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Life cycle analysis on the example of the "SPINE" chair project

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Abstract: The following work presents a life cycle analysis based on the design of the 'SPINE' furniture. The scientific article presents a comprehensive life cycle analysis of the "SPINE" chair. The study covers various stages of the project's life, starting from the design phase, through production, use, to the end of the chair's life cycle and recycling. The authors consider aspects of sustainable development, assessing the chair's environmental impact and identifying potential areas for optimization and improvement from an ecological perspective.

Keywords: LCA, eco-design, recycling, product life cycle

INTRODUCTION

The production of any commodity has an impact on the environment, there are times when this impact is negligible and materials can be subjected to various environmental processes such as recycling. However, nowadays, to a greater extent, the raw materials from which an object is made are not designed to do this. Newer and newer trends, technologies and materials exert the need for a new product among people. This leads to pollution of the planet and huge amounts of rubbish. Fortunately, the EU is introducing new regulations obliging manufacturers to use closed-loop, i.e. production with the possibility of reusing materials.

This is an important step for improving the quality of the climate, which will consequently build eco-friendly values among consumers. The public will pay more attention to what they buy, from whom and why. Such reflection before purchasing goods will make a real contribution to improving the environment. Therefore, new eco-balance tools are being developed to disseminate pro-environmental knowledge.

One such method is to carry out a product life cycle assessment (LCA). It is used during engineering design as an instrument to identify important aspects of a product's lifespan. The study starts by observing the demand for a particular good, then a design idea is developed. As a result, it focuses on the selection of materials and any technological processes so that they have the least possible impact on the environment.

This project attempts such an analysis on the basis of the author's 'SPINE' chair design, which is based on the principles of eco-design and the selection of appropriate production. The work is distinguished by the use of recycled raw materials and involves innovative production methods.

The aim of the work is to test the feasibility of performing a life cycle analysis on the example of the author's chair design using LCA studies of individual materials and processes. In addition, it is important to apply unit production and to demonstrate the design skills acquired in the course subjects.

The scope of work includes the design of the furniture, choice of materials, technology and transport distribution. However, the most important element is a thorough analysis of these processes and their impact on the environment, but also the identification of recycling methods for the finished piece of furniture. The work also includes an explanatory section on the research topic.

In this part of the work, the definition of the LCA method and the principles of the eco-design. The aim is to introduce the research topic and familiarise the audience with the issues necessary to understand the research problem

PRODUCT LIFE CYCLE LCA

The function of LCA (life cycle assessment) is to show environmental risks by identifying the origin of raw materials, production processes and determining impacts. The study covers the entire product development cycle from idea to final result. This includes raw material intake, production processes, distribution, transport and recycling (Kowalski, Kulczycka, Góralczyk, 2007) The LCA technique can be applied, though, not only to conventional cradle-to-grave and cradle-to-cradle analyses, but also to cradle-to-gate analyses that cover selected stages of the life cycle of a product with the addition of upstream environmental impacts, gate-to-gate analyses that cover selected stages of the life cycle of a product with addition of downstream environmental impacts 2003 (Lewandowska, Foltynowicz ,2008) The diagram below shows the different phases of an LCA typical of this method.

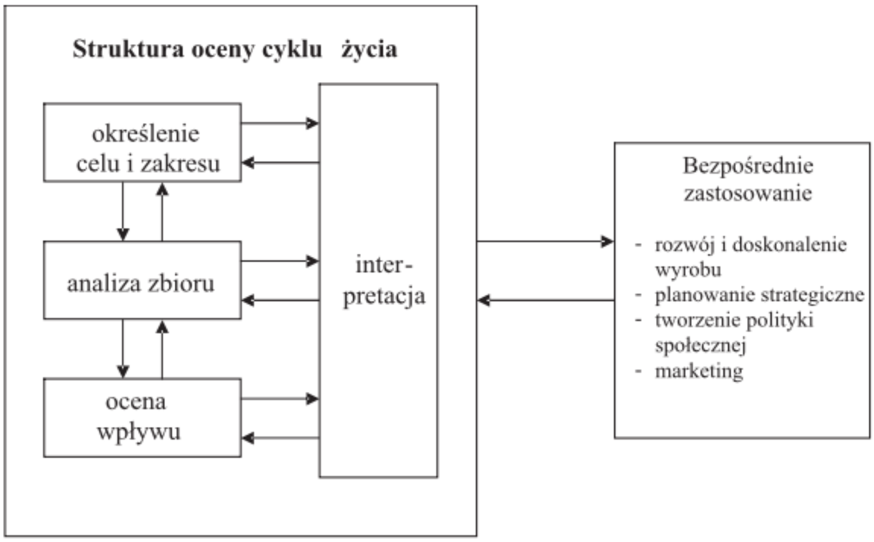

Figure 1. Life cycle assessment phases with application examples

Ultimately, the LCA facilitates decisions on further product improvements. Knowledge of environmental influences makes it easy to identify process problems or material selection. The method also makes it possible to determine the reciprocal environmental impacts of raw materials, with the result that some processes can be combined to, for example, remove excessive greenhouse gas emissions. If an LCA analysis of a product is not carried out, the environmental impact may go unnoticed and unanalysed (Grzesik, 2006)

ECO-DESIGN

Design can be defined as all the activities leading to a product that meets a given need. The process begins with noticing and then communicating this need, and ends when information is obtained on how and where to meet it (Spilka, Kania & Nowosielski, 2016). Eco-design differs from ordinary design in that an environmental quandary is identified at an early stage of product development. In the literature, eco-design is also referred to as DfE (Design for Environment), i.e. something is created with a view to having a positive impact on our environment or having as little negative impact as possible. Eco-design introduces new activities such as analyzing the effects of production and implementing methods to improve the end result. It also allows for an overall optimisation that consequently identifies the "critical" elements so that they can be changed and improved. (Karwasz, 2016).

The main essence of eco-design is the principle of prevention at the conception stage. A closed circud (production, consumption, waste, recycling and re-production) should then be pursued. There is one goal, to produce an environmentally friendly product throughout its entire life cycle, equivalent to fulfilling the principles of sustainability (Spilka & Kania 2016). The benefits of creating items in this way include refining the end result, cutting costs by verifying defects in advance and keeping up with changing customer concepts. It all comes down to having as little impact on the environment as possible (Burchart-Korol, 2010).

THE PREMISE OF THE "SPINE" ECO-CHAIR

The following excerpt presents all the necessary aspects of the author's chair, on which the whole idea of the study is based. The essence of the project from the design brief to the final visualisation is briefly shown.

Key principles of eco-design

The idea behind eco-design is to create a product that not only takes into account environmentally friendly materials, but is above all based on sustainable technological processes. The assumed form of production is customised unit manufacturing. The main elements of this method are: the use of "raw" materials - as little processed as possible, ergonomic design, recyclability.

The design of the 'SPINE' chair is inspired by organic forms as well as references to human and animal anatomy. The concept carries a functional and comfortable resting place and promotes ecological production materials. The combination of good design and high-quality raw materials will allow for an eye-pleasing, long-lasting use.

The construction of the chair is based on the use of closed loop materials and includes copper, cactus leather, linen thread and ceramic structural elements. The chair's frame is made of copper tubes, which guarantee a long service life. The use of just such a raw material is not random. On closer inspection, it is copper that is the best-quality semi-finished product, which can easily be recycled. Such materials also include, recycled clay, which after firing will become ceramic elements that hold the structure of the furniture. Many art studios offer mixed clay waste for next to nothing. This is an ideal situation where only the transport costs of the material are incurred. The third material is the innovative cactus leather used for the seat and backrest. Manufactured with a minimum of water, it not only ensures high environmental standards, but is also durable which will not lower the standard of the chair one bit. Linen threads provide a strong bond between the fabric and the chair structure.

In addition to materials, the design focuses on thoughtful technological processes. A life-cycle analysis will serve this purpose, revealing all the necessary information about every step from material selection to recycling possibilities.

Functional assumptions

The main functional concept of the project is to create a seat that is ecological and has an interesting design that stands out in the market. The 'SPINE' chair incorporates elements of dimensional ergonomics, which will consequently allow for comfortable use by a larger audience. Meeting aesthetic and dimensional requirements will ensure the creation of a product tailored to contemporary user requirements. It is aimed at an informed purchaser (Smardzewski, 2008)

Visualisation of the "SPINE" chair

During the design process, the main idea was to create a chair that refers in shape to the human spine and organic shapes. The ceramic plates are the "vertebrae" of the construction, stably supporting the form and providing balance. The rounded shapes are pleasing to the eye and to the environment, giving the chair its own unique character without being dominant.

It harmoniously blends in with its surroundings. The colouring of raw materials not only provides an interesting design, but also shortens the production process. The absence of colour modification steps for raw materials reduces the carbon footprint and does not introduce chemicals into the design.

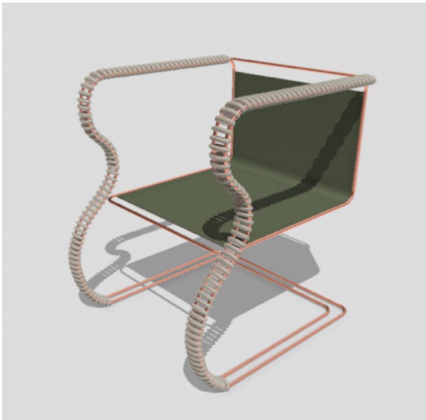

Figure 2. Visualisation of the 'SPINE' chair (Source: Own development)

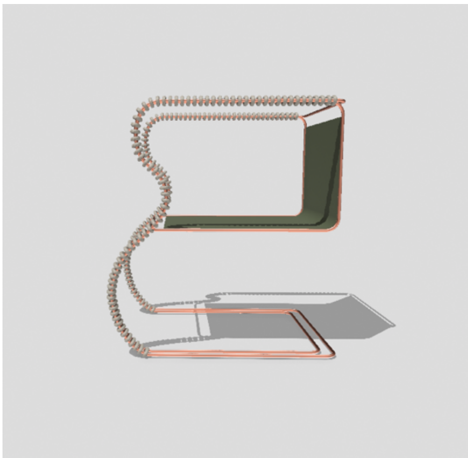

Figure 3. Visualisation of the 'SPINE' chair (Source: Own development)

PRODUCT LIFE STAGES

This chapter describes the main elements involved in the production of the 'SPINE' chair. It is a description of the extraction of raw materials, the production process, the distribution of transport and the use and recycling of the furniture.

Raw material extraction and specification

The raw materials from which the final product, the 'SPINE' chair, will be made are described below. Included in the description are the characteristics of the material, where it was taken and the environmental impact with copper, cactus skin and clay. These have the largest quantitative contribution to the project, so the analysis will be based on them. The remaining quantity of raw materials used (glaze, thread) in unit production is negligibly small. With the environmental impact, it would be best to carry out comparisons of greenhouse gas quantities, water consumption and energy requirements for production. However, not with every material are such data disclosed.

Copper

Recycled copper tubing was used for the chair's construction. The tubes have a diameter of 30 mm and a wall thickness of 6 mm. Such material has a weight of 4.03 [kg/mb]. They were sourced from a local scrap and recyclable materials collector that specialises in complex waste management solutions. The collected material with suitable parameters will be sent for remelting. The quantity needed to create the frame of one chair is 9 metres of pipe with a diameter of 30 mm and a wall thickness of 6 mm (allowance has been made for possible manufacturing errors). The LCA results for recycled copper are shown below:

Table 1. LCA for recycled copper (Source: Hong J. 2018 - Life cycle assessment of copper production: a case study in China)

Material	Energy demand [MJ/m^2]	Greenhouse gases [kgCO_2-eq/m^2]	Water consumption [m^3 water per m^2 material]
Recycled copper	1031,83	688,62	8,45

Clay

The project uses 156 clay tiles of the author's design made of chamotte clay commonly used in the ceramics industry. This material belongs to refractory products and is characterised by high firing temperatures (up to 1,700 degrees Celsius), which makes it highly resistant. The place where the clay used in the project is collected is the ceramic studios, which offer to collect the redundant clay waste from them at no cost. By using a secondary raw material, any environmental damage is minimised as much as possible. However, the clay has been extracted anyway, so its emission parameters must be considered (Komisja Europejska, 2007).

Figure 4. Visualisation of a ceramic tile (Source: Own development)

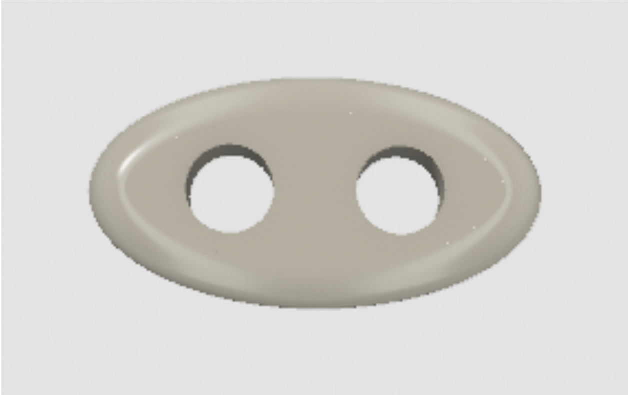

Figure 5. Visualisation of a ceramic tile (Source: Own development)

Table 2. Energy demand for refractory products (Source: Komisja Europejska)

Material	Energy demand [MJ/m^2]	Greenhouse gases [$kgCO_2$-eq/m^2]	Water consumption [m^3 water per m^2 material]
Fireclay	10,00	1,00	1,62

Glaze

The work focuses on environmentally friendly solutions, which is why a potassium feldspar glaze (K2O - AL2O3 - 6SIO2) was used. In this case, the material was purchased specifically for the production of the project. The composition is highly natural and chemically inert, the finely ground potassium feldspar mixed with water forms a thin layer on the surface of the fired clay protecting it from external agents. The amount used in the project is negligible and is therefore not taken into account in the LCA.

Cactus skin

The Desserto brand is where plant-based alternatives to animal skin are created. Ground cactus parts create a new material that absorbs carbon dioxide, which makes it inherently very environmentally friendly. Another advantage is its high tensile strength (Williams, 2022). Therefore cactus leather has been used for the back and the seat of the chair. Thanks to this fabric, the 'SPINE' design stands out from the competition, as it is definitely one of the less invasive leather-like products. Cactus is a natural carbon sink and Desserto has taken advantage of this fact, 14 acres of cactus cultivation is capable of absorbing 8100 tonnes of CO_2 per year while generating 15.30 tonnes of CO_2.

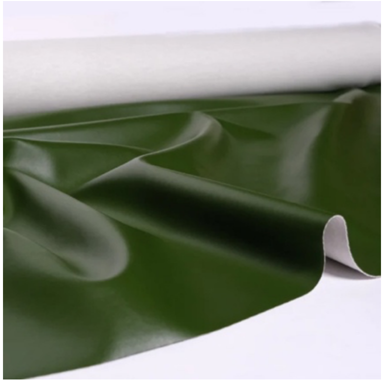

Figure 6. Skin material from the DESSERTO cactus (Source: https://desserto.com.mx)

Table 3. LCA cactus leather data (Source: https://desserto.com.mx/e-lca)

Material	Energy demand [MJ/m^2]	Greenhouse gases [kgCO_2-eq/m^2]	Water consumption [m^3 water per m^2 material]
Desserto	34, 33	1,39	0,02

Skin threads

The threads used are 100% linen with a diameter of +/- 2 mm. Parameters and colour may vary minimally along the length of the threads as the product is completely natural, but the differences are small enough that the final quality will not be affected.

Figure 7. Linen thread (Source: https://www.centralne.co/nici-lniane-100g- grubosc-2mm-szare-id-9181)

PRODUCTION PROCESS

In this section, the production process and LCA data for the most important stages are briefly presented. Further analysis of these results will not only allow technological improvements to be made, but also changes can be made that lead to a reduction in, for example, the carbon footprint. The process has been presented in the form of a process chart, which includes:

Input components - these are all the materials needed to create a complete product

The starting element - this is the finished concrete product, in this case the "SPINE" chair

Core operations - current production

Ancillary operations - these are operations that support the core operations, e.g. transport and storage

Table 4. Technological chart for the production of the "SPINE" chair (Source: development)

Input elements	Input elements	Input elements
- Copper tubes Ø30 mm x 9m with 6mm wall thickness - Reclaimed fireclay - Potassium feldspar glaze - Cactus skin - Linen threads 2mm thick	1.Chair design process 2. Collection of the implementing raw materials 3. Initial creation of the chair frame: - cleaning of recycled pipes - pipe bending with mandrel - pipe polishing 4. creation of ceramic tiles: - placing the clay in the moulds - drying of finished moulds - pre-burnout - glazing - final firing 5. Creation of a backrest and seat: - material blank 6. Completing the parts and assembling the chair: - placing ceramic tiles on the pipes - soldering of pipes - sewing the backrest and seat onto the frame 7. Packaging	„SPINE" chair
	Ancillary operations	
	1. Transport of raw materials 2. Transporting the finished product to the customer	

LCA DATA FOR SELECTED PHASES

The processes not described below were produced manually and are not included in the LCA analysis due to their negligible environmental contribution.

CREATION OF CERAMIC TILES

By far the most demanding part of the production process is the creation of the ceramic tiles. It is a time-consuming and energy-intensive cycle. Despite the unit production of a piece of furniture, there are as many as 156 tiles in each piece, which requires outright mass production. Below are averages for drying and firing the material.

Table 5. LCA data for fireclay (Source: Komisja Europejska)

Stage	Energy demand [MJ/m^2]	Greenhouse gases [$kgCO_2$-eq/m^2]	Water consumption [m^3 water per m^2 material]
Drying	3,0	0,20	1,62
Firing	6,3	0,40	

PIPE BRAZING

One of the steps in picking the parts and assembling the chair is the energy- intensive soldering of the tubes. The figures below are averages for a flask soldering iron dedicated to copper components.

Table 6. LCA data of copper bonding (Source: https://hoegert.com/produkt/lutownica-kolbowa-60w-2/#dane-techniczne and https://climatestrategiespoland.pl)

Stage	Energy demand [MJ/m^2]	Greenhouse gases [$kgCO_2$-eq/m^2]	Water consumption [m^3 water per m^2 material]
Brazing	0,21	0,024	0

DISTIBUTION AND TRANSPORT

Distribution starts with transporting the raw materials to the production site. Raw materials are transported by van and by air, while the final product, depending on the customer's order, can be transported by any delivery method (Czubata, 2001)

Table 7. LCA data for transport (Source: Elghozi, 2021 ; Ankur, 2022; https://ourworldindata.org/travel-carbon-footprint)

Stage	Transport method	Energy requirement [MJ/tkm]	Greenhouse gases [$kgCO_2$-eq/km]
Transport of raw materials	Vans	738,5	0,17
	Air transport	140	0,14
Transporting the finished product to the customer	Vans	738,5	0,17
	Rail transport	74,1	0,035
	Maritime transport	134,1	0,019
	Air transport	140	0,14

USE OF THE PRODUCT

The "SPINE" chair model is intended to be used for relaxation, but is also an important element in the surrounding space. In addition to the ecological raw materials, the form itself is reminiscent of nature; the organic shapes provide a friendly visual perception. The product leaves room for reflection on its essence in the world of furniture making, and prompts reflection on production through the raw materials used. Thus, this project does not only function as a restful functional form.

RECYCLING

Recycling is the process of putting an object back into circulation. Originally, this phrase was used in the context of the use of technological waste and secondary raw materials. The aim is to reduce the use of natural resources and to reduce the production of harmful waste (Świątkowska, 2017).

From the inception of the idea to create an eco chair, recycling was a priority. Despite the use of recycled materials, it is important to identify a solution for post- consumer life. In the case of copper, it is most likely that the chair's frame, i.e. the copper pipes, will go for scrap and then be melted down (Kucharski, 2010). The possibilities for recycling cactus leather, on the other hand, are many, all depending on the condition of the material. If it is heavily worn, it should be chemically recycled, which is what the manufacturer DESSERTO suggests. However, when the leather is in good condition it can be used for ornaments, art installations or leather goods. The possibilities are many, it all depends on the user's idea. The ceramic elements have been designed so that they can be used as candle holders in the future. A visualisation of this idea is shown below. The final material is linen thread, which can be donated to a company that in recycling natural materials.

Everything has been strongly considered from an environmental point of view and in line with the eco-design trend.

Figure 8. Visualisation of a ceramic tile chandelier (Source: Own development)

ASSESSMENT OF ENVIRONMENTAL ASPECTS AND THEIR IMPACTS

This section of the paper comments on the LCA results for individual materials and processes. The data are based on scientific publications relevant to the topic.

Assessment and interpretation of potential environmental impacts

The LCA data presented shows that the production of the presumably environmentally friendly 'SPINE' chair is heavily burdened with energy consumption in particular. Stages such as the firing of the clay and transport have the greatest impact on the end result.

The use of recycled materials realistically reduces any environmental impact, but it is impossible to create a chair from such materials and with such production methods while having minimal ecological impact.

Thoughtfully recycling a chair before it is manufactured is a modern and positively environmental measure. The further use of materials and giving them new functions reduces waste, which at the same time minimises any negative environmental impact. This is definitely a well-constructed design element of the 'SPINE' furniture. Unfortunately, despite the efforts, the chair presented is ecological only by design.

In reality, such production emitting huge amounts of energy eliminates it from the definition of eco-friendliness.

SUGGESTIONS FOR CHANGES TO THE PROJECT

Based on the data provided, a few design changes can be made which, in line with the LCA ideology, will positively influence the end result.

Firstly, using recycled copper generates unexpected amounts of energy demand and more. This was not a good choice; a much better option would have been to use recycled scrap, clean it and skip the remelting process. However, finding finished material with the right parameters and in the right quantity is also a challenge. Another better solution is to change the material. Despite DESSERTO's manufacturer's claims that the raw material is environmentally friendly, it is not fully biodegradable. Nowhere is it possible to get information about the exact composition of the leather. This raises the suggestion of whether there are elements in it that the manufacturer does not want to inform us about. These are just guesses, but why use a raw material from unknown sources when you can use something 100% eco-friendly and biodegradable. Linen fabric is such an example; it would go very well with the threads used, and its properly selected parameters would correspond to a strength similar to leather. In addition to its great composition, such a material is readily available domestically, eliminating transport distances. Consequently, the carbon footprint is significantly reduced. The choice of the innovative DESSERTO material was only appropriate at first glance; upon deeper analysis, it is not suited to the design brief. The opposite is true for ceramic tiles. Indeed, the amount of energy required to fire the clay is high, but there is no other way to ensure the longevity of the elements. Clay is a natural material and using it in a project increases the ecological value. The tiles not only function as a contouring part of the furniture, but also have their uses in recycling. In this case, one can agree that the design of the clay tiles has been thought through from cradle to grave. The same goes for linen threads, they do not have a negative impact on the environment and can easily be recycled.

Unit production is a good choice, as it results in the possibility to perform most processes manually. The lack of interference from multiple machines significantly reduces production pollution and adds value to the end result. With more and more conscious consumers opting for handmade products (created by their own hands), they have the feeling of not being involved in mass production. The product is made especially for them. Promoting such a trend is an element that contributes to raising awareness of ecology. Moving away from cheap mass production is one of the main objectives of the 'SPINE' chair and it has been fulfilled.

The overall process of creating the 'SPINE' chair presented here has an interesting concept, but is not without its faults and opportunities for change. It was clear from the outset that this would happen. This is what conducting a life cycle analysis, which is the most important aspect of the work, is all about.

CONCLUSIONS

The research method used in this study - product life cycle analysis - is based on the design of the 'SPINE' chair and allows important environmental factors to be identified. The creation of a collection of information on the environmental impact of individual production processes resulted in analysis and suggestions for changes to a more environmentally friendly design.

The aim of the work was to test the feasibility of the LCA analysis and to demonstrate design skills, both of which were met. The scope of the work also included a method for recycling individual materials after the chair's useful life, this was met as much as possible.

The 'SPINE' chair was intended to be a piece of furniture of the highest environmental performance in every aspect of production. Unfortunately, these were only assumptions that were not completely fulfilled. Due to the large amount of energy required during production processes and some of the materials used, the furniture cannot be classified as an ecological product.

This life-cycle analysis allows environmental impacts to be accurately tracked even before production begins. It makes it possible to further change processes and materials to be more environmentally friendly. It is an excellent modern engineering tool by which product defects can be spotted and then corrected.

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Streszczenie: Poniższa praca przedstawia analizę cyklu życia na podstawie projektu mebla „SPINE". Celem pracy była ocena, wpływu produktu oraz wszelkich procesów na środowisko. Artykuł naukowy prezentuje kompleksową analizę cyklu życia krzesła o nazwie "SPINE". Badanie obejmuje różne etapy życia tego projektu, począwszy od fazy projektowania, przez produkcję, użytkowanie, aż po koniec życia użytkowego i recykling. Autorzy biorą pod uwagę aspekty zrównoważonego rozwoju, oceniając wpływ krzesła na środowisko oraz identyfikując potencjalne obszary optymalizacji i poprawy z punktu widzenia ekologicznego.

Słowa kluczowe: LCA, eco-design, recycling, product life cycle

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