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Proposal for a Product Classification Strategy for the AI-Assisted Generative Design Approach in Industrial Design Process

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Abstract

There are numerous product types where the design processes surpass the product lifespan. This circumstance increasingly emphasizes the significance of time management in design processes over time. The generative design approach stands out compared to traditional design processes by generating alternative forms in a shorter timeframe. In the field of industrial design, the utilization of generative design is relatively recent compared to areas like architecture and computer technologies. The integration of AI-supported generative design algorithms into CAD software has eliminated barriers requiring software and programming knowledge, rendering generative design more feasible for designers. While there are numerous studies in the literature on topics such as generative design systems, the advantages provided by generative systems and their application areas, shortcoming have been observed in research evaluating the feasibility of generative design according to products. This study aims to propose a product classification strategy for the generative design approach in industrial design processes. Within the scope of the study, form classes, structural types in product design and example products created with generative design were examined through the working system of Fusion 360 Generative Design and a product classification strategy for the generative design approach has been suggested. A pilot study was conducted to test the proposed classification strategy within the scope of the study. Trials for form creation were conducted with two expert designers in three categories. Feedback was collected through interview and observation notes. The experts have expressed the view that the proposed classification is consistent with the working system of generative design and the concept of usability.

1. INTRODUCTION

Product development processes can be defined as the methods used by businesses for stages ranging from the ideation to the sales and even post-sales of a product before its launch into the market. These methods aim to facilitate the execution of the process in a controlled, efficient, and low-risk manner. Industrial design can be characterized as a sub-discipline that constitutes a critical segment of the product development process [1]. In the product design process, which requires labor-intensive effort, there is a cyclical process of iterative idea development and evaluation of alternatives, during which cognitive, psychological, and physical burdens are imposed on the designer at each step [2]. In this iterative design process, various factors such as resource utilization, innovation, budgeting, production technologies, and market conditions significantly impact success and effectiveness.

According to the literature, one of the fundamental factors that drives success and generates a competitive advantage in the design process has sifted. Competition, which was formerly driven by cost considerations, now predominantly centers on the time required for new product development. Time efficiency in product development and design processes is of paramount importance and

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> cannot be disregarded. This is because the time required to develop a new product now often exceeds the average product lifecycle in many sectors [3].

Artificial intelligence (AI) technologies are emerging as key enablers in optimizing design processes to achieve greater efficiency within compressed timeframes.

> With ongoing advancements, AI technologies, which are increasingly utilized at various stages of design processes, have become proficient in predicting and analyzing possibilities within extensive datasets. The motivation for utilizing artificial intelligence in product development processes is increasing by advancements in computational design technologies, which are based on user-inputted data, as well as by the valuable design insights obtained from online AI applications [2].

Generative design tools, enhanced by advancements in AI, are increasingly being employed in industrial and research applications to support the design process [4]. Additionally, the integration of AI-assisted generative design algorithms into CAD programs has made the use of generative systems more accessible for designers and has removed technical knowledge barriers required for operating these algorithms in certain software applications [5].

An examination of the literature reveals a considerable body of research addressing the advantages offered by generative design. However, the number of studies on AI-assisted generative design applications in product design is relatively limited compared to the body of literature in architecture and engineering [5]. Additionally, a research gap has been identified regarding the applicability of generative design to different types of products within the field of industrial design [6]. When the literature is reviewed, it has been observed that the examples of generative design applications in industrial product design tend to focus on products with frame and solid structures, which raises a question [4],[5]. Can the advantages offered by generative design, particularly in the generation of manufacturable form alternatives, vary depending on the type of product? The primary reason for proposing a classification for the application of the generative design approach in the industrial design process is the gap identified in the existing literature on this topic. This study aims to address this gap in the literature by focusing on the following research question:

RQ: Based on the form-generation methodology of AI-assisted generative design, how can products be classified according to the advantages of generative design in generating alternative forms?

Based on this research question, the study aims to propose a classification that guides users, namely designers, regarding the limitations of AI-assisted generative design. The feasibility of form alternatives generated through generative design in terms of product functionality has been examined through structures. As the development of artificial intelligence continues, the algorithm of generative design and the opportunities it offers may evolve. For this reason, the study proposes a classification strategy based on structures, rather than a direct classification based on product names or industries.

The findings presented in this article are based on the operational system of Autodesk Fusion 360 Generative Design and classification studies within the product design literature. Additionally, a pilot study was conducted to test the proposed classification strategy within the scope of the study. Form generation trials were conducted with two expert designers. Observation notes were taken during the implementations conducted with the participants in three categories. Additionally, feedback was obtained through interviews conducted after the implementations and data was gathered through descriptive analysis.

2. AI- ASSISTED GENERATIVE DESIGN

Artificial intelligence can be defined as a computational technique that enables a machine to make recommendations or decisions affecting real or virtual environments based on goals specified by humans [6]. Recent advancements in artificial intelligence (AI) are providing designers with new tools that can be integrated into the design process [4]. These tools are utilized by designers throughout various stages of the design process, from the early phases to post-design stages. In recent years, advancements in technology and software have accelerated the development of artificial intelligence (AI) and expanded its applications. “Today, AI is integrated into various services and digital platforms, such as intelligent assistants (e.g., Siri, Alexa), predictive text tools (e.g., Grammarly, Gmail), and autonomous vehicles (e.g., Tesla Autopilot)” [7]. With current technologies, generative algorithms are employed to support the design process. Artificial intelligence-supported algorithms are utilized to automate design tasks that previously required extensive manual manipulation [8].

Generative design is an approach that aims to create new design processes by offering alternative manufacturable forms, evolving in parallel with the advancement of computer, software, and manufacturing technologies, where designers interact indirectly with materials and products through a digital system as of the 21st century [9], [10]. From its early years up to recent times, practitioners have utilized methods of shape generation and replicating the generated shapes with variations in position or scale to achieve the generative system [5]. With the advancements in computer technologies, practitioners of generative systems have found the opportunity to conduct their work in digital environments. However, the level of knowledge required for successful programming has limited the widespread adoption of digital generative processes in the design domain. The integration of generative systems into CAD programs and advancements, especially in artificial intelligence technologies, have ensured the increased applicability and widespread adoption of the generative design approach by designers [5]. With the integration of AI-supported generative design algorithms into CAD programs, the utilization of generative systems has been simplified for designers and technical knowledge barriers required to run the algorithm have been removed in certain programs. The increasing feasibility and advantages in optimization have led to a rise in examples of large corporations collaborating on generative design processes. The cabin partition design for the Airbus A320 aircraft, designed in collaboration between Airbus and Autodesk Generative Design, presents crucial data to observe the advantages provided by generative design. The cabin partition, created with generative design support and manufactured with the assistance of a 3D printer, achieved a weight reduction of 30 kg compared to the standard partition, while using 95% less raw material [11]. As a result of this weight reduction, the decreased fuel consumption is predicted to reduce CO2 emissions by up to 166 metric tons per aircraft annually. These data can serve as an example of the time, resource, and cost savings that generative design can offer when integrated into processes.

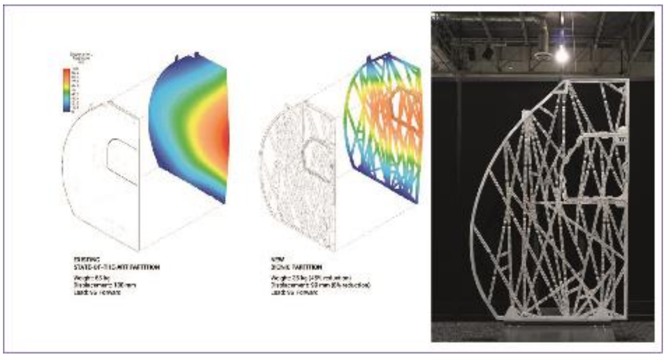


***Figure 1**. Cabin partition design for Airbus created using Autodesk Generative Design [11]*

Another example is a chair designed for Kartell by Philippe Starck utilizing Autodesk Generative Design [16]. Starck's chair design is described as the first chair produced through collaboration between artificial intelligence and humans [16].

***Figure 2**. Chair designed for Kartell by Philippe Starck utilizing Autodesk Generative Design [16].*

The seat bracket, designed using generative design in collaboration between General Motors and Autodesk, is one of the most prominent examples demonstrating the transformative impact of generative design [17],[18]. The software generated over 150 alternative design options based on parameters [18]. The new product, which is 40% lighter and 20% stronger than the original part, integrates eight different components into a single 3D-printed piece [18].

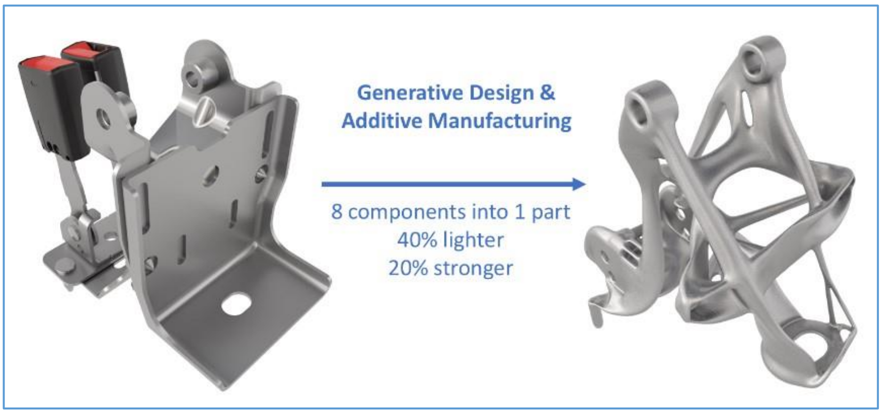


Figure 3. *The example of seat bracket designed using Generative Design [18].*

Current examples offer insights into the operational mechanisms of the generative design form-generation algorithm. Generative design creates organic forms based on the principle of minimum resource usage and maximum efficiency, within the parameters defined by the designer or engineer. Figure 4 [17],[18] presents a visualization of the alternatives produced by generative design, demonstrating the diversity of forms generated according to the specified parameters. Detailed information regarding the parameters established by the practitioner will be provided in the methodology section

***Figure 4**. Alternative examples suggested by Autodesk Generative Design based on different manufacturing methods [17],[18].*

Another example is related to the application of generative design in the lamp design shown in Figure5. The paragraph below, directly quoted from the author, clearly articulates the operational principles of the generative design approach.

> The base of the lamp was created using the generative design tool. In this case, five points were assigned in space: one up high to define where the lamp would be hanged from and four point that would connect the lamp to the shield. At each of this point, forces were defined in terms of weight load and moving forces to make sure that the structure would be strong enough to hold the weight of the lamp as well as external forces such as someone hitting the lamp accidentally from the side or below. A few areas were also defined as "obstacles" to make sure that the resulting shape remain within a certain envelop and didn't expand too much. The results of the simulation provided several exciting possibilities for the shape of the lamp [5].

***Figure 5.** Example of a lighting fixture designed using generative design [5].*

In the literature of generative design, the concepts of innovative form generation and time efficiency are emphasized. The basis of achieving formal innovation with this approach lies in moving beyond constraints associated with geometric forms and instead, in the ability to generate complex forms resembling natural structures [5]. The ability to create natural and unique forms is achieved through algorithms known as evolutionary algorithms or genetic algorithms. These algorithms mimic processes found in nature, such as evolution, reproduction, and selection, within a digital environment and aim to achieve optimal results for the intended output by exploring probabilities [1],[19]. In other words, genetic algorithms operate similarly to the evolutionary process, shaping optimal results within a search space defined by functional fitness constraints [19],[20]. Beyond its contribution to formal innovation, generative design also plays a significant role in process automation. The automation of complex and repetitive tasks, which would be challenging or tedious for humans to perform, by computer technologies, is a significant characteristic of generative design [5]. The process of generative design is guided by a designer who has a general idea of how the outcome might appear. The researcher's [5] statement regarding the control of the designer is noteworthy. In the literature, there is a debate about whether the generative design approach has the potential to completely replace designers in the future. In fact, some researchers have made a distinction between machine and human in design processes, referring to designers as "human designers"[21]. Generative design systems and the CAD programs operating these systems in computer environments are not currently capable of making design decisions independently of designer control. They generate alternatives within the constraints established by the designer. Here, it is crucial to elucidate the term "constraints established by the designer." The conceptual design decisions that need to be determined in the early stages of the design process are not included within these constraints. Decisions such as "a furniture design reflecting Scandinavian style" or "a gender-neutral toy design" are not data that can be input into the program where generative design will be implemented under current conditions. With the support of artificial intelligence applications, the conceptual design process can be guided, but generative design algorithms primarily work with quantifiable data such as weight, force, and material properties. The designer primarily establishes quantifiable boundaries. For example, in the generative design process, the boundaries set by the designer may include factors such as the maximum or minimum dimensions the product must reach, the choice of materials to be used, the method of production, the load it needs to carry, and the direction of the load.

One of the prominent concepts associated with productive design is optimization, which can lead to confusion between generative design and topology optimization. Topology optimization can be characterized as a subset of generative design. [22]. According to researchers [22], this is because the primary function of this tool is to optimize a design made by a traditional CAD system through algorithmic processing. Topology optimization relies on the removal and lightening of unnecessary geometries and materials from an object while preserving its performance characteristics. According to researchers, this involves the improvement of a design that has been morphologically established rather than the creation of a design. Generative design, on the other hand, begins by defining the constraints of the object to be designed and based on these constraints, generates hundreds or thousands of design solutions without relying on a preconceived morphological idea. In generative design, there is no obligatory initial form upon which the form will be based. However, depending on the algorithm operating the generating system, working with an initial form may help guide the designer towards the desired optimal outcome.

While designers may need specific knowledge to operate certain programs, they do not necessarily require full expertise in software-related calculations [5]. Some of the programs that fulfill these tasks include Autodesk Generative Design, Grasshopper, and Dynamo. The study will focus on the generative design process using Autodesk Fusion 360 Generative Design. The primary reason for this choice is that the generative system operates with an artificial intelligence-based algorithm, thereby minimizing technical knowledge barriers for the designer.

3. GENERATIVE DESIGN IN INDUSTRIAL DESIGN PROCESS

The product development process consists of stages such as planning, concept development, system-level design, detail design, testing and refinement, and production ramp up [1]. In the literature, it is possible to see some examples where the concepts of industrial design, product design, and product development are used interchangeably. Some researchers have raised objections to the interchangeable usage of these concepts [23]. The process of product design can be defined as a collaborative process involving industrial design and engineering design [23],[19]. Engineering design refers to the systematic, mechanical and even mathematical aspects of the design process that can be expressed with quantifiable values [15]. When a product is evaluated in terms of its inside and outside design, engineering design is associated with the inside design, which encompasses the components that ensure the functionality of the product [23]. Industrial design, on the other hand, can be associated with the outside design, encompassing components such as user interface, ergonomics and aesthetics, which play a role in the product-user interaction [23].

Industrial design is involved in various stages of the product development process, and the stages it participates in vary depending on the type of product [1]. When differentiating between user-centric and technology-driven products, it is observed that the industrial design process in user-centric products is involved in more stages of the product development processes. In technology-driven products, however, industrial design comes into play in the final stages of the product development process. In analyzing product development processes, categories such as engineering design and industrial design are delineated; however, for successful process management, collaboration among industrial designers, engineers, software developers, technicians, and other members of the project team is necessary. As emphasized in the definition of industrial design by the World Design Organization, industrial design is inherently interdisciplinary in nature [24].

The generative design approach enables designers to generate design alternatives based on technical specifications such as load, material requirements, weight, and durability. There are also online generative AI applications that do not rely solely on rational data. These tools can be applied across various aspects of design processes and in different creative field. Generative AI tools such as Midjourney, DALL-E2, and Stable Diffusion have demonstrated impressive capabilities in producing large volumes of realistic and speculative outputs with semantically coherent content features. These tools can be applied across various creative fields, showcasing their ability to generate content that is both meaningful and visually convincing [25]. However, these tools will not be addressed within the scope of this study.

The significance of generative design in design processes is increasing day by day, as it not only demonstrates design alternatives based on rational data but also serves as a decision support mechanism through optimization filters. The integration of generative design into the industrial design process can vary depending on factors such as the software used, the type of product, and many other variables. In this research, the operational mechanism of Autodesk Fusion 360 Generative Design will be examined. Fusion 360 Generative Design operates differently from programs like Grasshopper or Dynamo, bringing the process closer to real generative design [5]. This AI-based program takes predefined rules and objectives from the user and generates a multitude of shape grammars from scratch [26]. Thanks to artificial intelligence, the limitations typically associated with high-level knowledge requirements such as programming and algorithm creation are largely eliminated for designers. Generative design guides the designer to input data. These data consist of elements such as areas to be preserved in the generated alternatives, obstacles to be left blank, surfaces to be fixed, applied loads, production methods, and material selection. After the designer has input the designated data, the computer takes this information and automatically generates multiple designs. The algorithm, operating in a manner similar to natural processes, presents unique form alternatives to the designer. The ability of generative design to rapidly generate unique tens or even hundreds of form alternatives may appear as an advantage for design processes. However, generative design may raise a question. Based on the form-generation methodology of AI-assisted generative design, how can products be classified according to the advantages of generative design in generating alternative forms? The fundamental objective of this study is to formulate a product classification strategy that will provide guidance for research endeavors aimed at addressing these inquiries.

4. CLASSIFICATION EXAMPLES IN PRODUCT DESIGN

When developing a strategy for product classification in generative design, a literature review of product and form classification reveals a plethora of diverse classification studies that vary depending on the research context. Various definitions of products contribute to the diversification of classification studies. For instance, according to Kotler and Armstrong, products are not limited solely to tangible objects [27]. Researchers who include services, people, and organizations in the product definition typically categorize products into two main headings based on their purchase purposes and durability-tangibility [27]. As depicted in Table 1, products are subcategorized based on their users into consumer products and industrial products.

***Table 1**. Kotler and Armstrong's Product Classification* [27]

A) Durability and Tangibility	B) User	
	B.1. Consumer goods	B.2. Industrial goods
Non-durable	Convenience goods	Material and parts
Durable	Shopping goods	Capital items
Services	Specialty goods	Supplies and business services
	Unsought goods	

When considering the association between Kotler and Armstrong's classification study and the proposed classification study for generative design, it is noted that certain categories fall outside the scope. This is because the generative design approach is employed for processes dealing with tangible products. The operational mode of generative design systems is predicated on the generation of alternative solutions grounded in rational data. Therefore, it would be more appropriate to classify products based on morphological characteristics rather than categories such as shopping products or convenience products, given the nature of generative design systems, which rely on generating alternatives based on rational data. Another classification study aims to elucidate the relationship between manufacturing processes and feasible forms by classifying product components based on their geometries and complexities [28]. In this classification model, the forms are categorized as round, bar, section, open-semi-closed, tube, flat, and spherical [28]. While the study provides guidance in terms of formal characteristics, it should be noted that it is based on production technologies of the 2000s. Ashby and Johnson's classification study, on the other hand, is formulated independently of the development of production technologies, usage context, user group, and material properties, focusing instead on the structural form of the product or product component [29],[30]. As depicted in Figure 6, shapes are divided into three primary classes: prism, sheet, and three-dimensional. In this classification, the concepts of flat-dished and solid-hollow emerge as prominent for the proposed classification strategy for generative design. For generative design, which generates alternatives based on morphological structures, these concepts have been deemed significant.

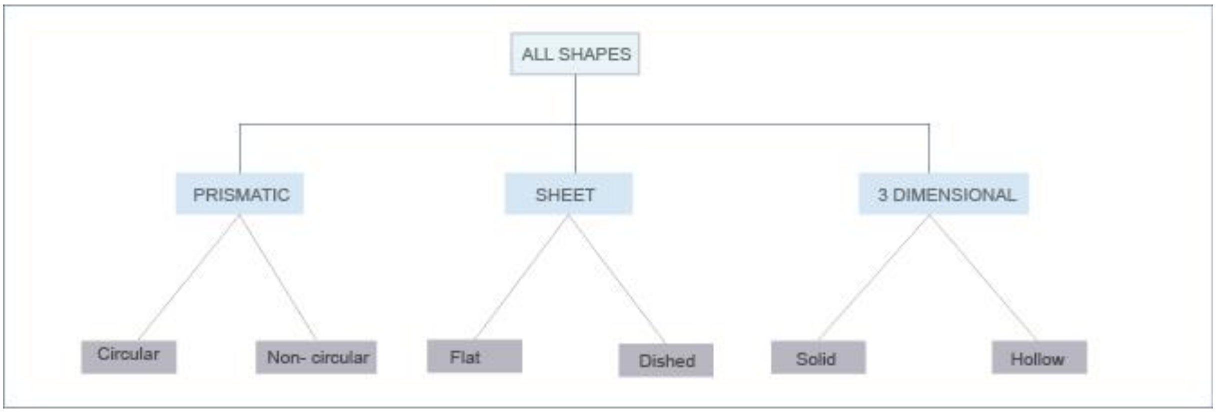


***Figure 6**. The shape classification [29],[30]*

The classification seen in Figure 6 can guide form-based research independently of conditions such as technology and manufacturing capabilities, solely based on formal characteristics. However, it is not sufficient on its own for creating a classification strategy tailored for generative design.

***Table 2**. General shape taxonomy* [30].

Piece	Preferential axis	Transversal section	Thickness	Boundary	Details
Hollow Solid	Straight Curve	Constant Variable	Simple Complex	Plane Curve Circular	With surface details Without surface details

The shape classification seen in Table 2 is based on the shapes of single-piece static objects. The classification based on products that do not require external energy to perform their function and are made from a single material is divided into solid and hollow parts [30]. Each class is further subdivided into separate categories based on properties such as axis, transversal-section, thickness, boundary, and surface detail [30]. Agudelo et al. states that if a designer has a product consisting of several parts, the classification can be utilized by dividing the product into its constituent parts, and if the part is analyzed as a whole, it should be considered as a single material.

Classifications created based on formal characteristics, usage, user groups, or sectors alone are not sufficient to develop a product classification strategy for the generative design approach. Because generative design generates alternative forms based on materials, manufacturing methods, and specified optimization filters. Considering the operational mode of the generative system based on these parameters, the concept of structure becomes prominent in the product. In design, structure is a term that delineates the physical constitution of a design objects. In industrial design, structure encompasses a system of assembled components arranged in an orderly manner to support the product, shape its form, and facilitate its functionality [31].

***Table 3.** Structure types in industrial product design* [31]

Shell structure
Solid structure
Frame structure a) Hollow section frame b) Solid section frame
Membrane structure a) Surface membranes b) Filled membranes c) Inflatable membranes
Plate structures a) Flat plate b) Corrugated plate c) Folded plate
Space frame structures
Suspended tension systems
Hybrid structures

In Table 3, types of structures in product design are depicted. Considering the function and design objectives of products, structure types that are not aligned with the objectives of the generative design approach will not be included in the scope of the research. For instance, there are products or design processes where it is not necessary to produce alternative forms or extract materials to lighten the product. Indeed, for such a product, the involvement of generative design in the industrial design process might not be meaningful. Hence, it is not appropriate to include certain types of structures within the scope of the study. The justifications have been elaborated extensively in the method section.

5. THE OPERATIONAL SYSTEM OF AUTODESK FUSION 360 GENERATIVE DESIGN

The first step within the scope of the study involves an examination of the operational mechanism of the generative design system. While various generative systems such as L-systems, shape grammars, genetic algorithms, and cellular automata exist [32],[33],[34], upon analysis, two main categories emerge: subtraction method and addition method [5]. Subtractive method involves the removal of unnecessary parts from the product, without compromising its performance, based on goals such as applied load, durability, maximum weight, among others. Parameters are inputted based on defined objectives, and alternatives are generated to achieve optimal performance. On the other hand, in the additive method, iterative generation of thousands of solution alternatives is pursued within constraints to achieve the intended objectives [5]. As we delve from the encompassing features of generative design into its more specific characteristics, analyzing the operational system of Autodesk Fusion 360 Generative Design within the scope of the study will provide guidance for forming the classification strategy.

Engineers or designers should follow certain fundamental steps to ensure the correct operation of the algorithm when using Fusion 360 Generative Design. As guided by the program interface, the parameters defined according to the objectives must be specified within the software. The following steps are followed in sequence:

1: Preserve Geometry: Users must first select the geometry they deem critical for the part. These bodies are "protected" and remain intact throughout the manufacturing process. This step is indicated as number 1 in the Figure 9. In Fusion 360, the protected geometry is highlighted in green [35].

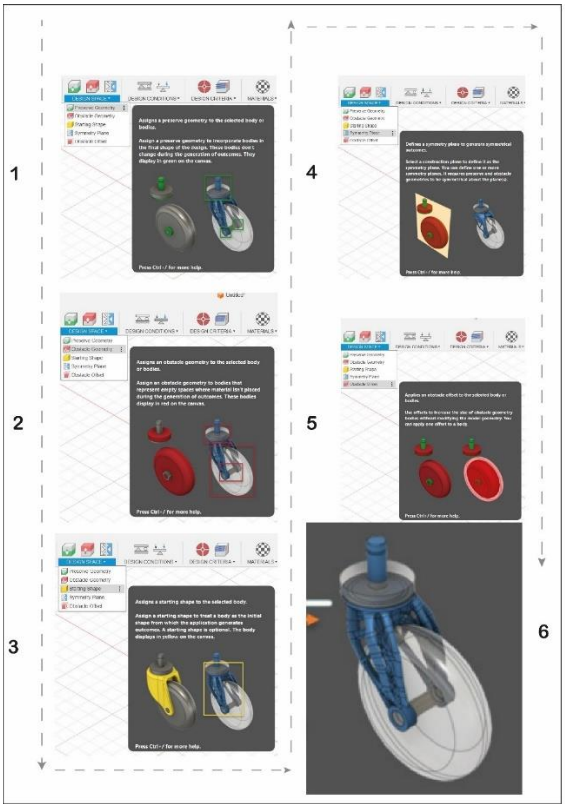
2: Obstacle Geometry: This refers to areas defined by the designer or engineer where material assignment is not desired. In Fusion 360, obstacle geometry is indicated in red [35]. It is indicated as number 2 in Figure 7.

3: Starting geometry: This can be optionally created. Its purpose is to ensure that alternative forms are generated in close proximity to the defined initial form. In Generative Design, starting geometry is represented in yellow [35]. It is indicated as number 3 in Figure 7.

4: Symmetries: Fusion 360 allows designers to constrain the design to be symmetrical around selected planes [35]. This is indicated as number 4 in Figure 7.

5: Obstacle Offsets: These are used to increase the size of the obstacle geometry bodies without altering the model geometry. This is indicated as number 5 in Figure 7.

After defining the geometries in the program, the following steps are undertaken: applying structural loads, selecting fixed points, and choosing the material and manufacturing method [35].



1 Assigns a preserve geometry to the selected body or bodies.

Assign a preserve geometry to incorporate bodies in the final shape of the design. These bodies don't change during the generation of outcomes. They display in green on the canvas.

Press Ctrl - / for more help.

2 Assigns an obstacle geometry to the selected body or bodies.

Assign an obstacle geometry to bodies that represent empty spaces where material isn't placed during the generation of outcomes. These bodies display in red on the canvas.

Press Ctrl - / for more help.

3 Assigns a starting shape to the selected body.

Assign a starting shape to treat a body as the initial shape from which the application generates outcomes. A starting shape is optional. The body displays in yellow on the canvas.

Press Ctrl - / for more help.

4 Defines a symmetry plane to generate symmetrical outcomes.

Select a construction plane to define it as the symmetry plane. You can define one or more symmetry planes. It requires preserve and obstacle geometries to be symmetrical about the plane(s).

Press Ctrl - / for more help.

5 Applies an obstacle offset to the selected body or bodies.

Use offsets to increase the size of obstacle geometry bodies without modifying the model geometry. You can apply one offset to a body.

Press Ctrl - / for more help.

Figure 7. *Autodesk Generative Design Interface and Tool Previews*

As shown in Figure 7, each step of the process is carried out under the control of the designer or engineer. This approach demonstrates that generative artificial intelligence algorithm does not operate independently of designers or engineers.

Generative Design utilizes evolutionary algorithms driven by artificial intelligence to produce alternative form solutions, akin to natural processes, constructing objects as single-piece and solid objects. Understanding its operation of both material addition and subtraction, to achieve optimum performance based on specified parameters, is crucial in comprehending its functionality. The algorithm accumulates materials in certain parts of the object to enhance its resistance against applied loads, while forming hollow structures in other parts. This situation indicates that generative design may not be feasible in the design process of certain products, as there are structures where material subtraction cannot be applied. Additionally, as seen in the product examples shared in Figure 2, Figure 3, Figure 4, and Figure 5,the fact that the generative design algorithm generates alternatives as single-piece and solid is important information for the classification method. This information has guided the classification strategy to categorize products into single-piece and multi-piece forms.

6. THE CLASSIFICATION PROPOSAL

After analyzing the operational system of Fusion 360 Generative Design, the generative design process shaped by formal and structural variables has been associated with the prominent concepts of formal and structural classification examples through a concept map. As illustrated in Figure 8, certain categories within product, form and structure classifications have been associated with generative design. This association has been made based on factors such as alignment with the algorithm's operational system, the need for the advantages provided by generative design, and compatibility with the algorithm's form generation strategy.

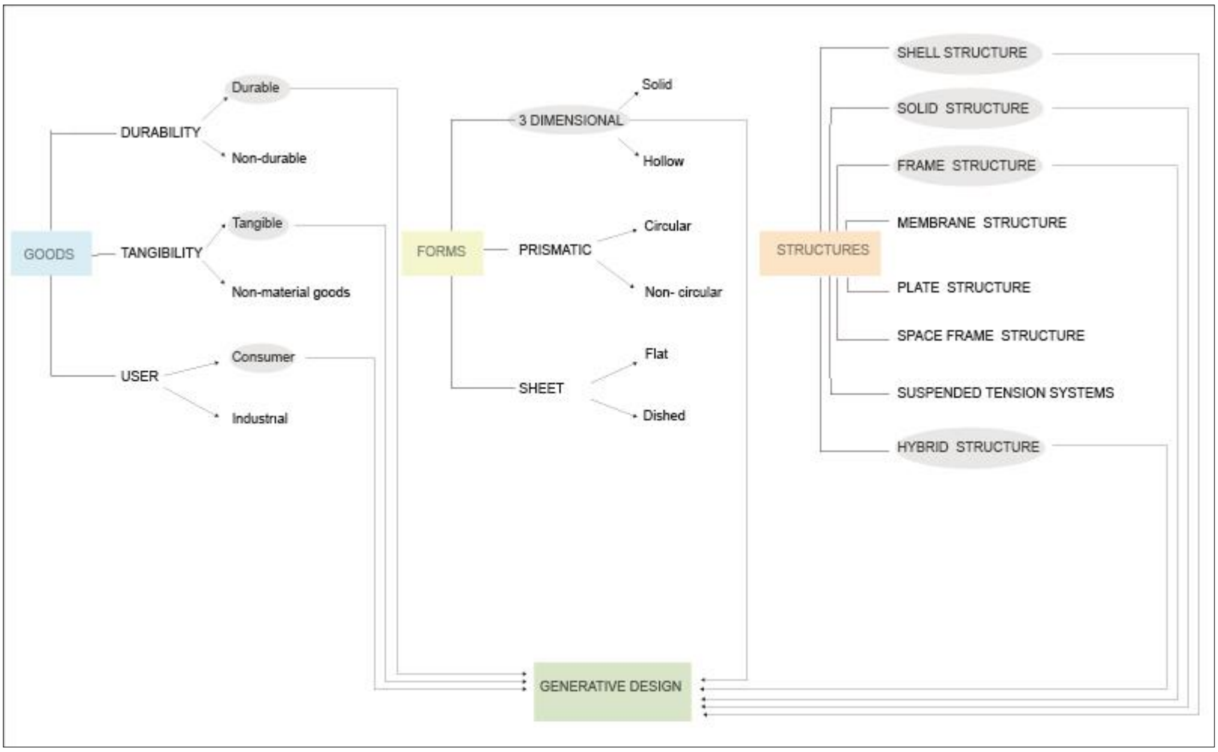


***Figure 8**. Consept map for the recommended strategy* [27],[29],[30],[31].

According to Kotler and Armstrong's classification [27] in marketing literature, non-durable and non-tangible consumer products are not included in the scope of the study. Industrial products, on the other hand, have not been included in the scope of the study as they are associated with materials and parts, capital items, supplies and business services. However, it should be emphasized that consumer products may also encompass items considered industrial products in the industrial design literature. In the classification of form, the approach of generative design, which relies on additive and subtractive methods for optimal performance and aims to create forms resembling those found in nature, is not suitable for prismatic and sheet form. Therefore, three-dimensional forms have been included within the scope of the study, while the prismatic and sheet categories have been excluded. The categorization of three-dimensional forms into solid and hollow shapes refers to shell structure and solid structure. Frame structures with load-bearing properties and allowing for natural forms, as well as hybrid structures consisting of two or more structures, have been included in the scope of the study. When it comes to frame structures, attention should be paid to the distinction between hollow-section and solid-section structures. Generative design is not suitable for hollow frame structures based on profile usage due to its operational algorithm. The operational system is suitable for solid frame structures.

Membrane, plate, space frame systems, and suspended tension systems have been excluded from the scope of the study due to their intended purposes in product design and the operational mode of the algorithm.

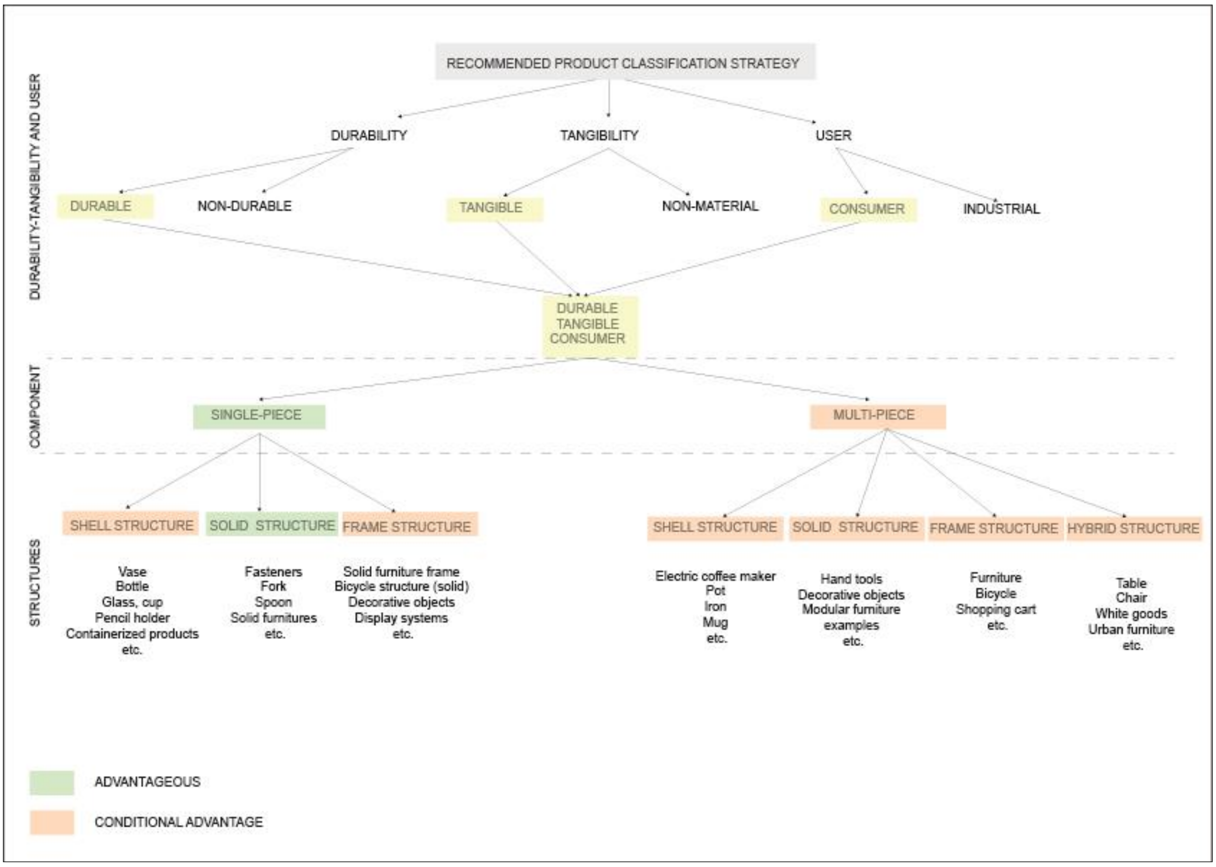


Figure 9. *Decision-tree based classification proposal*

Figure 9 displays the headings included in the product classification strategy for generative design. As seen in Figure 9, after distinguishing between single and multiple-component products in durable and tangible consumer products, product examples related to the types of structures within the scope of the research are provided. This classification proposal allows for a more specific inference about the status of the identified product in the generative design approach, moving from a general category based on the number of components and the type of structure to a more specific deduction.

7. PILOT STUDY

7.1. Method

The operational method of the generative design algorithm and the classification example developed based on the literature were applied and interviews with two expert designers. The designers conducted form generation trials using generative design for both single-piece and multi-piece products consisting of shell, solid, and frame structures. The participants are designers with a Bachelor's degree in Industrial Design, having completed a four-year program, and at least three years of industry experience. It was ensured that both participants had experience in digital product visualization and held a degree in Industrial Design. Observations were conducted during the implementations, and post-implementation interviews were held with the participants. Prior to the implementation, the researcher provided a one-hour training on the working principles of generative design. A 120-minute implementation was conducted for the product designs determined for each of the three categories. The implementation were conducted on separate computers and workstations under the same conditions in the workspace designated by the researcher. The classification suggestion was not shared with the participants prior to the implementation to avoid the risk of biasing their decisions. The researcher took observational notes throughout the implementation process. After the implementation, individual interviews were conducted with the participants, followed by a group interview. The interview questions were prepared in advance, and the interviews lasted a total of ninety minutes. The observation and interview notes were analyzed descriptively. Findings related to the classification suggestion were obtained.

7.1. Findings

Findings were obtained within the scope of the applied research. For the single-piece and solid structure example, a spoon was selected and applied as a case study. With the algorithm's operational approach suited to single-piece and solid structures, the designers were able to obtain form alternatives close to their desired outcomes and conduct a more controlled design process.

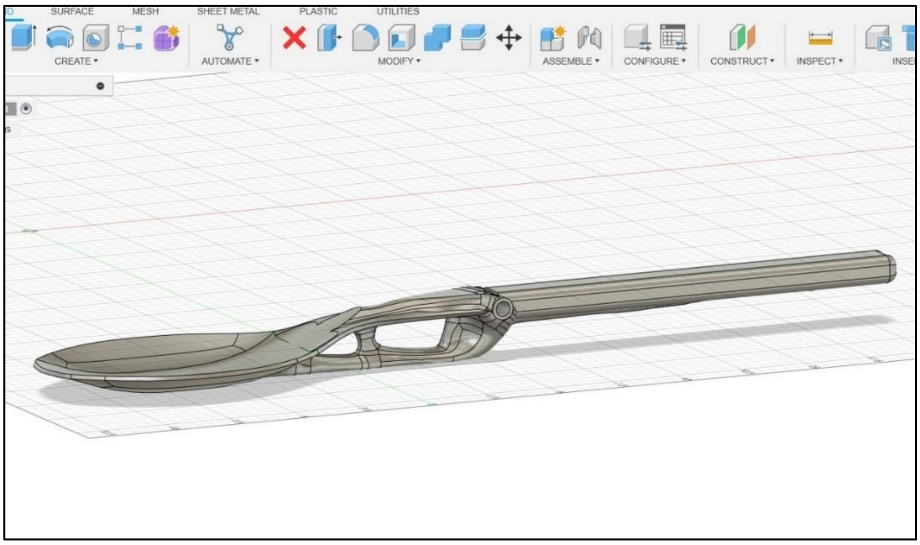


***Figure 10**. Generative form experimentation related to the spoon*

For the frame structure example, a chair was selected and applied as a case study. For the chair example, the expert designers' feedback indicated that considering the individual components separately in multi-part chairs would lead to more accurate results. Another suggestion presented is to address the carrier structure and the surfaces that interact with the body through two separate generative design applications. A chair that is not made of a single piece can also be categorized under the hybrid structure category, considering the structure of the components carrier structure and body related parts. According to the designers who applied the method, generative design may be more advantageous in terms of time management for a chair made of a single piece. Insights can be drawn regarding products with a single-piece frame structure based on the chair example.

***Figure 11.** An example of the form experimentation stages of a chair*

In the coffee pot example, where the shell structure is considered, the designers conducted separate trials for the body and the handle. However, they observed that the algorithm created hollows on the shell surface forming the body, and they stated that the generated forms were not functionally appropriate.

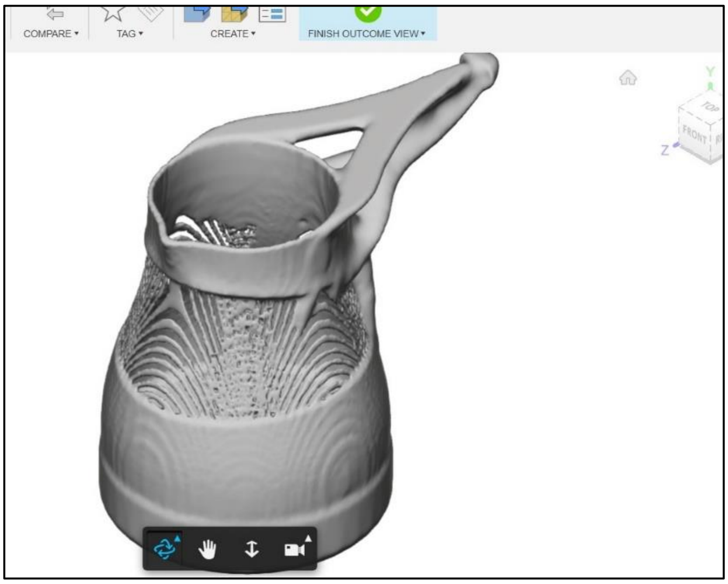


Figure 12. *An example of a coffee pot, illustrating the voids formed within a shell structure*

The designers noted that generative design produced non-functional forms in shell structures serving as the reservoir. However, they stated that generative design could be used for products where voided structures do not negatively impact functionality. In this regard, expert designers have provided the following examples: body-conforming medical products, surfaces that serve as secondary layers in products, or pencil holders made from perforated surfaces.

8. DISCUSSION AND CONCLUSION

Drawing upon the applications and perspectives of expert designers, the following inferences have been made. The category highlighted in green indicates the segment in the industrial design process where generative design offers the greatest advantages in terms of performance-based form generation. The categories highlighted in orange indicate segments where the advantage situation may vary depending on the circumstances. For example, the creation of two products with a single-piece shell structure through the generative design approach does not necessarily indicate equal advantages. A pencil case with voids on its surface serves its function, whereas a cup with voids on its surface would become non-functional. The success of industrial product design is not solely determined by producible form alternatives. There are many variables that affect the success of an industrial product. The proposed product classification is created not directly based on the product name, user group, or industry, but rather to shed light on various studies and can be developed depending on variables.

While numerous studies highlight the prominent advantages of generative design, such as generating alternative forms, time saving, efficient resource utilization, and optimization, there is a gap in the literature regarding the variability of these advantages on a product-specific basis. In this study, a classification strategy based on form, product and structure is proposed for the generative design approach, utilizing the operational system of Autodesk Fusion 360 Generative Design.

Fusion 360 Generative Design generates alternative forms resembling natural shapes through a rational, data-driven operating system. Under current conditions, the working algorithm generates solid and single-piece product alternatives. These alternatives are generated based on material and manufacturing method selection, applied loads, as well as fixed and constrained geometries. While it stands out for generating a greater number of alternatives in a shorter time compared to traditional design processes, not every alternative offered by the program is functionally usable. The most significant reason for this is the program's ability to maintain the rational constraints set by the designer while producing forms that do not compromise on structural performance. The algorithm, which operates through optimization and mimics natural processes, removes unnecessary parts and creates voids while considering the strength conditions. In other respects, for some parts, additions are made to enhance strength in the object. This process may not be feasible for every product.

The study, which examines the applicability of generative design through product structures, demonstrates that generative design is most advantageous in products with single-piece and solid structures. This category may include various products such as forks, spoons, fasteners, machine parts, solid furniture items, decorative products, and more. In shell structures, the feasibility of generative design varies depending on functional conditions. For instance, generative design may offer advantages in the design of products or product components where lightweight is emphasized and the formation of voids on the surface is desired. An example of this would be a hollow surface coating acting as a secondary component on the surface of a product or a pencil holder composed of hollow surfaces. However, in shell designs that do not allow for any hollow structures and serve as containers or protective layers for the function of the product, the use of generative design may not be suitable. In products containing an electronic system or in the shell design of a water heater, the hollow forms created by generative design may not be functionally suitable.

In multi-component products, designers can benefit from generative design when they need to see alternative forms for the overall shape of the product. This scenario can be utilized to explore alternative options for the general silhouette, independent of rational reality. Alternatively, the designer can disassemble multi-component products and initiate distinct generative design processes for each component. This approach may yield more precise results compared to the former. However, the designer must meticulously organize the relationships between the components and pay close attention to time management. The advantages that generative design can provide in frame structures depend on the circumstances. While generative design is suitable for solid-section frames, it may not be suitable to a hollow-section frames, under current conditions.

The aim of this study is to propose a strategy that is more comprehensive and can shed light on new research, rather than specialized product categories based on the working system, formal classification, and types of structures inherent to generative designs. Generative design can be effectively utilized in the earlier stages of the design process with the innovations brought by artificial intelligence tools. With every advancement in generative design systems, the strategy proposed in this study can be further developed.

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