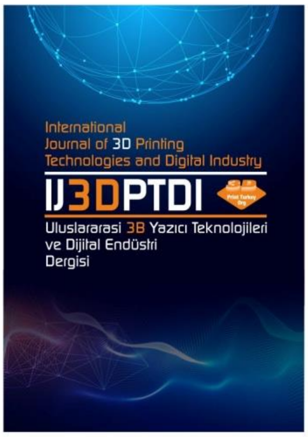

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FROM DESIGN CONCEPT TO PRODUCTION: USING GENERATIVE DESIGN OUTPUT AS DESIGN INSPIRATION

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ABSTRACT

With the rapid development of information technologies, the generative design has started to rethink the future roles of industrial designers. The simulation integrated into generative design helps designers to create manufacturable products. Therefore, this study examines how generative design can progress with conventional production processes and how this progress can help designers in the future. The potential of generatively obtained form-seeking processes to create optimal results is discussed within the scope of this study. For this purpose, a generative design triggered design process was conducted with a firm in the real sector about re-designing a bicycle frame. Generative design outputs have been optimized in terms of manufacturability. The effects of generative design-based inputs on the final product have been discussed through material usage and the sustainability. Based on the outcomes of the study, suggestions have been developed on how generative design can be transformed into results that can be a source of innovation.

Keywords: Generative Design, Designer Role, Design Processes.

1. INTRODUCTION

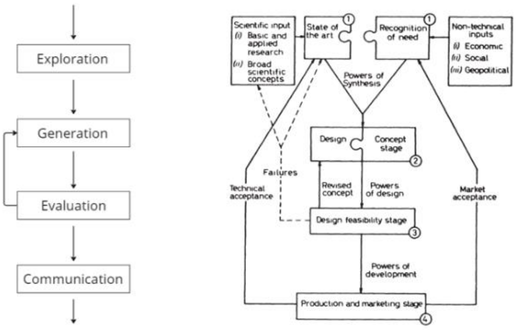
1.1. Design Processes

The digital revolution, which started with the production of the first transistor, reached its climax with the spread of personal computers. With the use of digital technologies in the industry, production processes have become more efficient. With digital automation, processes have started to take place faster and more smoothly. Thus, it enabled production to be made in a shorter time and with higher productivity. In addition, thanks to digital technologies, production processes have become more accessible and understandable [1].

It is undeniable that the digital revolution, accelerated by the spread of personal computers, affects every aspect of life. Designers use one or more design tools throughout the act of designing [2, 3]. The digital age, which started with the transition from analogue computers to digital computers, also enabled the evolution of the tools used by the designer [4]. Electronic pens and screens have replaced the paper and pen used by the designer; the mathematical formulas entered on the black screen during production have been replaced by Computer-Aided Design (CAD) software with modern interfaces controlled by peripherals called mouse [5]. Actions such as prototyping and optimization, which take a long time to perform with conventional methods, have become faster and more effective thanks to CAD software. Thus, the design processes have also changed with the changing industrial production processes.

The act of the designer seeking a solution to a problem forms the basis of the design process [6]. Although there are many interpretations of this process in the literature, the common process definition includes problem analysis, concept design, evaluation, enlightenment, and validation steps [7]. When viewed from a broader perspective, it is seen that the design process has a much more complex structure. In the process, a much more comprehensive structure emerges, including technical information on basic and applied sciences, economics, social and geopolitical issues, and the definition of needs [8]. The experiences gained at each step of the design process form the basis of the next step.

When descending from the main steps to the intermediate steps, prototyping and optimization can be seen among these steps [9]. Prototyping and optimization are cyclical, multidisciplinary efforts for finding a better solution [10]. In markets where new designs are constantly sought, speed and diversity gain importance in the new product development process. For this reason, it is necessary to select multiple alternatives from among potential solution proposals quickly. It is also essential for companies to produce many prototypes and perform optimization on these prototypes.



(a) (b)

Figure 1. Cross's simple four-stage design process model (a) and Gregory's definition of the design process (b).

The CAD software used by the designers in the design process is as essential as the steps of the process. The designers, who tried to prevent error by simulating the prototypes and analyses in digital environments before they were produced, started to produce more complex designs using CAD tools. As designs evolve into more complex structures with this software, there is a need for utility programs that will reveal the work done more effectively. One of these needs was to make it easier for designers to produce forms based on specific algorithms and within defined limits. The designers using algorithms and boundaries were looking for a CAD tool that would minimize the margin of error, effectively reveal form alternatives, and allow random occurrences in alternatives. [11]. For this reason, specialized CAD helpers emerged that would make iterations or changes in the textures of designs easier and faster. Although these assistants emerged as a software add-on at first, they have become stand-alone software over time. The design model made by producing forms with software which have these algorithms is called generative design (GD), and its history dates to the early 1900s. [12].

1.2. Generative Design

GD is a CAD technique that allows the quickly developing of design alternatives [13]. The GD, whose processes (See Figure 2) are cyclical and based on iterations [14], emerged with the effects of the digital age and showed itself first in the field of informatics and then in architecture [11]. The biggest reason why it is seen in the field of architecture was the fact that innovative architects and thinkers questioned the architectural designs of their periods at the end of the 19th century and the necessity of establishing the design on universal principles and keeping it away from individual tastes was realized [14]. During this period, the focus of attention of many architects and designers turned to nature. The book Art Forms in Nature, published by biologist E. Haeckel in 1904, attracted the attention of designers who shared the same idea, and the traces of nature can be seen in many designs made after this date.

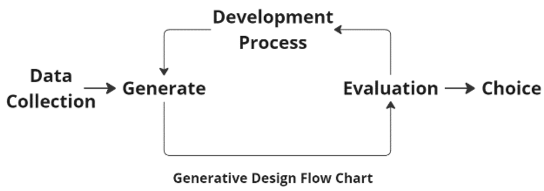


Figure 2. GD processes [15].

This software, which architects use when making decisions on buildings, has turned into a tool that includes simulation and optimization in its infrastructure with the advancement of information technologies (See Figure 3). This simulation transforms the form to be produced into optimal design solutions according to the specified materials and the forces given. While the previously created forms were defined only through aesthetic perceptions and textures, it has now made it questionable how well they will fulfil the functionality.

GD work is primarily done in the fields of architecture and engineering. In the literature research, it has been seen that architects mostly use GD to produce forms [16-18], and engineers use it to search for more economical solutions for the designs to be made [19-21]. In one, all variations of the desired design forms are observed, and in the other, the search for the best possible solution from all variations within the desired limits is discussed [22]. GD adopts a design approach that imitates the evolutionary formation of nature. With this approach, computer sciences involved in the GD process create difficulties for designers who have little expertise in these subjects [23]. With the spread of additive manufacturing in the industry the issue of GD comes to the fore more and gets closer to industrial design. Despite the convergence of GD with industrial design, there needs to be more work done in the field of industrial design literature.

(a) (b)

Figure 3. GD-1 [24] (Designer: Kiarash Kiany) GD-2 [25] (Designer: Lightning motorcycle).

Although the design processes have survived almost unchanged throughout history, they have changed rapidly since the Industrial Revolution and have kept up with technology. The most significant technological changes were undoubtedly the internet age, which became widespread with the digital revolution [26]. The limited native processing power of personal computers allowed designers to work with a limited number of forms while using GD. We can easily see the Internet's and internet-connected technologies' effects in the industry on GD [27]. Thanks to the cloud technology that emerged after the internet, GD work has become much faster and much more form study can be done on a remote server, independent of personal computers [28].

Since the production patterns of the GD outputs are determined in the problem definition process, the results are formed in accordance with these production processes. In this context, manufacturers need to have these production processes in their production lines for GD to be a valuable tool. However, for a designer, the output of this tool not always be the final product. If the outputs are considered as form suggestions, a design approach that can be progressed with different production processes can be put forward. Thus, the outputs of the GD tool during the production process will be carried over to the design process.

In their study, Singh and Merrick state that GD can become a helpful tool for designers when examined within a framework specific to industrial design [29]. The limited technical knowledge infrastructure of industrial designers, such as force, statics, and resistance, makes it difficult for them to use this tool. However, if this technical information is given to them, they can quickly adapt and include it in the design processes. This study aims to research how GD affects the role of industrial designers in the industry and how it can change it.

2. METHOD

A firm from the real sector was selected in the study, in which the potential of GD to be a resource for design and innovation in the processes leading up to production was investigated. In this context, interviews were held with jewellery design, furniture, and steel companies. The potential of working on a product that meets the criteria of having a function and a form that can be produced with GD has been questioned. In the study, it is aimed that the product to be designed with a GD will be under the effects of a structural force, that the designed product will not be hidden under another shell, and that the end user can easily observe it. The method of the study is a six-step process, and each step will be explained in this section. In this research, “Autodesk Fusion 360” CAD software was used for GD studies.

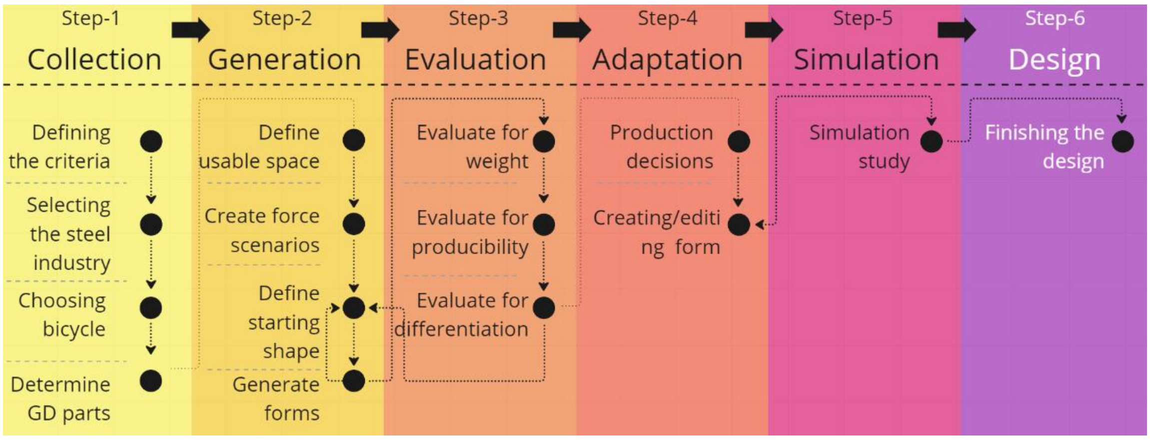


Figure 4. Research method.

2.1. Step 1

Within the scope of the study, the criteria for the product to be produced with GD were established. These criteria are that the product to be designed must be under the influence of a particular force, it should not require special conditions to be produced, and it is not covered with shell or other parts, making it difficult to see. In this context, because of the interviews, it was decided to collaborate with a firm from the steel industry about a bicycle, which is a product in which both function and form gain importance, and the bicycle frame was chosen as the product. Within the scope of the study, an example of a conventional product with defined functional limits was emphasized, a conventional bicycle was chosen, and it was considered a control example (See Figure 5).

Figure 5. The bicycle that has a conventional frame.

It was decided which parts would be included in the GD with the study on the bicycle. Accordingly, basic behaviour models were analysed by preserving the connection points in the product. Based on the decisions made, it was evaluated which parts would be included in the study and compared. In this context, those shown in green in Figure 6, and denoted by the letter “a” shows the parts that are planned to be included in the GD.

2.2 Step 2

After the bicycle frame parts to be included in the GD were decided, the areas that could be used by the GD were determined. As seen in Figure 6, those marked with the letter "b" on the bicycle form and shown in red indicate the areas where the GD tool is prohibited, that is, the areas closed to GD, and those that are indicated with "c" and shown in blue indicate the parts that will not be included in the design process. After the parts of the conventional bicycle are separated, the bare frame weighs 3.6 kg.

To be able to distribute the load in the GD tool, it is necessary to define the load scenario first. Figure 6 shows that the front wheel boundary is defined as a spherical obstacle so that the front wheel can turn left and right in the bicycle frame example. To define the space better where the GD tool will work, the moving or screwed parts of the green areas to be included in the design are marked with red barriers to prevent errors.
After the boundaries on the forms are determined, the loads are defined. The forces that will physically affect the bicycle frame were investigated, and a multi-scenario study was arranged in which all loads were affected. In the determined scenarios, a series of force inputs, including the buckling and rotational moments that the cyclist will exert the bike at the highest level, is created.

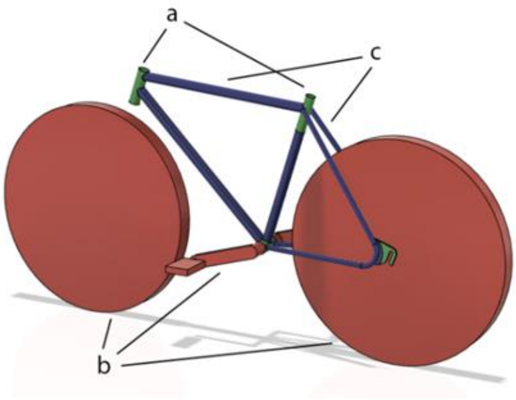


Figure 6. Boundaries of the bike frame

The definition of loads on the design is shaped according to the design outputs expected from the GD tool. This study is designed for an urban bike with users weighing a maximum of 130kg. As can be seen in Figure 7, the distributions are prepared to simulate various events such as statics (where the bike is not going and the user is stationary on it), rotation (individually resisting axial rotational force of the handlebar and middle section) and buckling (the stress caused by the sudden impact of the bike while it is in motion) as scenario-based inputs.

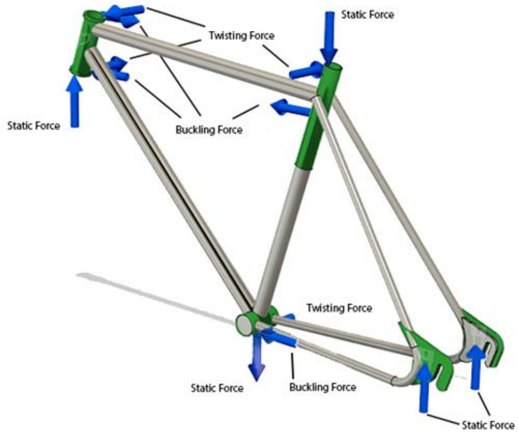


Figure 7. Load distribution.

2.3. Step 3

As a result of operating the GD processes, ninety-four GD studies and ninety-four load distribution scenarios were made. Each study was conducted with at least twenty-five iterations and four different materials. The total number of iterations was more than 9400. As a result of the study, the process continued a form deemed appropriate.

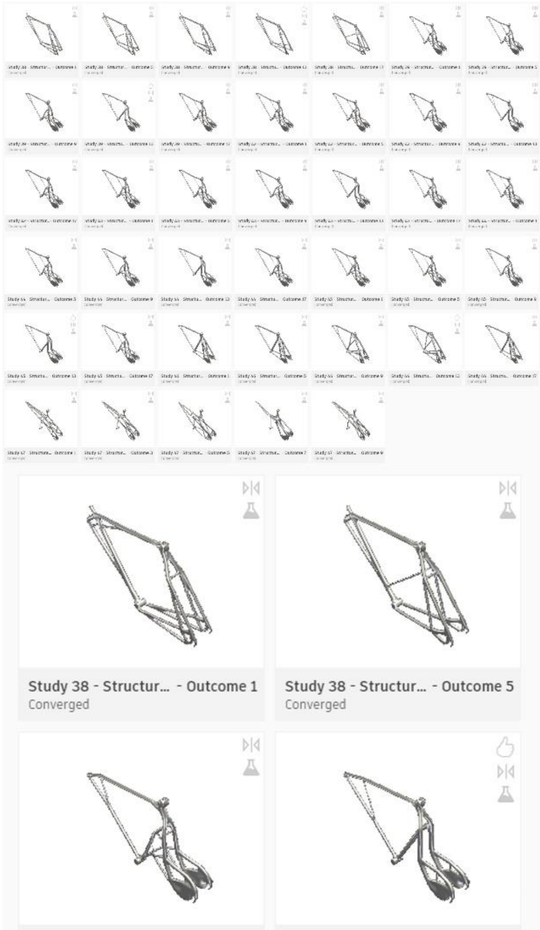


Figure 8. Thirty-nine out of ninety-four GD printouts and detailed sample images.

2.4. Step 4

A study was conducted to make the form obtained with iterations producible with the firm's production processes. In terms of being suitable for conventional production processes, it was decided to produce the resulting form by using conventional profile pipes. It has been reconstructed with basic forms so that the organic form can be produced more easily with conventional methods (See Figure 9). The lattice structure was defined on the edges of the new form, and the bearer system solution was created over this structure.

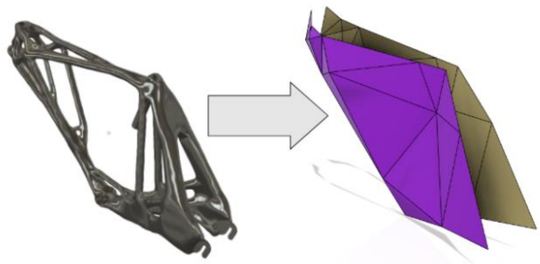


Figure 9. Organic shape to Basic Shape.

2.5. Step5

The simulation of the implemented form of the bearer system solution has been performed (See Figure 10). In this context, a new study has been initiated for the simulation, and the forces entered in the GD process have been repeated in this step. It has been investigated whether the new design relies on the given forces, like the GD output.

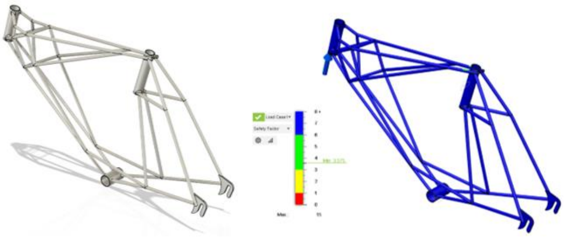


Figure 10. Design solution and its simulation result.

2.6. Step 6

After observing that the design idea works in the simulation, the other elements that can be included in the design are emphasized. The necessary parts are added to create the solution, the final changes are made to the design, and the final product is reached.

3. RESULTS

The GD tool, by its nature, aims to reach the optimized final form from a certain space by using the iterative space-freeing technique. For this reason, the form outputs produced by the tool are always solid structures, and it is entirely up to the designer's choose whether to use these outputs as they are. At this point, the first results that emerged in this study, in terms of form structure, are close to the structures available in the market, although partially different form outputs can be seen (See Figure 8). However, when the results are compared with the form structures in the market, it is seen that the GD tool cannot produce a lighter form in terms of weight. The first stage of the study was created using different materials to compare the material and design outputs. On the weight/safety table, steel-derived materials are clustered in heavy-weighted region; titanium is concentrated in the medium-weight region, while aluminium is concentrated in the lightest region.

After observing that the GD outputs reached similar results with each other, the form formation processes of each of the outputs were examined starting from the first iteration step. Looking at the common denominator of these outputs, it is seen that the initial iterations are the same. From this point of view, the subsequent iterations will not have hugely different form outputs. For this reason, it is aimed to obtain different results by creating a wider area that the GD tool can use.

It has been observed that the GD outputs with the initial form defined are more different and functional than the previously produced forms (See Figure 11). However, the fact that these forms are even heavier than the previous forms make them a design that cannot be produced. For this reason, a new process has been designed, inspired by the GD outputs.

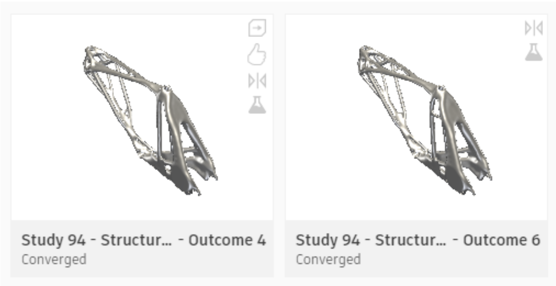


Figure 11. Output whose form has changed by giving the initial form.

In the process, it has been observed that although the path followed by the GD tool in creating the desired designs is different, the results are always the same. Since the frame to be designed cannot be produced in a hollow structure like conventional bodies, the structures are composed of completely solid materials, and therefore the frame designs are heavy. Since more than the GD tool is needed to create hollow forms, the created forms need to be reconsidered by the designer. It will be easier to produce if the physical strength of the output in an organic structure can be solved with a simpler structure. For this reason, the output was reconstructed using surfaces modelled with basic forms to transform highly detailed organic structures into simpler ones (See Figure 9).

The first study on the form in the basic structure (See Figure 12) shows that the lattice structure created by the GD tool can reach a positive result. The design's behaviour against the load is close to the area indicated by the green area numbered 3-6 and defined as favourable conditions. When the design is examined, it has been observed that the right and left sides of the hull diverge from each other in some areas and converge in some areas, and its structural integrity is disrupted. When viewed from the GD output (See Figure 9), it has been observed that those regions are thicker than the other sides.

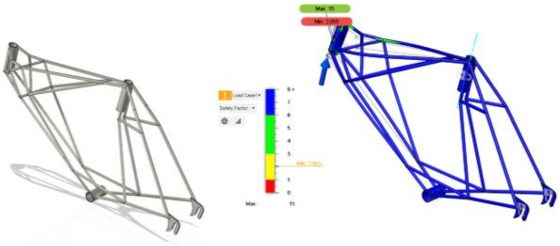


Figure 12. First model after basic form and its simulation result.

After the observation, an iterative design process was conducted on the design. This process created support points in the regions where bending was observed after the simulation. The static simulation of the new design was performed again, and progress was made to use the least material. In the process, not only additions were made, but also unnecessary parts were removed. When the final design (See Figure 10) is reached, a structure with a weight of 2.3 kg and a strength of up to 3.5 times the 130 kg force given is obtained.

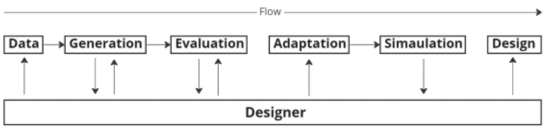


Figure 13. The GD process diagram in the study.

In the design process of the research (See Figure 13), the designer was assigned to evaluate, synthesize and re-flow multiple disciplines by taking tasks such as data identifier, output determinant, design idea selector, adaptor, simulation evaluator and designer. Considering the design processes, the process used in this research is shorter than French's ten-stage design process [30]. The main reason for this is that algorithms analyse the given data. There is no single right way in the design processes used in this research. If lighter structural integrity is expected from the design, it is known that this can be achieved faster with the GD tool.

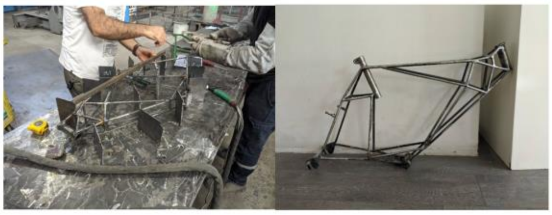


Figure 14. Production process and the final product.

At the end of the process, frame manufacturing was conducted on the defined production line and evaluated from an innovative perspective. A more functional design has been created with a different approach to the frame structure, which looks different from the products on the market. The study, which has been manufactured, was analysed, and it was observed that up to 33% reduction was achieved when compared to conventional bicycle frames. In addition, with this lightning, it has become a bicycle that users can carry more easily and ride with less effort.

4. CONCLUSION

This research aimed to reveal the potential of GD for conventional manufacturing techniques and examined the role of the industrial designer by questioning the place of the GD tool in the industry. While the article focuses on the form creation skills of the GD tool developed with simulation analysis, it also examined the results of the designs that will emerge by using the GD outputs as a source of inspiration in the design processes of industrial designers.

The study started with a literature search. The design processes with the developing technology and the role of the designer in the industry are discussed through GD. A special 6-step GD method was developed for this research, and product design was made with this method. With this method, which has steps such as data collection, production, evaluation, adaptation, simulation and design, GD is examined from a different perspective. GD outputs were evaluated as a source of inspiration, and it was ensured that the design ideas that could be put forward were based on the data.

In this study, the designer had roles that interfered with both design, production, and the safety of the design. The fact that GD is gradually taking place in the industry and is a sought-after tool in high-tech designs shows that the designer will also assume different roles in the future. It is foreseen that industrial designers can unleash this tool's potential, especially in the design of parts and products that will perform the same job by using lesser materials. This study proves that designers can realize extraordinary designs by incorporating GD tools into their production processes at a time when products are not only designed as a shell.

It is seen that the generative design process carried out in this article also contributes to the sustainability development goals of the United Nations. A transportation vehicle, which has great advantages about using clean energy, such as bicycle, is produced with less material than conventional vehicles, resulting in less carbon footprint. With less carbon-footprint it ensures the production is sustainable. Lighter bicycle means it can be used by a wider range of users, so that means it can reach more people and use more clean energy on transport. Also, when the materials lessened, manufacturing costs will reduce.

Lighter products create less carbon while manufacturing, shipping, repairing, and in usage. From this point of view, this research has an innovative approach to using generative design in the scope of sustainability.
Although creating a form with a GD tool may seem simple to an outside observer, it cannot be easy to find a suitable form, considering the production conditions. Forms created with iterations within limits set by the designer with specific algorithms often do not carry the desired aesthetic concern. For this reason, GD studies appear as a chain of work based on constantly getting different results with new parameters.

As a result, the emergence of a design can sometimes be hidden in the designer's mind and sometimes on the surfaces of a dice put forward. The designer designs by being open to all surprises, sometimes knowing where he will go and sometimes not knowing what will come out. At this point, the designer looking for inspiration often looks at other products and related works around him. These inspirations rarely lead the design to a vastly different point from other manufactured products. Although being different does not always mean being distinctive, it is always the first goal to create easily distinguishable differences in the products made by designers. The first feature that the GD tool provides to the designer is to provide optimized form outputs that will fulfil the function. The second feature is to inspire the designer with these outputs and create a space for reflection.

While it is difficult to generalize based on a single case, this study has shown that designers can look outside the box, find more innovative approaches in GD tools, and capture different approaches in design and manufacturing processes with these tools.

ACKNOWLEDGES
Authors can refer to companies, businesses, public institutions, or projects that contributed to the study in this section.

REFERENCES
1. Schwab, K., “The fourth industrial revolution”, Crown Business, New York, 2017.

2. Do, E.Y.-L., Gross, M.D., “Drawing as a means to design reasoning”, AI in Design, June,1996.

3. Ekströmer, P., Wever, R., ““Ah, I see what you didn’t mean” exploring Computer Aided Design tools for design ideation”, The Design Journal, Vol. 22, Issue 1, Pages 1883-1897, 2019.

4. Şeker, T.B., “Bilgi teknolojilerindeki gelişmeler çerçevesinde bilgiye erişimin yeniboyutlari”, Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, Vol. 13, Issue 1, Pages 377-391, 2005.

5. Woodbury, R., “Elements of parametric design”, Routledge, New York, 2010.

6. Brown, T., “Design thinking”, Harvard Business Review, Vol.86, Issue 6, Pages 84, 2008.

7. Lawson, B., “How designers think”, Architectural Press, Oxford, 2005.

8. Gregory, S.A., “The design method”, Springer, Birmingham, 1966.

9. Brown, T., “Change by design”, Harper Business, New York, 2009.

10. Gomes, S., Antoine, V., Sagot, J.-C., “Functional design and optimisation of parametric CAD models in a knowledge-based PLM environment”, International Journal of Product Development, Vol. 9, Issue 1-3, 2009.

11. Lobos, A., "Finding balance in generative product design", Norddesign 2018, Sweden, 2018.

12. Proctor, R., "Architecture from the cell-soul: René Binet and Ernst Haeckel", The Journal of Architecture, Vol. 11, Issue 4, Pages 407-424, 2006.

13. Khan, S., Awan, M.J., "A generative design technique for exploring shape variations", Advanced Engineering Informatics, Vol. 38, Issue 1, Pages 712-724, 2018.

14. Agkathidis, A., "Generative design: form-finding techniques in architecture", Laurence King Publishing, London, 2016.

15. Walmsley, K., "Getting started with generative design for AEC", https://www.autodesk.com/autodesk-university/class/Getting-Started-Generative-Design-AEC-2018, March 22, 2021.

16. Huang, Y., "Generative forms of historical architectural arts–the example of caisson in historical temple", International Journal of Culture and History, Vol. 3, Issue 3, 2017.

17. Schumacher, P., "Parametricism: a new global style for architecture and urban design", Journal of Architectural Design, Vol. 79, Issue, 4 Pages 14-23, 2009.

18. Janssen, P., R. Stouffs, "Types of parametric modelling", 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, Pages 157-166, 2015.

19. Fryer, T., "The end of the engineer?", Engineering & Technology, Vol. 12, Issue 9, Pages 26-29, 2017.

20. Gunpinar, E., Coskun, U.C., Ozsipahi, M., Gunpinar, S., "A generative design and drag coefficient prediction system for sedan car side silhouettes based on computational fluid dynamics", Computer-Aided Design, Vol. 111, Pages 65-79, 2019.

21. Renner, G., Ekárt, A., "Genetic algorithms in computer aided design", Computer-Aided Design, Vol. 35, Issue 8, Pages 709-726, 2003.

22. Chen, X.A., Tao, Y., Wang, G., Kang, R., Grossman, T., Coros, S., Hudson, S.E., "Forte: User-driven generative design", 2018 Conference on Human Factors in Computing Systems, Paper 496, Pages 1-12, 2018.

23. Curralo, A., "Generative Design and Information Visualization", 7th International Conference on Digital Arts, Pages 99-104, 2015.

24. Kiany, K., "Parametric Roof", https://parametrichouse.com/serpentine-sackler-gallery/, November 5, 2022.

25. Association of Equipment Manufacturers, "Generative design: solving design challenges with artificial intelligence", https://www.aem.org/news/generative-design-solving-design-challenges-with-artificial-intelligence, August 21, 2019.

26. Togay, A., Çetinkaya, K., "Üretken tasarım ve üretken tasarım etkisinde tasarımcı", 4th International Congress on 3d Printing (Additive Manufacturing) Technologies and Digital Industry. 2019. Antalya, TURKEY.

27. McDonagh, D., Hekkert, P., Erp, J.V., Gyi, D., "Design and emotion", Taylor & Francis, London, 2004.

28. Buonamici, F., Carfagni, M., Furferi, R., Governi, L., "Generative design: an explorative study", Computer-Aided Design and Applications, Vol. 8, Issue 1, Pages 144-155, 2020.

29. Gu, N., Singh, V., Merrick, K., "A framework to integrate generative design techniques for enhancing design automation", 15th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, Pages 127-136, 2010.

30. Cross, N., "Engineering design methods: strategies for product design", John Wiley & Sons, West Sussex, 2001.