process and environmental effects developed according to product design (Kasap & Peker, 2011, p. 102; Keoleian, 1995, p. 7)



M&E: Material and Energy
W : Waste (Gas, liquid, solid)
: plastic

The article entitled “An Environmentalist Approach: Green Design” examines the entire phases of the product life cycle with a holistic and proactive approach (Kıvılcım, 2013, p. 15). It states that after the industrial revolution, “buy, build, sell” industries, which have increased rapidly over the course of 200 years, are responsible for their irresponsible behavior of polluting the environment and shortening the life cycle of products to sell more (Kasap & Peker, 2011, p. 101-116).

In the process of Table 1, 80% of the environmental impacts of a product throughout its entire life

cycle are determined within the scope of design. The process of recycling, redesign, reproduction, and reuse is assessed in a holistic process against environmental influences that may arise during the life cycle of the product. The measures on the basic elements of environmentally protective design, green design, etc., cannot be taken, decided, or applied solely by the designer. It is evident that the designer can carry out all these measures and analyzes according to the production decisions which will produce the product and in the context of production systems depending on the production policies of the business. With regard to the designer and manufacturer, the entire process of the product life cycle must function as a whole.

3.2. Material Concept and Product Design

The mid-20th century was a period of breakthroughs in the development of materials. From this point of view, it could be said that every society and every age is shaped by a certain material. For example, stone was dominant in the productions of the Middle Ages. In the modern age, Mendelejew's renowned table on the periodic systems of the elements is still valid. This is because when examined closely, matter remains as matter and the operations are carried out on the same atoms. This structural characteristic of matter allows for various combinations and makes it possible to constantly develop new materials. Accordingly, matter is the substance of which everything is made. Material is a form of matter undergoing transformations, which can be synthesized, applied, and used. In other words, new forms can constantly be obtained. Considering that the designed products will be produced in high quantities with mass production, the importance of material selection has been increasing. It is important to choose the right materials in many aspects such as the strength of design, reliability, easy production, appearance, identity, price, style, and marketing.

The book entitled “New Chairs-Design, Technology and Materials”, a design concept and edited by Mel Byars is about seating furniture (Byars, 2006, p. 28-142). Based on works by many designers it primarily examines materials. In connection with this, it examines production technologies as well as how product design is related to the material. The research has thoroughly examined designs made with new, environmentally protective material. Materials such as steel plate, steel wire, aluminum, steel reinforced plywood, fiberglass, carbon fiber, epoxy, ready-made plastic, hardened cotton, rattan straw, or reed are materials that are now required to be developed as indispensable production materials for the design area. In this case, the designer and the manufacturer should work in cooperation. They should decide together whether the new materials will be small, medium, or large series, and conclude what will be the user’s behavior. They should consider that during the design process, they will have to do experimental work in parallel with each other.

3.3. The Idea of Design with Eco-Friendly Material and Technology

It is noteworthy that furniture design can be considered to be a good example of eco-friendly materials. According to the materials employed, pieces of furniture can be classified as wood, plastic, natural stone, glass, or composite materials. In an early period, pioneer designers also employed quite different materials.

In traditional solid production, natural materials such as wood and stone were mainly employed, whereas “in the process of new material development wood by-products were first employed in furniture design. Products such as plywood, chipboard, and fiberboard are materials developed from first environmentalist approaches thanks to their cheap and easy production which will respond to industrial production” (Yüksel, 2012, p. 48-51). From the 1950s, “In his wood-pressed furniture, Poul Kjærholm employed also natural and alternative materials from different fields. Some of these materials are rope, chicken wire, inexpensive powder aluminum mold material, and fiberglass. He was also impressed by the sculptor and designer, Gunnar Aagaard Andersen who carried out model studies with newspaper, chicken wire, etc. Poul Kjærholm performed inexpensive simple production experiments with these unusual materials” (Sheridan, 2007, p. 32-48). Apart from that, he mixed Peter Murdock’s papier-mâché with biodegradable synthetic material and turned it into a kind of cardboard material made into a thin layer, which gained strength through the folding method. Thus, he constructed furniture which could only carry children. Numerous layers would be necessary to carry adults. Frank Gehry employed a different material, a recyclable laminate material known for its flat

sheets, because it is cheap, and it can wiggle. Thus, by bending this material in three layers he obtained chairs which can also be sold today.

In terms of eco-friendly designs, the 1950s are considered to be a pioneering date as the years 1960s and 1970s were years when very expensive objects or pieces of furniture were designed and produced in the name of originality. Post-Modern and Memphis movements after Modernism; Primitive Art and Design Movement saying that art is in life; Ready Made movement which includes the use of everyday material and objects served as a model or became a pioneer for lives, designs, and productions of that period. It is also worth noting that some of them appeared as reaction designs.

The idea of making furniture from waste products led many designers to be a pioneer in this issue. For example, in 1953 Benjamin Baldwing designed a chair from a tractor seat. In 1963, Gaetano Pesce constructed furniture from waste polyurethane resin with different densities and he shaped the material by hand or by mold. He aimed to incorporate and synthesize industrial and hand production to create furniture models. Ettore Sottsass, the founder and a member of the Memphis Group said "We use everything done today. Production belongs to today, not the next generations." This thought had significance for his time because of its use of a variety of objects. Today, although its significance can be arguable, it accomplished a certain process. An example of the Primitive Art and Design Movement was produced in 1985. This is the "Prince Imperial" Chair by Elizabeth Garouste and Mattia Bonnetti. Composed of a tree branch in a vertical position and wooden plaques connected to it and surrounded with raffia on the seat and back, this chair represents a good example of primitive art. Ron Arad's waste car seat can be given as a significant example of sustainable design inspired by the movement of Ready Made. In this approach pioneered by Marcel Breuer and Andy Warhol, the idea that any object can be used as a sitting object affected sustainable design (Fiell & Fiell, 2002, p. 465, 560-563, 597).

The book entitled "Product und Umwelt (Product and Environment)" having a 1974 edition, tackled thoroughly several studies and contributed to sustainable design. Among these studies, the following can be counted: Gillo Dorfles's "Solutions Which Feel the Negativity Around Someone's Environment", Udo Haase's "Solutions to Traffic Problems", Ernst Bonda's "New Evaluation of Waste Paper", Michael Walz's "Less Consumption with Greater Meaning", Jan Kotik's "A Political Economy Analysis", Wulf Rüdiger Lutz's "Social Design" (Priewe, 1974, p. 23-120). In the 1990s, Herman Miller Company gave great importance to sustainability in order to protect the environment and ensure the sustainability of the future life of mankind. The company has been still implementing its practices in this direction.

Herman Miller operates with the principle that sustainable products require sustainable materials. Therefore, they have been carrying out a thorough examination of the materials, ingredients, and molecules in order that they could be trustworthy for people and have positive effects on the environment. In these examinations, it has been revealed that a middle-class American family has been using four million kilos of material for their needs in a year. Accordingly, Herman Miller has developed a rigorous protocol for assessing the life-cycle impacts of every product to recycle it for environmental health. Herman Miller has developed a sustainability protocol that measures the environmental impacts of materials, evaluates and balances performance, cost, and aesthetic criteria along with environmental criteria, and integrates them into product design with a holistic approach. The company has prepared Design for Environment Guidelines. It also created an assessment tool that analyzes the potential of product design (Bony & Lee, 2009).

Since 2001, the DfE team has been collecting information on the chemical structure of the material, and carbon emissions associated with the use of energy for the extraction, installation, distribution, and lifetime of raw materials to determine the carbon footprint. Recently, the company has announced that for its worldwide operations, it has been using 100% renewable electric energy. After more material research, the company developed a part made completely of a recyclable material which is cheaper than the original design for the development of the Mirra chair. In addition, instead of polyvinyl chloride, a combustible material, the company employed a thermoplastic elastomer for the chair's arm pad. It should also be noted that Herman Miller does not neglect processes with supplier

and distribution chains (Herman Miller, 2017). Over the last few years hopeful improvements have been witnessed.

Figure 1. Arçelik Piano Series washing machine (Alışveriş rehberi, 2017

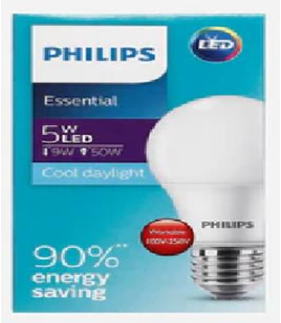


Figure 2. Philips LED lamps (ShopSM, 2017)

Figure 3. John Deere released R series tractors (John Deree, 2017)

There has been a decrease in the direct consumption of natural materials and the use of more energy-conserving materials with the increase in the research on bio-based materials. For example, the company Arçelik has been evaluating energy saving very well in its white goods. Arçelik Piano Series washing machine is produced for energy saving (Figure 1). Philips LED bulbs are highly efficient and have a very long lifespan. These lamps provide up to 90% energy savings compared to incandescent lamps (Figure 2). John Deere released R series, PVX and PSX engines are environmentally friendly. John Deere released the R series, mid-segment tractors with the PowerTech PVX and PSX engines featuring the latest technology products to provide green efficiency, diesel solution, and high power (Figure 3).

Figure 4. Ebm-Papst Company produces eco-friendly fans (Empapst, 2017)

Figure 5. Ebm-Papst Company produces eco-friendly fans made of aluminum-inserted plastic material (Empapst, 2017)

Figure 6. Wood and plastic-reinforced epylene granules (Empapst, 2017)

Ebm-Papst Company is attracting attention with its fans made of biomaterial and selling them on the international market. Ebm-Papst has been producing energy-saving fans for many years in ventilation, air conditioning, and refrigeration technologies. These fans have become energy-saving models thanks to high-efficiency engines and aerodynamically developed wings (Figure 4, Figure 5). By 2015, 15% of plastic materials have been replaced with "biomaterial". Production materials may consist of an aluminum-inserted plastic material, and of “epylene”, a wood and plastic composite material (Figure 6). They are light and easy to shape. Compared to conventional cast blades, aluminum is a material which consumes fewer resources. Bio-based materials are generally cellulose fibers, soya-based biocomposites, fibrous and wood-based particle boards, corn protein and natural biopolymers called zein, corn seed starch used in obtaining packaging pellets, granules, etc.

Designers have often considered nature as a ‘role model’ to find new solutions. Through experiments with living organisms, organisms such as bacteria, fungi, and algae were also included in the design process. The transfer of features from bio-systems to design makes new possibilities available in materials. Some of these features are structure, appearance, metabolism, growth, response, adaptation, motion, and reproduction.

The paper entitled “An Investigation on Growth Behavior of Mycelium-based Material In A Fabric Formwork” points out that the obtainability of an entirely natural material that can grow in the mold

indicates that this organic material can be widely employed in the field of design (Elbastı & Alaçam, 2016). In their works on eco-friendly design furniture, Ivy Liu and Jian Wong classified eco-friendly furniture in four groups (Liu & Wong, 2013, p. 10-154).” Recycling and reuse, production with natural materials, technological and handicraft production, and other approaches, such as pieces of furniture with alternative or multi-purpose use; furniture which can produce plants on their legs; designs with highly efficient use were developed.

It is also possible to ensure sustainability with the help of technological designs. Özcan, Çelebi & Arpacıoğlu developed a modular system for obtaining water (Figure 7). In this study, a pilot system using solar energy has been developed in terms of water and energy efficiency. This system cools the gaseous water in the air in a controlled manner with the help of thermoelectric modules. It also stores water by condensation. The proposed system includes different modules. These modules are such as fans, water tanks, and thermoelectric coolers. Thanks to this system, plants growing in different areas can be irrigated with water obtained from the air with optimum efficiency. It is aimed to protect water resources by developing a system using solar energy. (Özcan, Çelebi & Arpacıoğlu, 2022).

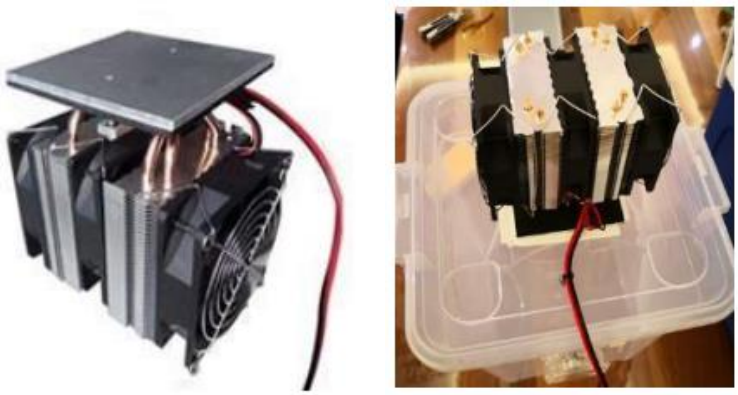


Figure 7. Thermoelectric cooler module block and water tank with copper, aluminum cooler, and fan circulation used in the system (Özcan, Çelebi & Arpacıoğlu, 2022)

3.3.1. Sustainable design studies

Sustainable design requires multi-dimensional thinking. The process necessitates being eco-friendly in every step, from gathering raw material to the decision of processed material to the sale of the product to its storage, service, use, and recycling of the material after its use and even to the process in the production environment and energy saving.

A great number of projects were realized in the İstanbul Technical University Department of Industrial Product Design from 2003-2012 regarding sustainable design. The author of this article and her team also took part in the projects carried out in the ITU Industrial Design Department. The projects addressed sustainability from different perspectives. Guided by the author of the article and her team, 8th-semester students designed various products focusing on sustainability. Students designed different products for different companies. Some companies were producing both with traditional methods and with machines. For this reason, products have been developed in accordance with the production methods of the companies.

Some of the projects can be found in the following examples (Figure 8, Figure 9). Students developed their designs by focusing on different aspects of sustainability. Some designs focused on the use of eco-friendly materials (Figure 8). Some designs focused on production with simple production techniques without consuming much energy (Figure 7c). Some designs focused on creating awareness of sustainability (Figure 8d, Figure 9).

Some designs that contribute to sustainability by using environmentally friendly materials are shown below (Figure 8). One of the projects is a book display unit (Figure 8a). One of the important features of this book stand is that it is made from pieces leftover from furniture production. Another feature of the book stand is its easy disassembly and assembly. The modularity of the design simplifies production

and reduces the cost. The use of ready-made metal profiles in the product speeds up production and reduces the cost.

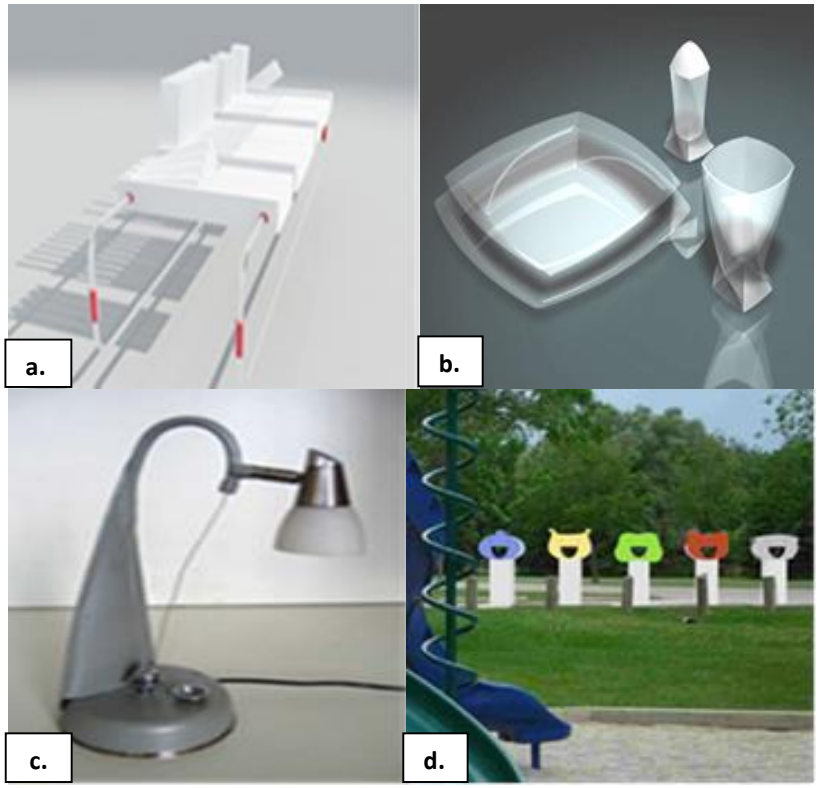


Figure 8. Sustainable-oriented designs focused on environmental materials. **a.** Book display unit designed by Sabiha Yıldız, **b.** Tableware designed by Gökhan Karasu, **c.** Table lamp designed by Aybige Keskin, **d.** Waste container designed by Merve Karasu

Another design is tableware (Figure 8b). The tableware is made of glass. In order to popularize the use of glassware, the designer produced all the pieces of tableware from glass. Although the plates are usually produced from porcelain and ceramic, the designer produced the plates from glass.

Another design is the table lamp (Figure 8c). The table lamp was designed for children. An easy-to-use and safe lamp has been created. The table lamp is produced from eco-friendly materials such as metal and glass. In the production of the lamp, manual production, and machine production were used together.

One of the projects was designed to raise awareness about sustainability (Figure 8d). This design is a garbage system design for waste materials. This product aims to raise awareness among children about waste materials and sustainability. However, it is aimed that children can easily understand the waste garbage. Therefore, different material containers are produced in different colors.

Some designs that contribute to sustainability with the use of energy are shown above (Figure 9). One of the projects is a waste bin (Figure 9a). The waste bin is built into the floor. The waste bin uses solar energy. This waste bin stores energy with simple solar panels. Solar energy has enabled the waste bin to move up and down the floor. Systems that produce their energy are very important for cities and energy conservation.

Another product is a light buafor design for marinas and the sea (Figure 9b). This product also stores solar energy. The product illuminates the surroundings with the energy it stores. It is a very useful and eco-friendly product for marinas.

One of the projects is a cooling system design (Figure 9c). It aims to cool fruits and vegetables with natural methods in rural areas and camping areas. Clay is used in the product. The product performs its function in the best way thanks to its design and material.

Another project is a hair dryer design (Figure 9d). This product uses infrared rays instead of metal wire resistances. During the design process, the designer researched energy systems. Designer researched the energy system mentioned in an article and a patent. The designer used this energy system in the hair dryer he designed. This project has served to save energy. Besides, the designer has found safety measures to prevent hair and the body of the product from burning.

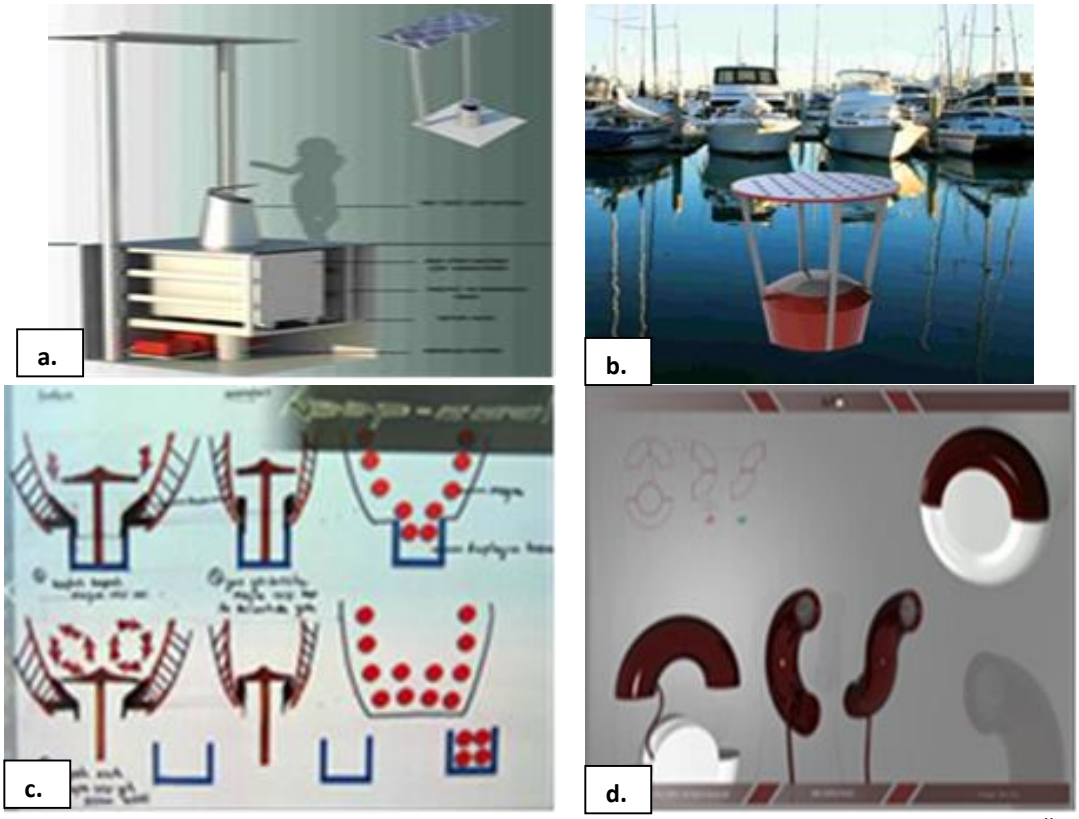


Figure 9. Sustainable-oriented designs focused on energy saving. **a.** Waste bin designed by Hilal Özdil, **b.** Light buofor designed by Sinan Sever, **c.** Cooling system designed by Mert Sezer, **d.** Hair dryer designed by Burc Öç

It is observed that all products developed with the theme of sustainability in industrial design contribute to sustainability by means of different features. Some of the products are produced with eco-friendly materials. Some of the products use natural energy sources. Some of the products use energy resources for minimum amounts. Some products store energy and produce their energy. And some products have been produced with traditional, simple, low-energy consuming production techniques. These products contribute to sustainability by reducing energy consumption in production. Some designs use new technologies and consume less energy while operating. Some of the products contribute to sustainability by raising awareness about sustainability.

As can be seen from the products developed within the scope of the article, it is possible for various sustainable designs to be made. Original projects focusing on different aspects of sustainability can be developed.

More attention should be paid to sustainability in the near future. It can be said that sustainable designs should become widespread. It would be beneficial to consider issues such as sustainable design, eco-friendly design, and social design in industrial design. Thus, the design of the future will be in its ideal position.

3.3.2. A laboratory study based on sustainable design

It should be noted that for quite a long time, the author of this article has been examining materials on the basis of product design and working on realizing the design with minimum materials, minimum parts, and environmentally protective material (Günal Ertaş, 2007, p. 120, 121).

a.

Here, a study carried out in the context of sustainability is described. The study was carried out on a chair with metal construction. It is aimed to develop the chair in terms of sustainability. That's why the chair was redesigned (Figure 10a, Figure 10b, Figure 10c, Figure 10d, Figure 10e).

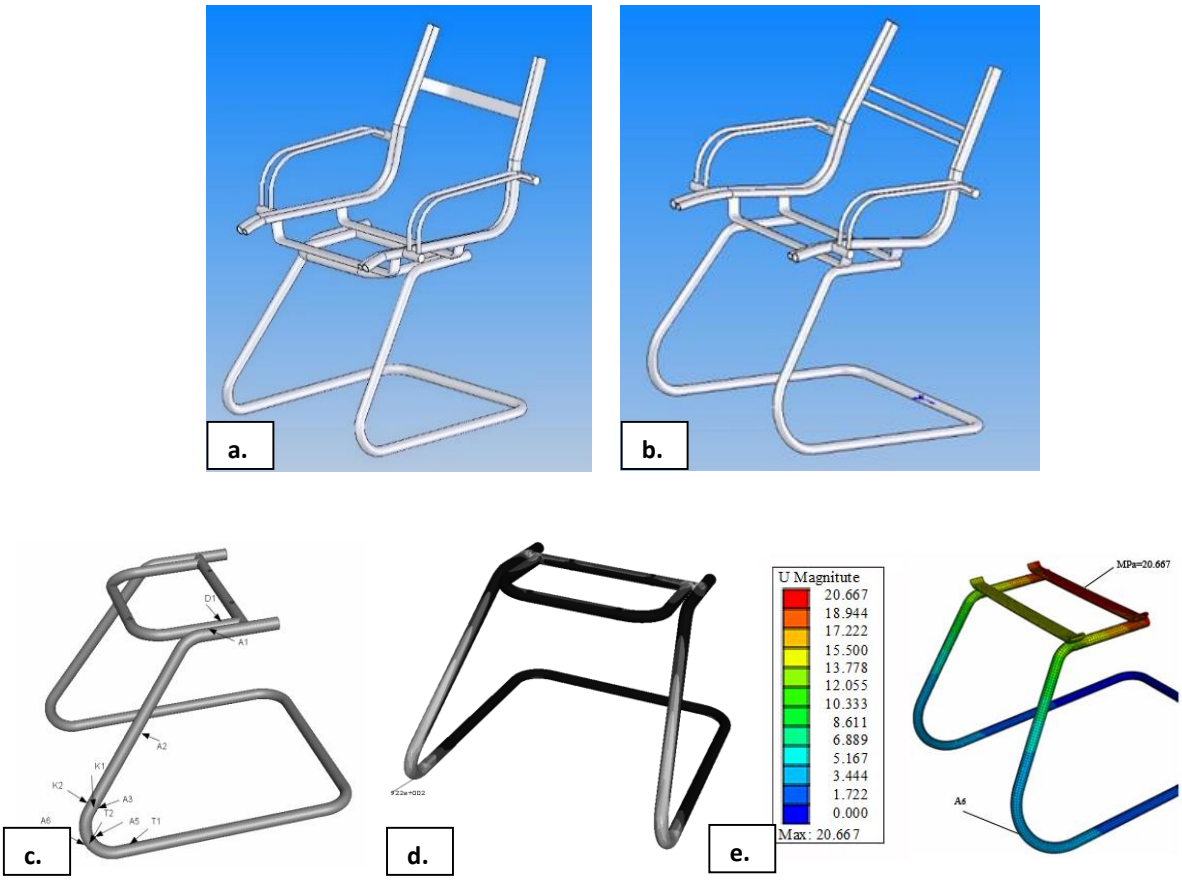


Figure 10. The original and redesigned version of the chair and tension diagrams of these chairs Upon laboratory experiments, a new chair frame is proposed with a reduced number of components (Günal Ertaş, 2007, p. 120, 121) **a.** Original chair made of tubular profile, **b.** Redesign of tubular chair, **c.** Measurement points of the chair, **d.** Tension diagram of the original metal chair, **e.** Tension diagram of the redesigned chair

In the experimental study, strain gauges were placed on the metal chair. Deformations at different points of the chair were measured. The tensile and strength values in various parts of the chair were calculated. Then the original chair was redesigned. The weight, tension, and strength values of the redesigned chair were calculated in a computer program. The original chair and the redesigned chair were compared with each other. The newly proposed chair design is advantageous in terms of sustainability (Günal Ertaş & Şatır, 2021). Figure 10a shows a metal chair design. Figure 10b shows the redesign of the chair. The new chair is made of another type of steel by reducing the parts and material of the original chair. The redesigned chair has advantageous aspects compared to the original chair.

Both experiments and computer analyzes have shown that the redesigned chair is sustainable. The tensions at various points remained below the yield stress. So, no problems occurred with the redesigned chair. The redesigned product has achieved goals such as reducing the number of parts, lightening the structure, reducing the cost, and shortening the production process. Although the dimensions were reduced and some parts were removed, the structure is still a resistant one. During the redesign process, the visual effect of the original chair design was preserved, the production process was shortened, the cost was reduced, and the required strength was provided.

The differences between the original chair and the redesigned chair are interesting and striking. The superiorities of redesigned chair over the original chair are expressed below:

- The weight of the current chair's frame structure is 13 kg. The suggested frame structure of the chair is 9 kg. A redundant 4 kg was removed by reducing the length of the pipe, decreasing the number of parts, and changing the steel employed. The product became more portable.
- The metal pipe diameter of the original chair is 25 mm whereas the metal pipe diameter of the new design is 21 mm i.e. 4mm less.
- The proposed redesigned new chair is 4 pieces fewer than the other (Günal Ertaş, 2007).

The reduction in the number of parts in the structure made welding unnecessary at four points, thus decreasing the number of processes and shortening production time. The new design is lighter by making the diameter of the metal frame construction smaller and by reducing the number of parts. Lightness also makes the design easier to use. It is evident that thanks to all these new features, the production of the chair has been improved in terms of sustainability (Günal Ertaş & Şatır, 2010).

A sustainable design viewpoint requires that factors related to people as well as technical and aesthetical factors are considered together. Sustainable products can be produced with the help of industrial designs developed with the help of technical methods. It is of vital importance in terms of economy and environment that the design is made by paying attention to the following issues: selection of eco-friendly materials suitable for design; optimization in utilization of material and components; utilization of fewer materials and components without compromising sturdiness; choice of eco-friendly material that prevents depletion of natural resources; production with easily available materials.

Traditional methods can be used in industrial design. In addition, advanced technologies and modern production methods can be used in industrial design. Eco-friendly sustainable products can be produced with the help of contemporary manufacturing techniques and new technologies. During the design process, some software can be used such as finite elements, Solidworks, and various measurement, testing, and analysis methods. These programs can help to produce sustainable design (Günal Ertaş & Şatır, 2021).

4. Evaluation and Conclusion

As we see in Table 1 in the case studies, in the article, in the experiences of Herman Miller Company sustainable design is a very comprehensive process. This process includes various stages such as material selection, application of eco-friendly production methods, energy saving, service, purchasing, recycling process, and usage of recycled materials (Kasap & Peker, 2011; Keoleian, 1995). All details regarding sustainability should be considered in design decisions. Even the acquisition of raw materials alone affects other decisions. Hence, it can be argued that sustainable design should include the following stages:

- **Preliminary design decisions made in collaboration with the business:** At this stage, the designer and the experts on the subject give idea support. Designers should know the eco-friendly materials suitable for their designs.
- **Design process decisions:** At this stage, decisions could include the following objectives: to reduce resource consumption, not to harm the environment, for example, the selection of bio-based, recyclable materials, to ensure minimum material consumption, to evaluate waste materials, to reduce the number of parts of the product, to determine ideal dimensions of the product, to enable the product to occupy less space during transportation and storage, to provide modularity, to design replaceable parts in the product in case of malfunction, to ensure the product reliability and long-lasting use, to develop relations between production,

material shape, cost and environmental effects, to discover the possibilities and limitations of design (Günal Ertaş & Şatır, 2010).

- **Production process decisions:** At this stage decisions on the following points would be significant in terms of sustainability: the selection of regional, environmentally protective, bio-based, non-chemical material, using recycble materials, reduction in the material to be processed, the production process with fewer operations and less waste, reducing the number of components and adjustments of product, the optimization of material wall-thickness, creating various solutions to extend the service life of products, the reduction of energy consumption, decreasing workmanship, reducing the number of operations and production time of production process (Günal Ertaş & Şatır, 2021). Some of these decisions affect the price of the product and the amount of sales.
- **Decisions regarding the use of products after sale:** Decisions regarding the use of the product after sale may include the following purposes: to facilitate the use of products, to reduce energy consumption, to give importance to energy saving systems, to reduce the amount of material to be consumed during usage, to facilitate product maintenance and cleaning, to encourage and raise awareness of product users, to support the long service life of the product.
- **Decisions on second use or recycling of the product:** Products should be produced with recyclable and reusable materials such as paper, glass, metal, and plastic. Some products made of glass, stainless steel, rustproofed tin, and metal are very suitable for second use. In addition, almost all eco-friendly products can be recycled.
- **Modular design:** Designing modular products can contribute to sustainability. Thanks to modularity, it can be ensured that the products are low-cost, long-lasting, and offer different options (Sonego, Echeveste & Debarba, 2018).
- **Changeable parts of the products:** Products can be sustainable through design. The parts included in the products can be changed and renewable. Changing the parts of many products such as household appliances, furniture, office systems, and vehicles will extend the product life. This will increase the sustainability of the products. Changeable parts can contribute to sustainability in design (Holtewerta & Bauernhansla, 2016; Interchangeable Products with an Advantage, 2023).

The product parts can be recycled by using environmentally protective, correctly selected materials. Product material can be dissolved in nature and sustainable design can be achieved by making it harmless to nature.

The characteristics expected from the design vary depending on the correct components in accordance with the current environmental protection conditions. It can be claimed that industrial designs are expected to contain the following characteristics: authenticity in terms of sustainability, high performance, long life, effective work function, robustness, lightweight and low cost. By optimizing the quantity of the material, the number of the product parts, and the size of the parts, the lightness of the product is ensured, the production period is shortened, and the cost is reduced. It is also worth noting that the energy consumption for production is tightly connected to all these optimizations.

Acknowledgements and Information Note

The article complies with national and international research and publication ethics. Ethics committee permission was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

The article is single-authored and has no conflict of interest.

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