Machine as the Designer of Generative Solutions in Chair Design

Çağrı Uludüz[1] , Çağlar Aydın[2]

ORCID NO: 0000-0002-9951-855X[1], 0000-0001-6481-9523[2]

[1] Erzurum Technical University, Faculty of Engineering and Architecture, Department of Architecture, Erzurum, Turkey
[2] Karadeniz Technical University, Faculty of Architecture, Department of Architecture, Trabzon, Turkey

The use of artificial intelligence in design processes has become highly visible. The utilitarian use of this new technology in design raises questions about the relationship between man and machine and its contribution to the final product. This study, which was carried out specifically for chair design, analyzes the design outputs obtained from Autodesk's Fusion 360 software, and examines how far the generative system can realize the chair design without the contribution of the designer. The contribution of generative design to the design process has been examined in terms of form, material and manufacturing technology. In this context, it reveals that the role of the designer in creating a complex design product cannot be ignored.

Received: 11.08.2021
Accepted: 18.03.2022

Corresponding Author:
cagri.uluduz@erzurum.edu.tr

Uludüz, Ç., Aydın, Ç. (2022). Machine as the Designer of Generative Solutions in Chair Design. JCoDe: Journal of Computational Design, 3(1), 81-104. https://doi.org/10.53710/jcode.1070450

Keywords: Artificial Intelligence, Computational Design, Design Tools, Design Research, Furniture Design.

Sandalye Tasarımında Üretken Çözümlerin Tasarımcısı Olarak Makine

Çağrı Uludüz[1] , Çağlar Aydın[2]

ORCID NO: 0000-0002-9951-855X[1], 0000-0001-6481-9523[2]

[1] Erzurum Teknik Üniversitesi, Mühendislik ve Mimarlık Fakültesi, Mimarlık Bölümü, Erzurum, Türkiye
[2] Karadeniz Teknik Üniversitesi, Mimarlık Fakültesi, Mimarlık Bölümü, Trabzon, Türkiye

Günümüz tasarım ürünlerinde, yapay zeka kullanımı oldukça görünür olmaya başlamıştır. Fakat, bu yeni teknolojinin tasarım alanında faydacı kullanımı, insan-makine arasındaki ilişkinin yanında elde edilen son ürüne katkısıyla ilgili soru işaretlerini de beraberinde getirmektedir. Sandalye tasarımı özelinde gerçekleştirilen bu çalışma, yapay zeka olgusunun tasarımcı katkısı olmadan bir sandalye tasarımını ne kadar ortaya koyabileceğini üretken tasarım sistemine sahip bir yazılımdan elde edilen sonuç tasarım çıktıları üzerinden yapılan analizlerle ele almaktadır. Bunun yanında, üretken tasarımın tasarım sürecindeki katkısı form, malzeme ve üretim teknolojisi bağlamında irdelenmiştir. Bu bağlamda, çok yapılı/kompleks bir tasarım ürününü oluşturmada tasarımcının rolünün göz ardı edilemez olduğunu ortaya koymaktadır.

Teslim Tarihi: 11.08.2021
Kabul Tarihi: 18.03.2022

Sorumlu Yazar:
cagri.uluduz@erzurum.edu.tr

Uludüz, Ç., Aydın, Ç. (2022). Sandalye Tasarımında Üretken Çözümlerin Tasarımcısı Olarak Makine. JCoDe: Journal of Computational Design, 3(1), 81-104. https://doi.org/10.53710/jcode.1070450

Anahtar Kelimeler: Sayısal Tasarım, Tasarım Araçları, Tasarım Araştırması, Mobilya Tasarımı, Yapay Zeka

1. INTRODUCTION

The design and manufacturing styles of chairs are changing with the developing technology throughout history. It is an undeniable reality that the computer has become an indispensable part of the design process with the computer technology that has developed. This study questions to what extent computer technology can contribute to the design of a chair without designer intervention.

Especially in the industrial revolution, innovative materials and manufacturing technologies showed themselves in every field of design. For this reason, the years of the industrial revolution have been a period that can be called the breaking point in which innovative approaches in furniture design were introduced. In the history of furniture design, although the shaping of furniture was done with traditional methods until this period, the idea of using steam, the most important energy power of the period, brought innovation to these methods (Postell, 2012). This innovative production technology, called the steam bending technique, was first used by Samuel Gragg in 1808 in the chair design called Elastic Chair. This technology led to the emergence of Michael Thonet's No.14 chair, which is considered the most successful mass production product in the history of furniture design (Thompson, 2011).

In the 20th century, the technology that developed with the help of machines in the previous century gave birth to the emergence and development of artificial intelligence, which could take over the mental workload of humans with the information processing power of computers (Li & Du, 2007). Joris Laarman's Bone Chair (2006), Autodesk's Elbo Chair (2016) produced with the Dreamcatcher project, and AI Chair (2019) which is jointly designed and produced by Philippe Starck and Autodesk, are chair designs from the recent period with the undeniable contributions of generative design **(Figure 1)**.

No.14[1]
1859
Michael Thonet

Bone Chair[2]
2006
Joris Laarman

Elbo Chair[3]
2016
Autodesk Dreamcatcher Project

A.I. Chair[4]
2019
Philippe Starck & Autodesk Fusion 360

Figure 1: Chair Design from the Industrial Age to the Age of Artificial Intelligence
Phaidon,2006; Laarman, 2015; Harsuvanakit, 2016; Jordahn, 2019).

Generative design is a design process that helps to discover unknown or unclear alternatives to a design with the help of mathematical and logical methods. Mathematical and logical methods describe algorithms comprising design parameters and objectives. These algorithms search for the most appropriate parameters such as material, manufacturing method and manufacturing cost among many design alternatives during the design process. As a result of this process, alternatives that cannot be obtained with traditional design are achieved. These generative design products' general characteristics are (McKnight, 2017):

- Reduced weight
- Maintained or improved performance
- Reduce development time
- Increased creativity
- Increased efficiency
- Customized product development.

With the use of generative systems in today's product design, we encounter two different design processes outside the traditional process: generative design and data-driven generative design **(Figure 2)**. Among these, the designer takes an active role and makes the most contribution to a design product in the traditional design process. Especially in furniture design, the choice of creative ideas for the solution of the determined function, and the presentation of form and construction in design are completely realized by the decision of the designer. In generative and data-driven generative design, it is seen that the role of the designer is quite small. In these processes, the designer leaves the final product design outputs in the hands of the machine by entering the parameters (design area, material, production technology, etc.). The designer makes the choice of the final product proposals and can decide to repeat the design process by choosing one of the traditional, generative or data-driven generative design processes for their development. Considering all this, the level of the designer's contribution in the design process of generative and data-driven generative design, which proceeds in partnership of machine and human, cannot be clearly expressed. With the advancing technology, artificial intelligence somehow challenges the designer in the field of design, so we need to question today's design approaches (Giaccardi & Redström, 2020).

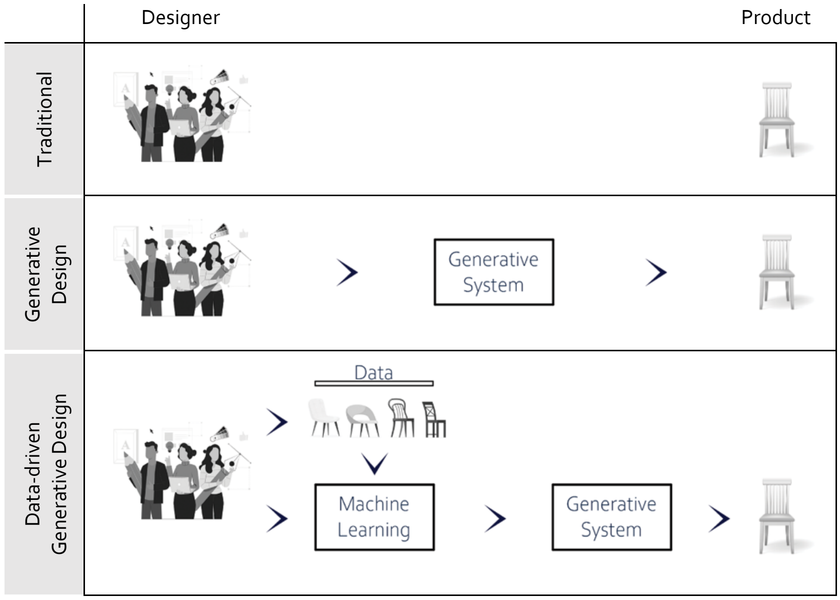


Figure 2: Generative Design Systems (Bidgoli & Veloso, 2018).

Although there are many furniture designs produced with generative design methods, scientific studies in this context are very few. In their study, Barros, Duarte & Chaparro (2015) discuss the generation of chair designs with shape grammars and their improvement with optimization tools offered in CATIA. Bidgoli & Veloso (2018) enabled the designer to design by interfering with the chair design generated as a point cloud by the DeepCloud system they created using the machine learning method. In this method, system learns from a database and sets inputs and constraints instead of the designer. Apart from these, Li and Lachmayer (2018) discussed generative design approaches for modeling creative designs; Liu et al. (2019) created chair design images with the support of artificial intelligence using generative adversarial network and finally Ramesh et al. (2021) created an application in which they used text as data and transformed it into furniture visuals.

The chair, which is one of the furniture that people use every day, has been tried to be generated in the “Autodesk Fusion 360” software with the generative design method. In the study, it is aimed to question the design outputs generated with the ready-made generative system without the intervention of the designer. It seeks answers to the questions of whether a chair design can be created by artificial intelligence alone or how much it contributes to the design.

2. MATERIAL AND METHOD

Chairs have been the subject of innovative studies and they have become the first objects designed and mass produced in cooperation with artificial intelligence (AI Chair by Philippe Starck & Autodesk, 2019). This study, which examines the relationship between design and artificial intelligence through furniture design, has been discussed in terms of chair design for these reasons.

Various software have been examined to observe the generative design solutions of artificial intelligence. Currently, Solidworks Simulation (Dassault Systèmes), xDesign (Dassault Systèmes), Functional Generative Design (Catia, Dassault Systèmes), xGenerative Design (Dassault Systèmes), Siemens NX and Autodesk Fusion 360 software offer generative design support. As can be seen in **Figure 3**, Autodesk Fusion 360 is the software that includes the most features, offers free use, and is used in chair design (AI Chair, 2019) has been chosen for this study.

This study was carried out with the Generative Design plugin, which allows the use of artificial intelligence in Fusion 360 software. In order to obtain a design output in the Generative Design plugin **(Figure 4)**, a 3D model must be defined. This model should consist of three different parts; Preserved geometry, which is the masses that will be connected with each other and will not change, obstacle geometry that allows us to determine the area that artificial intelligence should not particularly interfere with, and the starting shape that is desired to be processed **(Figure 5)**. According to the design problem which we expect from artificial intelligence to be solved, at least two of them must be defined as preserved geometries.

	Solidworks Simulation	xDesign	Functional Generative Design	xGenerative Design	Siemens NX	Autodesk Fusion 360
Nonstructural parameters			✓		✓	✓
Iterative algorithms	✓	✓	✓		✓	✓
Remove and add material		✓		✓		✓
Incomplete CAD model		✓				
Accurate CAE analysis	✓		✓		✓	✓
Multiple results				✓		✓
AM controls	✓		✓		✓	

Figure 3: CAD software packages using Generative Design (Westerveld, 2021). (CAD: Computer-Aided Design, CAE: Computer-Aided Engineering, AM: Additive Manufacturing)

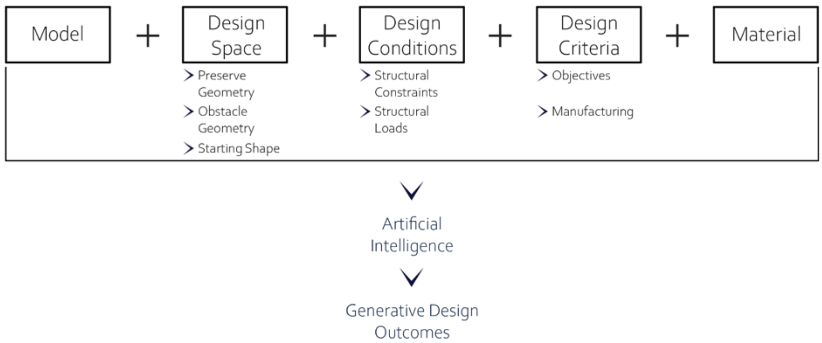


Figure 4: Generative Design Process of Autodesk Fusion 360.

After the 3D model is created, it is necessary to specify the design conditions for this model. The design conditions include the data of two main values: structural constraints, which masses are selected as fixed, pin or frictionless, and structural loads, where force, pressure, momentum and bearing load are determined.

After determining the 3D model and design conditions that artificial intelligence will analyze, the design criteria should be selected. In the design criteria, objective (minimizing mass or maximizing stiffness) and manufacturing types (unrestricted, additive, milling, 2-axis cutting or die casting) to be used should be specified. Finally, the material selection should be made for the 3D model to be used in generative design analysis, then it is sent to the cloud network of the software for artificial intelligence to process the data and generate design outputs.

2.1 Identification of Design Problem

Model proposals have been developed to examine the artificial intelligence-design relationship. The parts that make up the chair are divided into three: the seat, the backrest, and the legs. Since these parts are generally rectangular or circular in shape, the seat, backrest, and foot elements are first defined with 2x2, 3x3, and 5x5 points, and in the next stage with rectangular planes instead of points. The use of anthropometry and ergonomic data is inevitable when designing a chair, which is a product that interacts with the human body. In order to answer the question of whether the machine can develop such a solution in the generative design process, ergonomic and anthropometric values are ignored. In this respect, only anthropometric data defining the standard dimensions of the elements that should be in a chair design in the developed problem models are discussed. The standard dimensions are 40x40 cm for the seating surface, 40x40 cm for the backrest, and 40 cm for the foot heights (Panero and Zelnik, 1979).

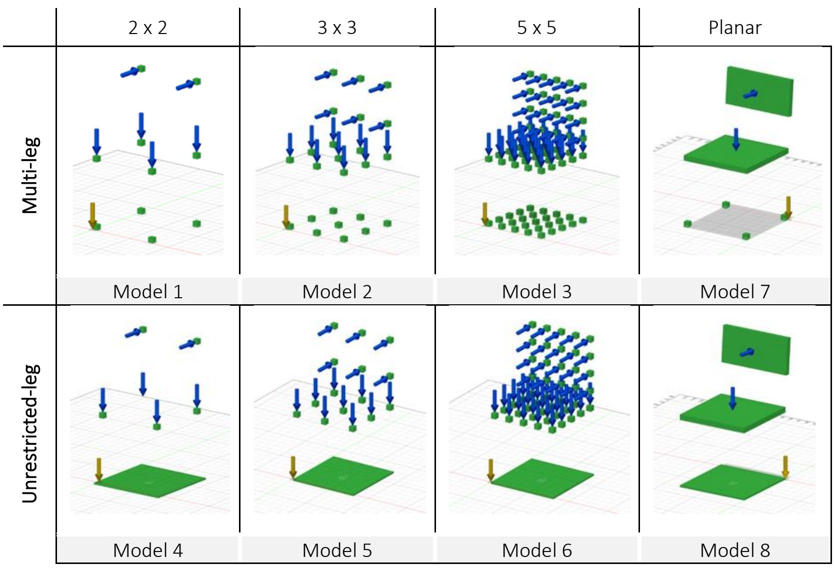


Figure 5: 3D design models

First, model proposals called Model 1, Model 2 and Model 3 are created to examine what kind of seat, backrest and leg formations will be produced by artificial intelligence. Chair parts are defined with points in these models. In Model 4, Model 5 and Model 6, the leg parts are defined as planes in order to examine the shape formation in the leg part of the chair without limiting it to points. In Model 7, the seat and backrest part of the chair are defined as rectangular planes and the legs are defined as points. For unrestricted leg formation, the leg part is defined as a plane in Model 8 **(Figure 5)**.

In every chair design that is expected to be created by artificial intelligence, the 3D model is made ready for analysis by placing obstacle geometry so that the artificial intelligence does not interfere with the volume that will allow a person to sit **(Figure 6)**.

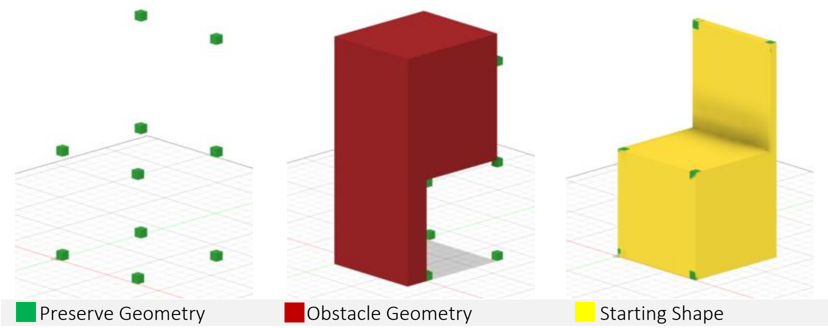


Figure 6: Creation of Generative Design Model (Autodesk Fusion 360)

The following values were kept constant in all 3D models, and the analyzes to be performed by artificial intelligence were carried out in the gravitational environment (g = 9.807 m/s2):

- *Structural Loads:* A force of 1100 Newtons, which corresponds to 110 kg of weight, is applied to the seat surface of the chair, and 450 Newtons, which is approximately equivalent to 45 kg of weight, is applied to the backrest. These force sizes are applied based on the ISO 7174-2 coded "Furniture - Chairs - Determination of stability" standard.
- *Objectives:* It is aimed to minimize the mass for minimal material use in the design outputs. The safety factor value is based on the program's standard value of 2.00.
- *Manufacturing:* By using two different options as unrestricted (both additive and reductive) and additive only, it is desired to monitor the differences between the design outputs that artificial intelligence will obtain without any limitation or by imposing a limitation on the use of manufacturing technology.
- *Materials:* Titanium 6Al-4V and Orgasol Invent Smooth-PA12 offered by the program were selected for the design masses in

each 3D model in terms of their suitability for the selected production technologies. These two different choices also aim to observe the effect of material use in artificial intelligence analyzes performed on the same model.

3. RESULTS AND DISCUSSION

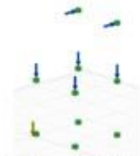
In the study, the contribution/functionality of the Generative Design plugin of Autodesk Fusion 360 to a design problem was tested. In this context, it has been examined whether the artificial intelligence of the program can design a chair on its own without the need for a designer. In the first stage of the study, the seating surface and backrest of the chair were defined with dots. In the second stage, these elements are given as surfaces. The results and feedback produced by the Fusion 360 software are evaluated and explained below **(Table 1; Table 2; Table 3; Table 4; Table 5; Table 6; Table 7; Table 8; Table 9)**.

In the first stage of the study, designs with fixed and non-fixed number of legs were produced. When the produced design outputs are evaluated;

For generated designs with fixed number of legs (Model 1, Model 2 and Model 3):

1. In Model 1, where the number of points forming the planes of the chair (seating, backrest, leg/s) is the least, it has been concluded that the similarity ratio in terms of form in the design outputs created by artificial intelligence is the least and the design outputs differ in mass.
2. It has been observed that the design outputs created for Model 2 and Model 3 have a very high similarity ratio in terms of form.
3. While the backrests create more hollow structures in Model 1; a solid surface formation was observed in Models 2 and 3.
4. While there is monolithic leg formation in Models 2 and 3; It has been determined that more free leg forms are formed in Model 1.
5. In Model 2 and Model 3, no difference was observed in terms of form formation between additive and unrestricted manufacturing technologies. It can be said that this form difference occurred only in Model 1.

MODEL 1



Manufacturing Methods

Unrestricted								Additive							
	Design Output	Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration		Design Output	Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	3,511	15.557	185.2	44	1		Titanium 6Al-4V	-	7,184	31.828	6.4	27
2		Titanium 6Al-4V	Y+	10,269	45.492	18.7	22	2		Orgasol Invent Smooth - PA12	-	7,233	6.945	4.2	27
3		Titanium 6Al-4V	Z+	9,684	42.903	57.8	24								
4		Titanium 6Al-4V	X-	1,908	8.452	190.2	58								
5		Titanium 6Al-4V	Y-	3,616	16.019	11.2	44								
6	-	Titanium 6Al-4V	Z-	-	-	-	-								
7		Orgasol Invent Smooth - PA12	X+	3,445	3.307	23.5	44								
8		Orgasol Invent Smooth - PA12	Y+	10,123	9.719	23.4	23								
9		Orgasol Invent Smooth - PA12	Z+	3,601	3.457	23.5	45								
10		Orgasol Invent Smooth - PA12	X-	3,415	3.279	23.3	45								
11		Orgasol Invent Smooth - PA12	Y-	3,428	3.291	23.1	45								
12		Orgasol Invent Smooth - PA12	Z-	3,426	3.29	11.6	46								

Table 1: Design outcomes of Model 1.

MODEL 2															
															
Manufacturing Methods															
Unrestricted								Additive							
Design Output		Material	Orient.	Volume (cm^3)	Mass (kg)	Max von Mises stress (MPa)	Iteration	Design Output		Material	Orient.	Volume (cm^3)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	54,494	241.41	5.7	5	1		Titanium 6Al-4V	-	46,446	205.757	3.8	9
2		Titanium 6Al-4V	Y+	51,158	226.634	6.4	7	2		Orgasol Invent Smooth - PA12	-	44,094	42.33	3.7	10
3		Titanium 6Al-4V	Z+	50,387	223.217	4.2	7								
4		Titanium 6Al-4V	X-	52,259	231.51	6.3	6								
5		Titanium 6Al-4V	Y-	55,080	544.009	6.2	5								
6		Titanium 6Al-4V	Z-	50,321	222.925	4.2	7								
7		Orgasol Invent Smooth - PA12	X+	54,136	51.971	5.5	5								
8		Orgasol Invent Smooth - PA12	Y+	49,855	47.861	5.5	7								
9		Orgasol Invent Smooth - PA12	Z+	50,124	48.12	4.5	7								
10		Orgasol Invent Smooth - PA12	X-	52,272	50.182	5.8	6								
11		Orgasol Invent Smooth - PA12	Y-	52,414	50.318	6.3	6								
12		Orgasol Invent Smooth - PA12	Z-	47,967	46.049	3.7	8								

Table 2: Design outcomes of Model 2.

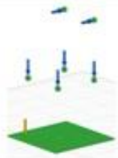
MODEL 3

Manufacturing Methods

Unrestricted								Additive							
Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration	Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	54,751	242.547	17.3	5	1		Titanium 6Al-4V	-	50,990	225,886	16.6	7
2		Titanium 6Al-4V	Y+	52,721	233.554	18.8	6	2		Orgasol Invent Smooth - PA12	-	50,981	48.942	15.2	7
3		Titanium 6Al-4V	Z+	50,767	224.902	14.5	7								
4		Titanium 6Al-4V	X-	54,490	241.394	19	5								
5		Titanium 6Al-4V	Y-	54,904	243.227	18.5	5								
6		Titanium 6Al-4V	Z-	52,830	234.037	14.9	6								
7		Orgasol Invent Smooth - PA12	X+	54,742	52.553	16.7	5								
8		Orgasol Invent Smooth - PA12	Y+	52,331	50.238	22.7	6								
9		Orgasol Invent Smooth - PA12	Z+	50,728	48.699	13.9	7								
10		Orgasol Invent Smooth - PA12	X-	54,428	52.251	17.7	5								
11		Orgasol Invent Smooth - PA12	Y-	54,906	52.71	16.1	5								
12		Orgasol Invent Smooth - PA12	Z-	52,805	50.693	14.3	6								

Table 3: Design outcomes of Model 3.

MODEL 4



Manufacturing Methods

Unrestricted								Additive							
Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration	Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	5.518	24.447	441.2	37	1		Titanium 6Al-4V	-	7,346	32.546	93.6	31
2		Titanium 6Al-4V	Y+	6,330	28.043	441.2	31	2		Orgasol Invent Smooth - PA12	-	17,536	16.835	17.4	62
3		Titanium 6Al-4V	Z+	11,734	51.984	441.2	20								
4		Titanium 6Al-4V	X-	5,685	25.188	251	33								
5		Titanium 6Al-4V	Y-	5,620	24.898	441.2	34								
6		Titanium 6Al-4V	Z-	14,946	66.214	221.4	15								
7		Orgasol Invent Smooth - PA12	X+	5,630	5.405	23.5	47								
8		Orgasol Invent Smooth - PA12	Y+	11,497	11.038	23.4	63								
9		Orgasol Invent Smooth - PA12	Z+	12,117	11.632	23.5	31								
10		Orgasol Invent Smooth - PA12	X-	5,460	5.242	23.5	35								
11		Orgasol Invent Smooth - PA12	Y-	6,226	5.977	23.5	42								
12		Orgasol Invent Smooth - PA12	Z-	17,063	16.381	23.4	12								

Table 4: Design outcomes of Model 4.

MODEL 5

Manufacturing Methods

Unrestricted

	Design Output	Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	58,728	260.169	441.1	5
2		Titanium 6Al-4V	Y+	51,672	228.908	441.2	8
3		Titanium 6Al-4V	Z+	57,879	256.406	321.3	6
4		Titanium 6Al-4V	X-	58,715	260.111	441.2	5
5		Titanium 6Al-4V	Y-	55,002	243.659	415.6	6
6		Titanium 6Al-4V	Z-	58,514	259.22	441.3	5
7		Orgasol Invent Smooth - PA12	X+	46,681	44.814	23.5	17
8		Orgasol Invent Smooth - PA12	Y+	33,910	32.554	23.5	22
9		Orgasol Invent Smooth - PA12	Z+	37,863	36.349	39.4	14
10		Orgasol Invent Smooth - PA12	X-	31,087	29.844	23.5	25
11		Orgasol Invent Smooth - PA12	Y-	44,164	42.398	26.5	18
12		Orgasol Invent Smooth - PA12	Z-	36,600	35.137	23.5	21

Additive

	Design Output	Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	-	5,479	24.274	26.9	59
2		Orgasol Invent Smooth - PA12	-	5,408	5.192	20.6	64

Table 5: Design outcomes of Model 5.

MODEL 6

Unrestricted								Additive							
Design Output		Material	Orient.	Volume (cm^3)	Mass (kg)	Max von Mises stress (MPa)	Iteration	Design Output		Material	Orient.	Volume (cm^3)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	58,360	258.536	441.3	5	1		Titanium 6Al-4V	-	16,085	71.257	25	31
2		Titanium 6Al-4V	Y+	52,672	233.339	441.2	8	2		Orgasol Invent Smooth - PA12	-	15,328	14.715	23.2	32
3		Titanium 6Al-4V	Z+	58,907	260.961	441.2	5								
4		Titanium 6Al-4V	X-	60,837	269.511	441.3	4								
5		Titanium 6Al-4V	Y-	55,990	248.036	407.7	6								
6		Titanium 6Al-4V	Z-	56,137	248.689	441.3	5								
7		Orgasol Invent Smooth - PA12	X+	47,719	45.811	23.5	15								
8		Orgasol Invent Smooth - PA12	Y+	40,782	39.151	23.5	14								
9		Orgasol Invent Smooth - PA12	Z+	52,366	50.272	23.5	9								
10		Orgasol Invent Smooth - PA12	X-	58,038	55.717	23.5	12								
11		Orgasol Invent Smooth - PA12	Y-	43,299	41.472	23.5	19								
12		Orgasol Invent Smooth - PA12	Z-	48,305	46.373	23.5	16								

Manufacturing Methods

Table 6: Design outcomes of Model 6.

For generated designs without number of legs constraint (Model 4, Model 5 and Model 6):

1. Compared to models with leg constraints, less material is used and more hollow forms are generated.
2. Although there is a similarity with the first stage in the design outputs in which the additive manufacturing method is used, differentiation is observed in all three elements (seating, backrest, leg/s) that make up the chair.
3. In the design outputs where the unrestricted manufacturing method is used, more structural solution suggestions are encountered instead of a massive form formation.
4. Although the formation of the legs are not fixed in Model 4, the formation of four legs can be explained by the fact that it is the form that will best realize the portability of the forces applied to the surfaces.
5. A monolithic leg form is formed in Models 5 and Model 6.
6. In Model 5 and Model 6, we can talk about a fixed seating element, not a portable chair.

Examining the design outputs created by artificial intelligence through all the problem models (Models 1, 2, 3, 4, 5 and 6) of the first stage;

1. The use of different materials does not create significant differences on the design outputs in terms of form.
2. Unrestricted manufacturing method reduces material usage.
3. As the number of points on the planes (seating, backrest and leg/s) forming the chair in the problem models increased, the design outputs produced by artificial intelligence created more massive and closed forms. While 2x2s create open forms; Models with 3x3 and 5x5 created more closed forms. The most monolithic state is observed as Model 3.
4. Model 1 and Model 4 have a more delicate structure compared to the others, which can be explained by the decrease in the number of points where the load is applied.
5. Some design outputs are in forms that we can call chair design away from human ergonomics.
6. As the number of iterations increases, the use of materials decreases regardless of the manufacturing technique, and more hollow forms are formed.

7. Where leg form wanted to be analyzed as unrestricted; Models 1, 2 and 3's design outputs have a solid backrest, while Models 4, 5 and 6's have more open. Beside, when the manufacturing and leg types are unrestricted in Model 4, 5 and 6, the leg profile has been observed that it becomes thinner.
8. In Models 1 and 4, the fact that the points to be connected by the artificial intelligence or the load to be applied by the person sitting on the chair are only on the corners of the seating and backrest surfaces did not create any planar form on the seating and backrest surfaces in these models. In this respect, for a surface to be formed within the program, there must be preserved geometry in at least one coordinate on this surface where the load will be applied. Because of this situation, in the second stage, the seat and backrest elements that make up the chair design are defined as planar and the final products are obtained.

In the second stage, models with defined seating and backrest surfaces were given to the software. When the generated design outputs are evaluated;

1. In Model 7, the leg element consists of a closed volume. In Model 8, where we wanted the leg to be non-fixed, we can observe the free-form formations for it. This can be associated with the low number of iterations.
2. On the contrary, we encounter a reduced volume in the design output number 12, which is produced on the Z- axis with the additive manufacturing technology in Model 7. Since the number of iterations did not increase in the titanium-produced derivative number 6, the volume did not decrease. It emphasizes the importance of the axis in the additive method.
3. It has been observed that the design outputs generated with unrestricted manufacturing in Model 7 and the design outputs 6 and 12 generated on the Z- axis in additive manufacturing of all models have the same form characteristics.

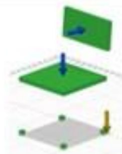
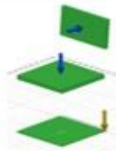
MODEL 7															
															
Manufacturing Methods															
Unrestricted								**Additive**							
Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration	Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	34,703	153.736	1.9	18	1		Titanium 6Al-4V	-	27,573	122.152	1.2	24
2		Titanium 6Al-4V	Y+	31,751	140.664	1.2	23	2		Orgasol Invent Smooth - PA12	-	11,364	10.91	2.2	41
3		Titanium 6Al-4V	Z+	27,211	120.545	2.3	23								
4		Titanium 6Al-4V	X-	34,883	154.533	1.9	19								
5		Titanium 6Al-4V	Y-	24,387	108.038	1.8	26								
6		Titanium 6Al-4V	Z-	28,326	125.488	1.3	23								
7		Orgasol Invent Smooth - PA12	X+	57,213	54.925	1.1	8								
8		Orgasol Invent Smooth - PA12	Y+	61,726	59.257	1.3	9								
9		Orgasol Invent Smooth - PA12	Z+	57,022	54.742	1.2	8								
10		Orgasol Invent Smooth - PA12	X-	60,034	57.633	1	7								
11		Orgasol Invent Smooth - PA12	Y-	56,382	54.127	1.1	9								
12		Orgasol Invent Smooth - PA12	Z-	11,597	11.134	2.3	42								

Table 7: Design outcomes of Model 7.

MODEL 8


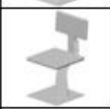
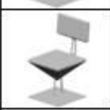
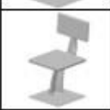
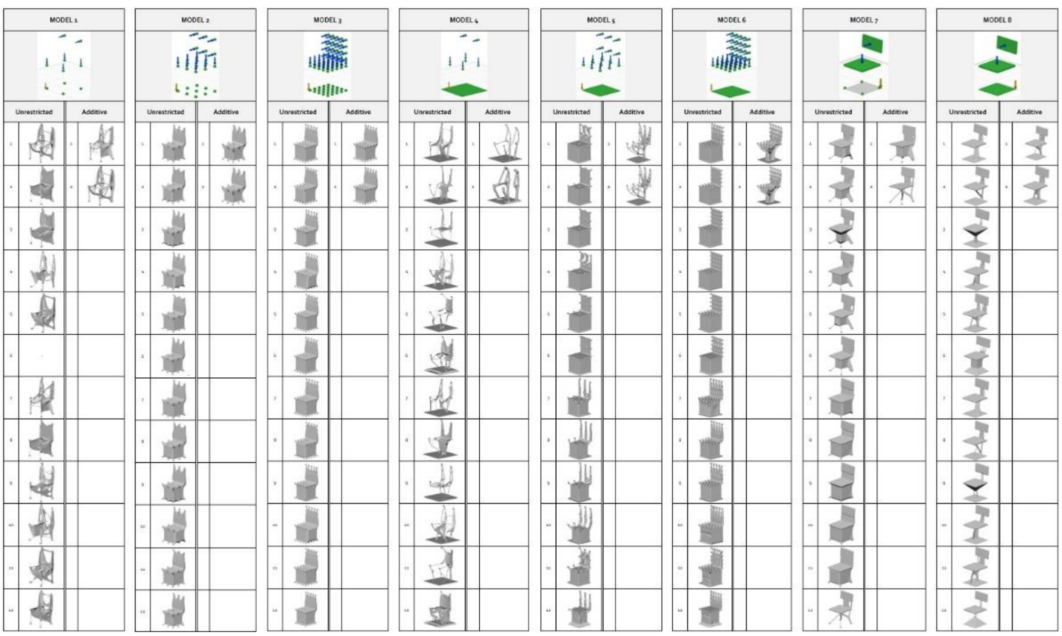
Manufacturing Methods															
Unrestricted								Additive							
Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration	Design Output		Material	Orient.	Volume (cm³)	Mass (kg)	Max von Mises stress (MPa)	Iteration
1		Titanium 6Al-4V	X+	13,103	58.047	2.5	51	1		Titanium 6Al-4V	-	12,468	55.236	2.2	43
2		Titanium 6Al-4V	Y+	13,431	59.501	2.6	45	2		Orgasol Invent Smooth - PA12	-	13,320	12.787	2.2	39
3		Titanium 6Al-4V	Z+	20,417	90.45	99.3	28								
4		Titanium 6Al-4V	X-	12,672	56.138	14	54								
5		Titanium 6Al-4V	Y-	12,375	54.823	3	38								
6		Titanium 6Al-4V	Z-	28,242	125.115	43.8	23								
7		Orgasol Invent Smooth - PA12	X+	12,821	12.308	2.8	50								
8		Orgasol Invent Smooth - PA12	Y+	12,616	12.111	2.7	49								
9		Orgasol Invent Smooth - PA12	Z+	20,444	19.627	23.5	31								
10		Orgasol Invent Smooth - PA12	X-	12,516	12.016	4.3	43								
11		Orgasol Invent Smooth - PA12	Y-	12,843	12.329	2.9	39								
12		Orgasol Invent Smooth - PA12	Z-	20,795	19.964	23.5	30								

Table 8: Design outcomes of Model 8.

As a general review is made for all the result products;

- It is clearly observed that the addition axis (x+ … z-) creates constraints on the final outputs in the additive manufacturing method (Model 1, Model 4 and Model 7). In general, this situation is due to the nature of the additive manufacturing method. However, design outputs 6 and 12 of Model 1 and Model 7 produced on the Z-axis with this manufacturing technology show that there are deviations in the results of the program.
- As the number of iterations increases, the program decreases the mass volume as it is intended; we can observe the formation of forms with voids. In addition, due to the material difference, there is an insignificant change in the forms.
- Although the design outputs were solved in accordance with the aim of minimizing mass, the size of solid volumes reached high weights in contrast to a chair design which should be portable.
- In the generative design analysis, material selection did not provide any remarkable difference in form formation in the design output. Therefore, it can be mentioned that material reactions should also contribute to this design process.
- The whole model is made of a single material and there is no possibility to choose different materials.

Table 9: Design outcomes for all models.



4. CONCLUSION

The approaches of designers to new designs are changing with the developing new technologies. Generative design offers designers opportunities such as saving time, alternative design solutions, customizing the design, and better performance in the final design. Despite these, the generative design plugin is insufficient in its current state contrary to design a whole product by itself and the designer's experience is the most important input of this design process.

When we look at the design outputs generated by the generative design method;

- The software tries to optimize the structural forms it creates for the given purpose by reducing the use of materials. In parallel with this, the resulting products are very close to each other in terms of form, within the possibilities given by the manufacturing methods.
- Considering the form formation obtained in both stages; The low number of inputs in the model proposals given for the analysis of the software supports the presence of more alternative forms. Defining chair elements with planes instead of point inputs provides better results in order to create a chair design. When the seating and backrest surfaces were defined, it was possible to reach chair designs in various forms with generative design.
- The design outputs obtained against the given design problem require reconsideration within the designer-generative system relationship. The generative design method can be used as a support system for the designer to find the optimum structure in the design process, rather than being a system that produces a design product on its own
- In the generative design process, the software lacks material diversity and the combined use of production technologies due to the use of a single material and/or manufacturing technology. These constraints necessitate the design product to be in a monolithic structure or separate consideration of elements/parts of a design product.

Generative design plugin needs to be developed in order to be used as a valid design tool. In this context, visual inputs similar to the desired product may be given at the beginning of the design process, and it can be expected to allow the designer to intervene through the results. When the software is evaluated as an artificial intelligence, it can be expected that data such as ergonomics, anthropometry and culture can be processed by the software in addition to visuals.

References

Anonymous. (2020, January 24). A.I. - *Introducing The First Chair Created With Artificial Intelligence.* Philippe Starck. https://www.starck.com/a-i-introducing-the-first-chair-created-with-artificial-intelligence-p3801.

Barros, M., Duarte J. P. and Chaparro, B. M. (2015). A grammar-based model for the mass customisation of chairs: Modelling the optimisation part. *Nexus Network Journal,* 15, 875-898. https://doi.org/10.1007/s00004-015-0265-5

Bidgoli, A. and Veloso, P. (2018). Deepcloud the application of a data-driven, generative model in design. *ACADIA 2018: Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture,* 176-185. https://arxiv.org/abs/1904.01083

Bruno, C. (2020). Creativity 4.0. A method to explore the influences of the digital transition on human creativity within the design process. In L. Rapino & I. Mariani (Eds.), *Design Research in Digital Era*,75-90. FrancoAngeli.

Buonamici, F. et al. (2020). Generative design: An explorative study. *Computer-Aided Design and Applications*, 18(1), 144–155. http://doi.org/10.14733/cadaps.2021.144-155

Giaccardi, E. and Redström, J. (2020). Technology and More-Than-Human Design. *Design Issues*, 36(4), 33-44.

Harsuvanakit, A. (2016, October 12). *Elbo Chair- Generated in Project Dreamcatcher, Made with Fusion 360*. https://gallery.autodesk.com/fusion360/projects/elbo-chair--generated-in-project- dreamcatcher-made-with-fusion-360.

Jordahn, S. (2019, April 11). *Philippe Starck, Kartell and Autodesk unveil "world's first production chair designed with artificial intelligence"*. Dezeen. https://www.dezeen.com/2019/04/11/ai-chair-philippe-starck-kartell-autodesk-artificial-intelligence-video/

Laarman, J. (2015, June 25). *Bone chair*. Joris Laarman. https://www.jorislaarman.com/work/bone-chair/

Li, D. and Du, Y. (2007). *Artificial Intelligence with Uncertainty*. CRC Press.

Li, H. and Lachmayer, R. (2018). Generative Design Approach for Modeling Creative Designs. *IOP Conference Series: Materials Science and Engineering*, 408(1), 012035. http://doi.org/10.1088/1757-899X/408/1/012035

Liu, Z., Gao, F. and Wang, Y. (2019). *A Generative Adversarial Network for AI-Aided Chair Design*. http://dx.doi.org/10.1109/mipr.2019.00098

McKnight, M. (2017). Generative Design: What it is? How is it being used? Why it's a game changer. *KnE Engineering*, 176–181. http://doi.org/10.18502/keg.v2i2.612

Panero, J. and Zelnik, M. (1979). *Human Dimension and Interior Space*. The Architectural Press Ltd.

Phaidon. (2006). *Pioneers: Products from Phaidon Design Classics Volume One*. Phaidon Press.

Postell, J. (2012). *Furniture Design*. John Wiley & Sons.

Ramesh, A. et al. (2021). Zero-shot text-to-image generation. *In International Conference on Machine Learning*, 8821-8831

Thompson, R. (2011). *The Manufacturing Guides: Product and Furniture Design*. Thames & Hudson.

Westerveld, C. E. (2021). *Generative Design: Recommended actions to smooth the way for production of generative designs with additive manufacturing* [Master's thesis]. http://essay.utwente.nl/85976/