Generative Design for Sustainable Industrial Products A Case Study on Optimizing Gaming Mouse Design

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Introduction

Growing concerns about climate change and environmental issues alongside worries regarding poverty, and widening gaps between societies show itself as a cause of the popularity gain of sustainable development (see, Sustainable Development Solutions Network—SDSN—of the United Nations launched in 2012). In terms of reducing impacts, several concepts like ecodesign and product design were suggested to the companies as production process strategies in the 1990s (Clark et al., 2009). Sustainable development aims to define the boundaries associated sustainability process. Setting groups of people to share knowledge and commitment to align environmental and economic development interests is the point to include in this term. According to (Scoones, 2007) This effort is directed towards closing the gap between environmental and economic issues. Organisations supporting the form of sustainable development concept, and a great number who adopted this as one of the fundamental principles for achieving their goals faced difficulties in moving from just theory and ideals into tangible and real-world outcomes. The importance of sustainability has been a critical topic, especially for developing countries and there are significant works around P-SPD (Policy for Sustainable Development) or SPD (Sustainable Development) tools. For instance, the same tools and studies are reported in such countries as China, India, Malaysia, and Singapore (Ahmad et al., 2018). The question arose: How did the implementation of sustainable development look like? As a result, numerous planning methodologies, analytical frameworks, measuring metrics, systems of auditing, and evaluation protocols became quite prominent (Scoones, 2007). At the consumer level, promoting sustainability by selecting those goods that are produced immaculately could give one some kind of contentment or satisfaction in life. Nevertheless, changing for meaningful purposes does not only involve buying these products but also reducing general intake. Sustainability in itself can only be realized if the demand for ecologically friendly products is coupled with reducing the overall pattern of consumption (Clark et al., 2009). On the other hand, to overcome the hedonistic inclinations of consumers, it is important to make known that spending money on well-made and well-designed products is worthwhile if these items are also ethically made and sustainable (Harper, 2017). To contribute to this mindset the designers should possess a profound understanding of design for sustainability. Acquiring deeper consciousness about it, and communicating and sharing the idea of sustainability goes beyond mere recycling or using recycled materials (Bhamra & Lofthouse, 2016). For this purpose designers working on different methodologies to adhere to this issue. The idea of taking inspiration from nature and adapting its methods to design and produce new products is a key among certain professionals in the field of design for sustainability. Biomimicry design is one of the main ideas that serve this purpose

(Ceschin & Gaziulusoy, 2016) Imitating nature's diverse forms, systems, and processes for tackling the most critical challenges about material usage is the main objective of biomimicry practice (Nkandu & Alibaba, 2018).

Making strong enough to withstand the forces is the main approach conventional engineers apply to designing things. However, shapes and structures in nature are much better able to be flexible and responsive, alternating between rigid and flexible as necessary**.** In creating structures, some methods borrow from the different ways in which nature finds the perfect shape and its purpose (Dutta et al., 2020). In nature, organisms have evolved to be quite adaptable and function in specific environmental limits, while they manage energy and material resources. These organisms, just like humans experience a similar environmental state and therefore are forced to deal with the same issues that humans themselves face (Nkandu & Alibaba, 2018). Ilieva et al., 2022 state that it is crucial to carry out design experiments to participate actively in thinking about the roles of designers and nature, as well as delving into the design process itself. This active reflection opens up a deeper insight into the way nature works, enabling designers to take inspiration from natural solutions and incorporate them into sustainable design processes.

If proper implementing methods can be found, finding the perfect shape could also mean efficient material usage, less energy consumption, and less material waste which is sustainable at the product innovation level. The generative design method is one of the popular candidates for applying this approach. Being aware that there is no general definition of generative design it could be characterized as a form generation process with AI-driven algorithms of computational tools like Grasshopper, Processing, and Rhinoceros which are restricted by boundary rules (Agkathidis, 2016)Generative design tools work exactly like nature itself. In nature, evolution found the perfect form within the centuries trying again and again and eliminating the nonsuitable forms for the given environmental conditions.

In computational tools, the environmental conditions are the rules and boundaries that the designer defines. Unlike nature with the help of cloud technology, high-performance computing powers allow doing continuous iterations and optimizations in a limited time (Martorelli & Antonio, 2023). On the other hand, one should keep in mind that the results of the generative design process are highly dependent on the boundary rules that are defined by the designer

Since generative design can operate at the conceptual stages of design which happen at the very beginning, the conditions of design space can be redefined again and again until the optimized model occurs (Krish, 2011). The capability of exploring a wider range of designs within a short time frame saves costs while leading to time and labor reduction (Singh & Gu, 2012). With generative design, designers can create conceptual designs while optimizing the material usage. Especially in today's world optimizing plastic use is important for having a sustainable mindset. According to Barnes et al., 2009, the devastation caused by plastics is not limited to places where humans dwell. Multivalent plastic fragments in various sizes are now ubiquitous, from soils to lake beds and faraway Antarctic shores to tropical seabeds. The amassing and dispersal of plastic dust have led to the pervasiveness of such matter in all areas of worldwide environments, indicating the remarkable effect that plastics have imparted upon earth surfaces. Additionally, throughout the manufacturing phase, a wide range of chemicals are used to increase their effectiveness. Among

them, these additives include plasticizers that involve a range of compounds such as flame retardants, stabilizers, antioxidants, and other chemicals like antimicrobials. (Thompson et al., 2009).

The article discusses the generative design and its contributions to sustainability using the case study methodology of qualitative research. The redesign of a gaming mouse specifically tailored for competitive game players will be discussed through the lens of generative design. This case study aims to reimagine the conventional gaming mouse design, emphasizing efficiency, performance, and environmental consciousness. In this concept, the conventional gaming mouse is the Logitech G Pro X Superlight. The reason for choosing the gaming mouse design, especially in this case study, relies on the fact that the vast majority of these products and their internal parts are made from ABS (acrylonitrile butadiene styrene) due to its qualities such as shock resistance, stiffness, and durability (Ganeshan et al., 2020). Additionally, there is a growing interest in competitive gaming and lightweight gaming mice. The outcomes of the research made by Conroy et al., 2022 show that even 5-10 gr differing mass affects the response time of players specifically in First-Person Shooter (FPS) games. Also, the research conducted by Thomsen et al., 2008 indicates a correlation between mouse usage and its mass properties which may impact muscle usage, potentially leading to the development of carpal tunnel syndrome. Given that a significant portion of gamers extensively utilize the mouse, it becomes imperative to consider this association seriously.

Furthermore, this research is guided by two pivotal inquiries that form the crux of the investigation:

1. How does generative design facilitate the integration of biomimetic principles into product aesthetics and functionality, promoting sustainable solutions inspired by nature?
2. In what ways can generative design be optimized to reduce the environmental impact of product development by minimizing material consumption, and ensuring sustainability without compromising functionality or aesthetics?

Methodology

A practical and exploratory approach is handled in this paper focusing on the application of generative design towards sustainable product development. The core of this research revolved around employing generative design methodologies. A case study method has been adopted as a research method. For this purpose in terms of making clear comparisons, a reference product (in this case a gaming mouse) has been chosen. The properties of the Logitech G PRO X Superlight mouse were appropriate because of its popularity among competitive esports game players (*Best Mouse for VALORANT [334 Pro Players, Nov 2023]*, n.d.). For modeling and creating a study, Autodesk Fusion 360 has been the software that is decided to use along with its Generative Design extension to reimagine the design of the Logitech G Pro X Superlight mouse. Form mode and form editing tools of the Autodesk Fusion 360 software are used to model the reference geometry. Since the technical drawings of the reference product are not publicly available, form mode and form editing tools are decided to be the optimal solution for modeling purposes. With these tools only the reference views and general dimensions of the product are enough for having the 3D model of

the targeted object. The reference dimensions and images were imported from the (*Logitech G Pro X Superlight Wireless Gaming Mouse*, n.d.). An exploration into optimal material distribution and structural configurations within the mouse's outer shell was conducted. The research methodology involves a multi-step process to quantitatively compare the mass of the default Logitech G Pro X Superlight body with the generatively designed version in digital environments. For digital mass comparison, ABS plastic material was assigned to the CAD design of both modeled and generative-designed models in Autodesk Fusion 360. Throughout the generative study process, data on various design iterations, material utilization, and sustainable attributes were systematically collected. Performance metrics including material efficiency, and environmental impact were analyzed to evaluate the sustainability implications of the generatively designed mouse shell. The approach that was handled in this research facilitated an iterative design process, examination of various design parameters and their influence on sustainability outcomes were the main focus through all the stages of research. This article was written based on this approach and aims to investigate the contribution of the generative design method to sustainable product design by examining it in an applied way.

Background

Autodesk Fusion 360 is the CAD/CAM/CAE software that uses the cloud-based approach for creating a space for collaborative product development. The Software combines organic modeling and solid modeling tools aiming to make a fast and easy use (*Fusion 360 Help | Getting Started with Fusion 360 | Autodesk*, n.d.). The cloud-based approach lets the users make high computational analysis in remote environments even with mediocre-level personal computers and laptops. Additionally, Autodesk`s Student License lets the users access the software without any extra cost, and unlimited tokens for online cloud-based generative design study analysis let the students make more experiments out of any overuse concern. That is why Autodesk Fusion 360 has been chosen as the main study software for this research. For creating a consistent study the modeling software and its tools should be understood rightfully. For this purpose, the entire Autodesk Fusion 360 documentation was analyzed. Help.Autodesk.Com the official website of Autodesk Fusion 360 contains all the necessary information, tutorials, and example projects. Also, the articles and personal projects published on the blog page of Autodesk such as (*Philippe Starck Designed a Production Chair With Generative Design*, n.d.) and (*Lounge Chair - Generative Design | Autodesk Community Gallery*, n.d.) examined

Process

Autodesk Fusion 360 is used for modeling and creating generative design studies. Firstly, for having the reference 3D model, form modeling and form editing tools are used to model the base body. With the referencing the front and top views of the Logitech G Pro X Superlight gaming mouse.

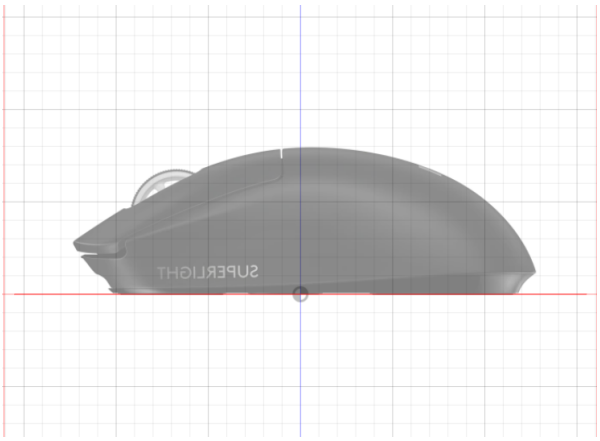

Figure 1 Front View of Logitech G Pro X

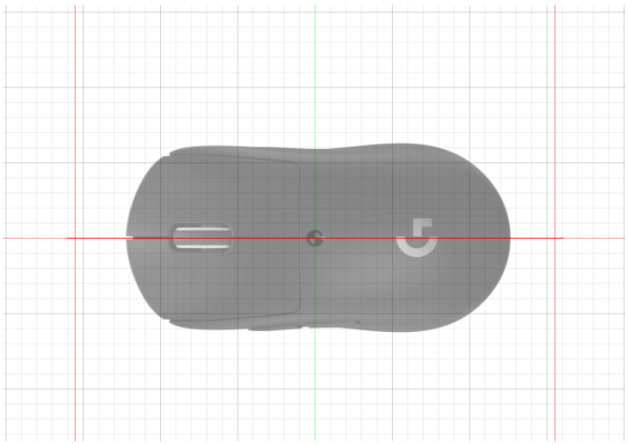

Figure 2 Top View of Logitech G Pro X

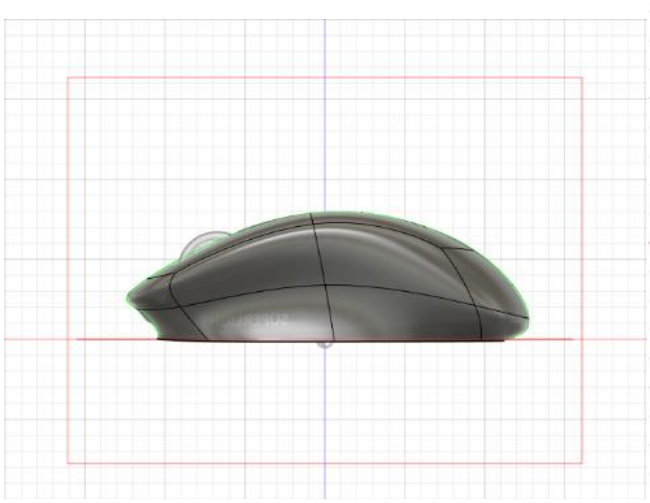

Figure 3 Referenced 3D Model Front View

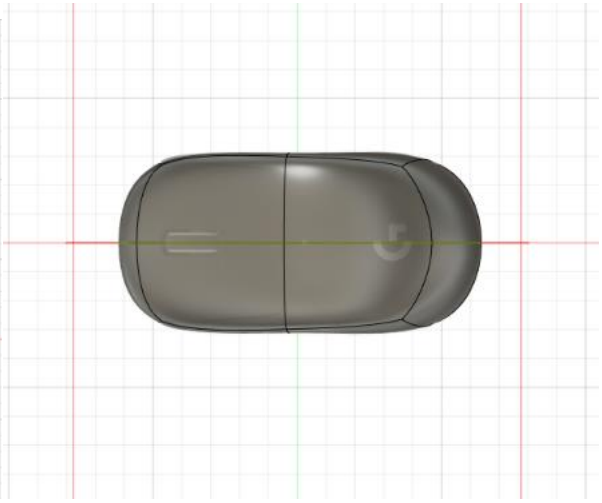

Figure 4 Referenced 3D Model Top View

After finalizing the model, the created form solidified and a solid model was created. For the generative design study, additional geometries were modeled to occupy areas that desired to not be used by the algorithm. In Fusio 360 it is defined as an obstacle geometry.

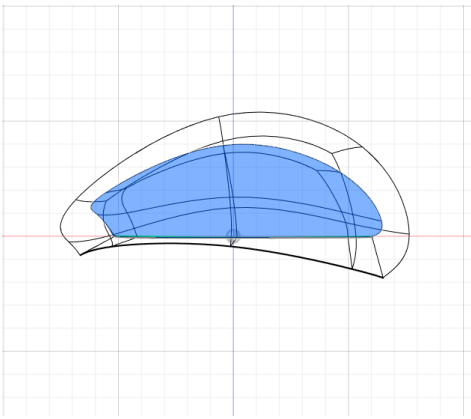

Figure 5 Wireframe View Front. Outer Obstacle Geometry

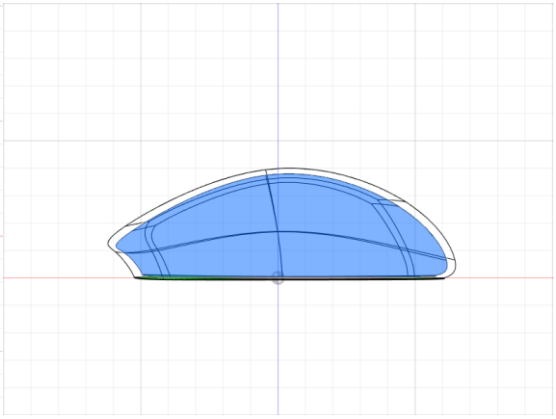

Figure 6 Wireframe View Front. Inner Obstacle Geometry

Preserve geometry is the important input for the algorithm that informs where are the points of non-iteration. Obstacle Geometry, and Preserve Geometry both are components of Design Space. For this reason, extra sketches were drawn to the front and top view, and new bodies were created with the split body command. Through experimentation, the strategic determination of sketches' drawings and split lines are determined. While these sketches drew the main shape of the reference gaming mouse was considered.

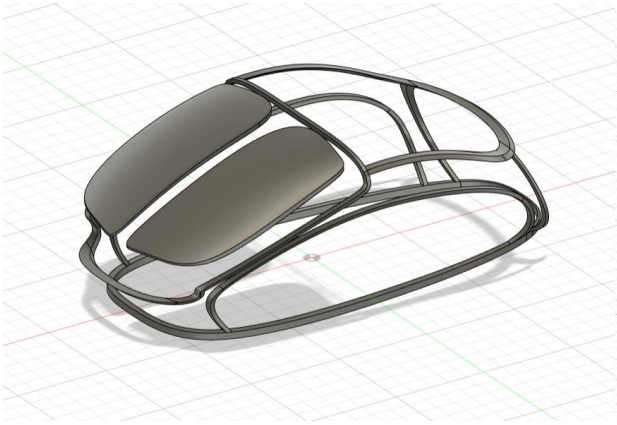

Figure 7 Splitted Lines in Design Workspace View

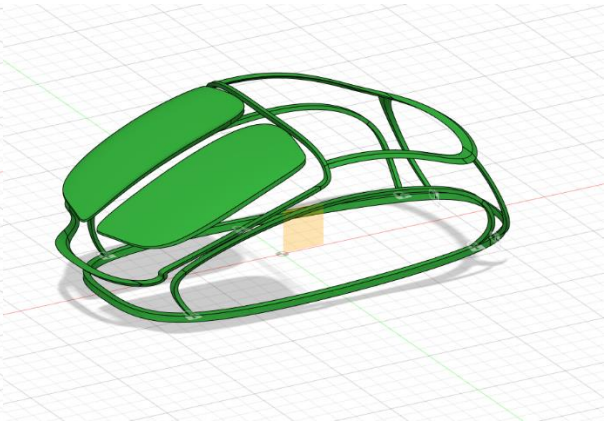

Figure 8 Splitted Lines in Generative Design View. Assigned to Preserve Geometry

In the generative design workspace, numerous forces are introduced onto the faces of these divided lines. The positioning of these forces takes into account the directionality corresponding to the hand's position. Typically, for structural loads, forces of 500 N are applied vertically, while 250 N forces are applied horizontally. The deliberate increase in force magnitude is aimed at accommodating the need for greater space coverage. Only one structural constraint is applied to the bottom of the design.

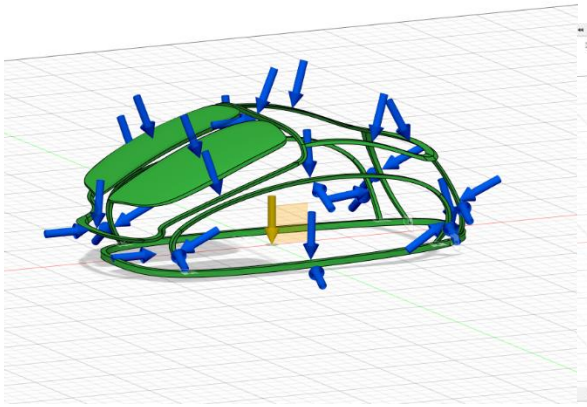

Figure 9 Applied Structural Forces

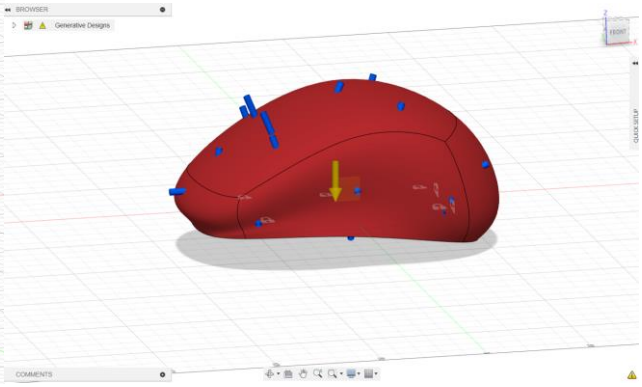

Figure 10 Final Study

Results

The results of the study are shown in Figure 11, figure 12, and Figure 13. It should be considered that these are the results of the 3rd attempt. The first two results are not indicative of the outcome, as adjustments and refinements were made in subsequent attempts. Adjustments are mostly made in the structural loads. The objective is defined as a minimized mass ABS material assigned and Additive Manufacturing methods chosen.

Figure 11 Generative Designed Gaming Mouse Front View

Figure 12 Generative Designed Gaming Mouse Top View

Figure 13 Generative Designed Gaming Mouse Perspective View

In total 32 iterations were made by the algorithm and the final result achieved from the properties of the original model had a 211.839 gram total mass while the generative designed model only has 40 gr. The Generative Designed model is more than 5 times lighter than the original design

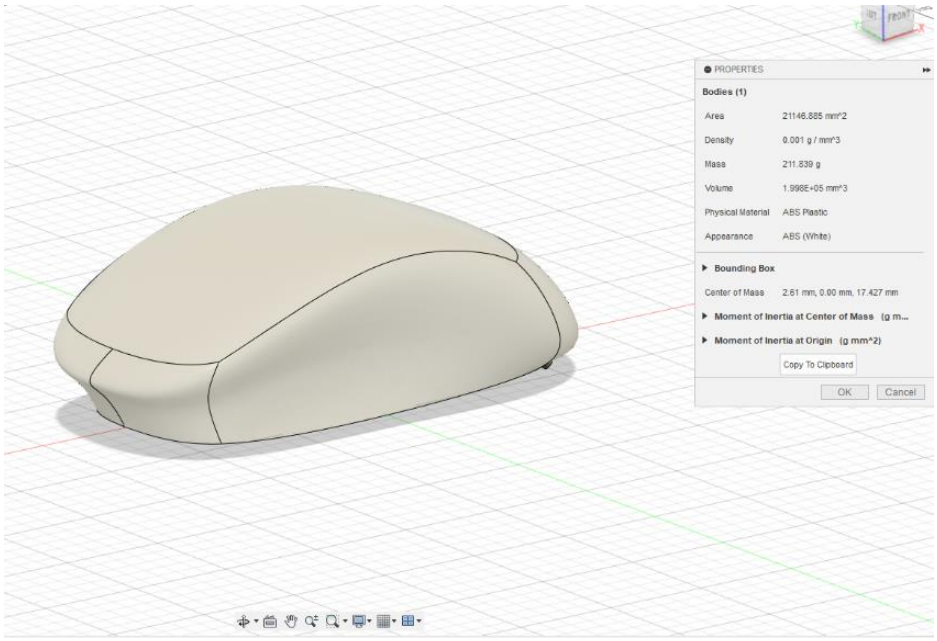

Figure 14 Referenced 3D Model Properties

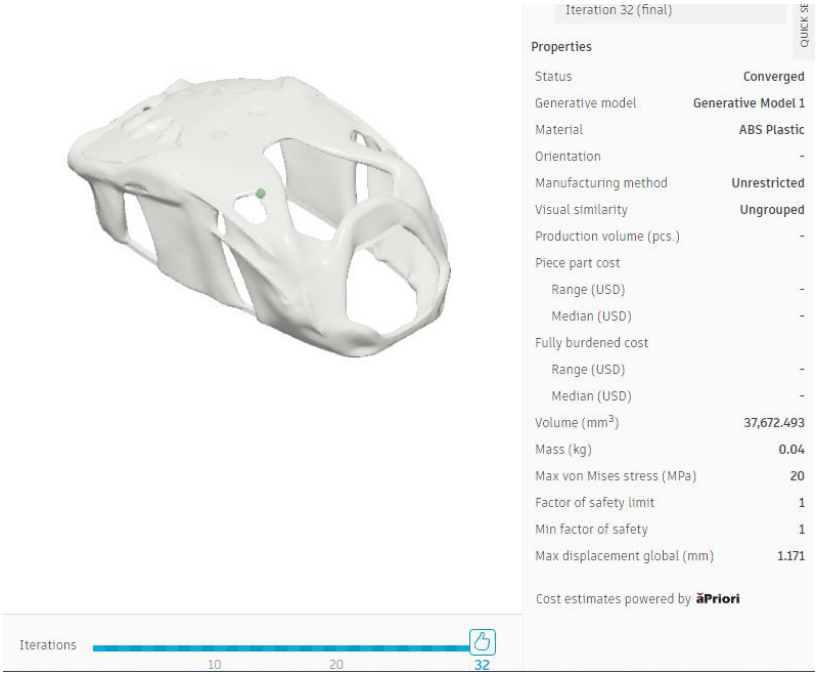

Figure 15 Generative Designed Model Properties

Conclusion

Product designers are increasingly prioritizing sustainability as a central concern in their design processes. Numerous approaches and methodologies are being researched and implemented to address this critical aspect. (Clark et al., 2009) One of the prominent approaches in this concern is the material optimization that this paper aims to investigate. The main goal of this approach is to improve the objective functions of the product while maintaining environmentally, economically, and energetically efficient sustainable processes (Sadollah et al., 2020). For this reason with today's developing technological world new algorithms and methods are being developed. Generative Design is one of these methods. Generative Design is the method that imitates the form-finding procedure of nature. In nature, biological materials tend to achieve the most appropriate solution in less energy or material usage, optimizing efficiency through evolution's fine-tuning and resource-conserving designs. The generative design tries to biomimic this approach with improved computational mathematical algorithms (Radakovic, 2021). The core principle of this method also lets designers generate new alternative forms too. In the conceptual phase of the product development process finding the shape variations is always a challenging phase for the designers. At this stage, the generative design could be a useful tool to explore numerous shape variations efficiently and effectively (Khan & Awan, 2018)

In this research generative design and its contribution to sustainable product development has been analyzed through the case study methodology. For this purpose shell design of the Logitech G Pro X Superlight mouse was examined and remodeled in Autodesk Fusion 360 CAD/CAM/CAE software. Remodeled object studied with generative design extension of the software. The outcomes of the process show that using generative design techniques for creating industrial products is slightly different than using them for optimizing mechanical parts of machines in engineering. The algorithm tends to find the easiest way to generate forms that suit the given performance-driven objectives. But it is not the thing that is always desired by the designer. The emphasis on efficiency may not inherently prioritize user-centric aspects like comfort, aesthetics, or human interaction. In the case of gaming mouse design, these concerns manifested. Handling these issues solely relies on the designer(s). While creating a generative design study, the algorithm should be manipulated in several ways. For this purpose in terms of keeping the generated bodies in desired forms, extra obstacle geometries are used on outer and inner spaces. Obstacle geometries were used as sandwiches, goal was to force the algorithm to follow the desired shape. Additionally, preserve geometry created with the split body tools with form following sketches. The sketch drawings and created split lines were decided experimentally taking into account preserving the main form of the referenced mouse: Logitech G Pro X Superlight. Finally, in terms of forcing the algorithm to generate more filled connections extra loads are added to the preserved geometry surface.

Discussion

In this research, Autodesk Fusion 360 and its Generative Design extension were used for creating a case study about optimizing plastic material usage in Gaming Mouse. Different approaches have been experimented and their result were explored. Even the final results of the study showed promised results, the generated shell is beyond being suitable for use in gaming mice. The main issue is still the body design still has wide gaps and falls short of meeting the primary demands and comfort requirements that gamers looking for. To tackle this challenge further research and development should focus on creating more precise preserved geometry lines and loads. In addition all, modeled shells and generatively designed bodies could be manufactured utilizing additive manufacturing methods and real-world experiments should be conducted. This would let the designer gain a deeper understanding of the generative design process and its contributions to sustainable product development. Furthermore, thorough user testing and feedback iterations would be essential to make sure the revised shell meets the particular needs and preferences of gamers.

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