# Role of artificial intelligence technology in the development of furniture design Process

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## Abstract:

Artificial intelligence (AI) empowers innovative applications in furniture that are presented in generative models. In recent times, there are many implementations of machine-learning approaches to develop the furniture design process. Due to contemporary individuals' requirements, rapid fluctuations in customers' preferences, and the geometrics complexity of designs, furniture designers need to explore multiple alternative solutions during the design process. This study aims to clarify the current AI technologies implemented in furniture design to develop the design process and boost furniture designers' abilities and performances in their work. Therefore, this study presents two models: the first one is for the design process to differentiate between the design conducted by humans and the design implemented by AI. The second model clarifies the role of the furniture designer inside AI systems for the design process. Based on the review study, the author presents a SWOT analysis of the strengths, weaknesses (limitations), opportunities, and threats of using AI to design furniture. A survey was conducted to measure furniture designers' responses to the SWOT analysis. The findings of this paper have enclosed that, (89.4%) of furniture designers view AI performs better in generating initial ideas than other design tasks. (87.2%) view AI is not sufficient without the involvement of designers. (72.3%) view AI is a professional design tool that will enhance interactive design and virtual design. (78.7%) of them are afraid of losing designers' identities due to using the same AI techniques.

## Keywords:

Artificial Intelligence(AI), Furniture Design, Generative Design, Machine Learning, SWOT analysis eses:

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## 1 Introduction:

New technologies invade various aspects of life, aiming at the well-being of human life and making it easier. Artificial intelligence(AI) is one of these important and developed technologies in the current era. AI seeks to learn machines how to simulate the human brain to do human tasks. As a result of recent advancements in information systems and numerous databases, AI has taken its place in different sectors from simple tasks to significant and accurate ones. AI technologies have been empowered in many applications in today's society such as astronomy, healthcare, finance, data security, robotics, automotive, and predicting natural events. Moreover, AI appears in many design fields at different levels of skills which could be beyond designers' imagination with unpredictable results (Anantrasirichai, Bull . 2022). AI techniques have a very important impact on developing the furniture design field. It could be used on both: the creative side in generating innovative designs and the scientific side in calculating loads, design constraints, and statistical analyses. AI can be used for the exploration of solutions for furniture design generation. Barros developed a technique for investigating potential chair-generating designs (Barros et al. 2014). Schmitt and Weiß. (2018) presented a model that produces a variety of novel chair shapes to inspire designers during the design process. AI is also used to present technical solutions to improve furniture quality and production efficiency (Long G, Lin B, Cai H, Nong G, 2020).

The furniture design process is a multidisciplinary activity requiring exploration, improvement, and testing until productive solutions are created. That creates a need for furniture designers to explore multiple alternatives to reach possible design solutions for the design task. Especially, contemporary furniture design is increasingly influenced by the principles of complex system engineering. Products are becoming more and more sophisticated, necessitating the integration of numerous technologies. The research aims to clarify the recent AI technologies implemented in the furniture design process that could boost their abilities and performances in the design process. The research discusses the role of the furniture designer inside AI systems for the design process. The research also aims to evaluate the impact of using AI in the furniture design process. Therefore, it was necessary to conduct a study that presents and analyze furniture designers' point of view about the current situation. The results of this research can help in establishing a framework for developing the furniture design process and defining the challenges, and future potential of AI associated with furniture design.

## Problem:

The research problem is limited to the following questions:

1- How can the current AI technologies implemented in furniture design develop the design process?
2- What is the role of the furniture designer inside AI systems?
3- What do furniture designers think about the changes that occurred in the furniture design process after using AI techniques?

## Objectives:

This study aims to:

1- Study the AI techniques implemented in the furniture design process.
2- Study the machine learning approaches applied in the furniture design process.
3- Define the role of the furniture designer inside AI systems for the design process.
4- Measure and analyze the effect of applying AI technology on the furniture design process and the furniture designers' roles and skills.

## Significance:

The importance lies in the following points: -

1- Assure the importance of studying the applications of AI technology in the furniture design process and the designer's role in the AI system.
2- Consecrate on analyzing the advantages and disadvantages of applying AI technology to furniture design.

## Methodology:

Descriptive approach through studying and describing applications of AI technology in the furniture design process. Analytical approach through using SWOT analysis to determine the strengths, weaknesses opportunities, and threats resulting from applying AI technology to furniture design process. The survey through conducting an online survey aims to collect furniture designers' opinions on applying AI technology to the furniture design process.

### 2 An introduction to artificial intelligence

AI is the link between humans and machines relationship. In recent decades' people depend much more on programmed machines and automation systems that could be controlled by human orders. Now, AI has great innovations that are making an impact on the way people around the world live and do business.AI technologies are projected to make computers and machines learn, perform tasks, create choices, and take actions without human intervention. Artificial intelligence uses autonomous systems that refer to the ability of a machine to operate without a human operator. It is a technology that is constantly developing itself. These changes rely on parameters that humans program, which occur actions with a volume and speed never before possible or expected (Schmidt et al .2021). Haenlein and Kaplan (2019) define AI as a system's ability to explicate data to learn and use it to achieve specific objectives and missions. High-Level Expert Group (HLEG) defines AI as a software and hardware system designed by humans, which uses symbolic rules or numeric models to process information, derived from given data and choose the best action (Samoili et al .2020). AI systems can either perceive the environment through data acquisition and can also adapt their behavior by analyzing how the environment is affected by their previous actions.

### 2.1 AI for design tasks

The AI algorithm's formula aims to mimic human thinking and creativity. AI is rapidly being used in the creation of designs (Irbite, Strode .2021). Unlike designers, AI capabilities operate problem-solving without volume or speed limits (Vergantiet al .2020). On one hand, it could be simply used to accelerate traditional design tasks as an intelligent tool. Designers can use many programmed intelligent tools to analyze, model, evaluate, redesign, and improve designs. Also, there is a hybrid design system in which designers and artificial intelligence work closely together to produce results. On the other hand, it might simulate and automate a designer's thoughts in the whole design process. In other words, AI can be combined with artistic movements to create a product design. This ability significantly accelerates the growth of several design fields.

Artificial Intelligence has a great impact on the design process, it includes collaborative Intelligence, creativity enhancement, and idea development phases (Figoli et al .2022). AI can help designers effectively in their work during the different design stages. It could present numerous conceptual ideas in the first design stage by generating innovative forms (Pena et al. 2021). It could provide specific databases containing large numbers of examples that match some given criteria as a reference for the design idea. In the design creation stage, deep learning can process large amounts of data to develop itself to create alternative designs according to design constraints. AI has a high performance in evolving and modifying designs stage by testing and learning the alternatives till selecting the perfect ones. Moreover, In the design Optimization stage, AI could achieve quality and acceptable cost, and nominate the perfect materials, colors, and finishing. Furthermore, AI helps design experts make decisions in design activities. For example, the man-machine intelligent design system is

currently used in decision-making automation or assisting design professionals in making decisions during design activities (Andreolli et al .2017). The application of Al in the design process can be particularly beneficial in time-consuming and saving efforts compared with designer ability. The model shown in Fig.1 clarifies the differences between design by humans and design by AI in the design process stages. AI can present numerous conceptual ideas, generate thousands of complete designs, test and refine alternative designs, choose the perfect designs then analyze parameters and conditions to optimize the designs perfectly. These facilities open great opportunities to innovate creative designs that never could be imagined.

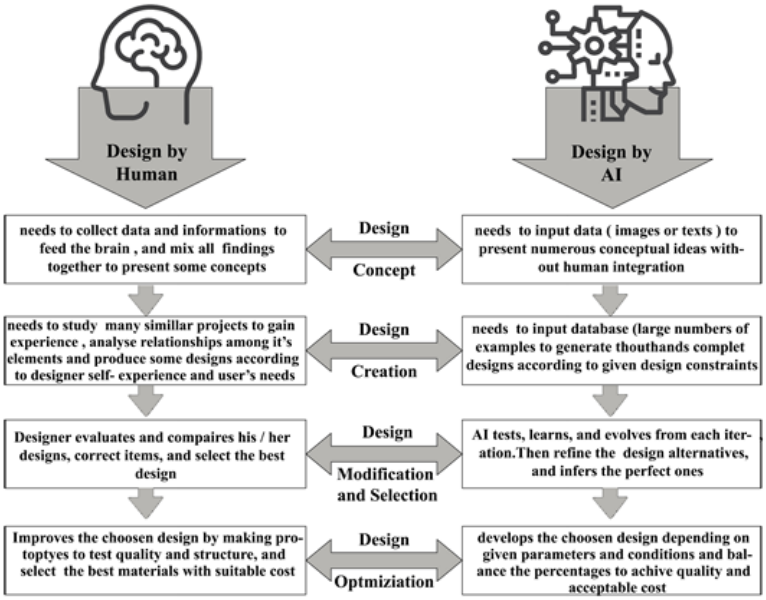


Fig.1 Differences between design by humans and design by AI in the design process stages. by the author

**2.2 Machine learning approaches applied in the Design Process**

TO clear understanding, How AI could be applied in the design process. We need to identify the method that makes machines learn or the software program. Many different AI techniques can be applied to aid with the design tasks and enhance the design process. These consist of expert systems, genetic algorithms (GAs), formal grammar, case-based reasoning (CBR), neural networks, etc.

Expert systems are one of the earlier Artificial Intelligence (AI) applications, they refer to computer programs that behave like human experts. They use programming techniques of artificial intelligence to build rules that represent knowledge-knowledge engineering for solving design problems. Knowledge-Based Expert System (KBES) programming is different from regular programming. It simulates experts' work in design tasks that require involve judgment and experience-based heuristic solutions. So it allows the computer to aid in the decision-making process and solve unorganized, non-deterministic design issues such as synthesis, assessment, and modeling (Janjanam et al.2021). Most expert systems can generate plausible answers to some ill-structured problems that lack an effective algorithmic solution. Today, hybrid expert systems that use methods like artificial neural networks and genetic algorithms are available in addition to traditional expert systems (Mehmet et al.2016).

Genetic algorithms (GAs) are used in programming artificial systems based on explaining the adaptive processes of natural systems. This can be used to produce creative, optimized, and evolutionary designs that simulate natural systems. It is a computerized artificial intelligence technology that uses the methodology of evolution and conflict to reach the optimal solution in the same way that genes arise and develop. Genes are passed on from one generation to the next by pairing the alleles in the parents' chromosomes. The new generation results from the natural selection of the best alleles and pairing them together to produce children with higher quality characteristics than the previous generation. Genetic algorithms technique mimic how genes work. In design processes, Designers consider each design as a chromosome that contains design items as alleles. Then the designer cooperates with technicians in genetic programming by encoding the design items with automated systems. This process includes identifying each item with a symbol and giving it digital value for the quality or preference. Hence, the pairing occurs between design items that carry the highest quality values – artificial selection- to output new designs. Zhang (2022) improved genetic algorithms for the process of industrial product design, which has a faster speed and better

effect for solving complex problems than the traditional design process. In his experiment, product genes are input, the assignment algebra of the first created population of product genes is set to 0, and the fitness function value of each product gene is computed. Then obtain the best product genes based on the design process. Uusitalo et al (2022) used an interactive evolutionary algorithm to create a pendant lamp design that resemblance to a whale's chest-skin corrugations. The evolutionary design software was equipped to ultimately fabricate a physical prototype. The genes were encoded for guiding the generation process such as length, width, the curvature of the back sheet, amount of wave ribs, and other parameters.

Formal grammar is another method of AI programming techniques, that accurately describes the structure of designs in two or three dimensions. Designers already benefit from the grammar approach programming when they are building grammar to design shapes, and further processing those forms. Li (2018) presented a grammar programming technique for modifying 3D shapes by using Rhinoceros 3d program. This method requires launching a new grammar script and configuring it as a grammar document. Two layers are produced by the script: one with a single frame for the starting form and another with two frames for the two shapes as a rule. Hence, it is allowed to create three-dimensional shapes with lines and text annotation dots for identified spots.

Case-based reasoning (CBR) is one of the machine learning approaches used to solve design problems. It depends on recalling an earlier identical situation and using the details and expertise of that situation. CBR applies derivational analogies to modify prior design cases to produce new designs. The CBR process is a cycle made up of four consecutive actions. It performs by matching a case in the case library that matches the new case, then finding the answer to a historical case's problem, modifying the case solution to suit the differences in the new case, and finally merging the new case solution into the case library (Dalal et al .2012; Khan.2014). CBR has been used effectively in software engineering that is used in the design process. It is favored over other artificial intelligence due to its low learning need, low pre-processing cost, and adoption flexibility (Khan et al.2019).

Many types of AI neural networks (ANNs) in deep learning, could be used to generate models for design purposes. These ANNs are systems for processing data based on specific rules. It acts like neutral cells in the human brain through specific algorithms which recognize the input data, divide, and classify data to learn, and improve its performance gradually. Learning in a neural network is closely related to how we learn in our regular lives and activities. The right choice of the ANNs type depends on the nature of the required process that determined the layer's kind (hidden layers or single-layers), the number of hidden layers, learning speed, learning control (supervised or semi-supervised or unsupervised), universal approximation, number of relevant data, memory term, the connection between layers, the connection between nodes and layers, and the connection between input layers and output layers.

Convolutional neural networks (CNNs) have multilayers that consist of an input layer, hidden layers, and an output layer. CNN has represented the state of the art for complex problems such as image classification and recognition. CNN can be used for the recognition of design-related information in images. For example, CNN is used as a visual categorization technique for different furniture types, extracting visual feature maps for furniture through the shape, color, material, and size, recognition method for furniture design components such as functional features, materials, seating capacity, style, and type of seating furniture, and also recognizing the interior design styles demonstration of according to reference images (Kim and Lee . 2022). Another example is an unsupervised learning class of CNNs called deep convolutional generative adversarial networks (DCGANs). They are applied to create new designs of bedrooms by learning a hierarchy of representations in the generator and discriminator and ranging from object parts to scenes (Radford et al .2016). Recurrent neural networks (RNNs) are employed in applications involving time series that required effective real-time implementations. RNN compresses the input to produce a code and then generates the output using the code produced by the encoder. it is used in some design applications such as contrast enhancement, colorization, object recognition, and denoising. Generative Adversarial Networks (GANs) generate new data with identical statistics as the training set, it proved capable of learning complex, high-dimensional distributions. GANs are used to generate novel three-dimensional models like tables, automobiles, chairs, and sofas from images (Wu et al.2016). Variational Autoencoder (VAE) is used in automatic image generation. This is due to its ability to demonstrate the probability distribution for each feature set's attribute. Denoising Autoencoder (DAE) is used in dimensionality reduction because the algorithm forces the hidden layer to learn more robust features to result in meaningful data.

## 3 AI applications for furniture design

The furniture design process is a complex issue, the designers should take into their consideration

people's physiological and psychological needs. This process includes many criteria such as functionality, quality, cost, manufacturability, maintainability, and durability, and it extends to adaptation to the environment and society. Designers spent a lot of time searching data on products, sketching ideas, choosing materials, testing structural stability, applying aesthetic factors, etc. They produce one or two design results through hard work for a long time. However, artificial intelligence can produce thousands of results in a short time. AI technology is helpful for designers to better analyze and apply complex data in the process of product design. It can more accurately simulate designers' thinking and make problem__solving more intelligent. Artificial intelligence's outputs may produce a unique shape that humans would not have thought of.

### 3.1 Generative Design (GD) for Furniture Modeling

One of the most AI approaches applied in designing furniture is generative design. The generative design depends on using algorithms to simulate nature's developing approach (Yönder. 2020). Nature is full of various configurations which are different in form, size, colors, and other details for the same creatures. GD starts by putting the desired objectives in the final product and then explores all the alternatives and the solutions that could be reached to choose the best ones (Li and Lachmayer. 2018). The generative design system depends on repeated learning by artificial intelligence, it tests, learns, and evolves from each iteration. The GV approach uses unsupervised machine learning methods such as Generative modeling and generative adversarial networks (GAN) (Goodfellow et al. 2014). which aim to comprehend data by learning to reproduce it. In particular, they have gained designers' attention for their ability to produce almost identical designs.

GA uses Cloud computing to design software that generates thousands or millions of designs, experiments with the different configurations, refine the alternatives, and infers the perfect. This process enables designers to reach new choices that could not be reached by a single designer's work to obtain the most efficient design (Radakovic.2020). GD allows Designers or engineers to collaborate with artificial intelligence algorithms in the design process by using software to define the goals and constraints of the project. These include design parameters such as geometric dimensions, spatial requirements, permissible loads and operating conditions, target weight, performance, materials, manufacturing methods, and cost constraints (Walia and Breedon . 2021). The software explores all the possible permutations of a solution; at high speed, it generates high-performing design alternatives—many that designers would never think of them—. It addresses the inputs, tests, and learns from each repetition to evolve multiple great designs. Although a generative design approach may sound complex, it's important to remember that it's not limited to solving complex design problems; it can solve simple ones too.

Software for generative design can be found as standalone solutions or as extensions for bigger engineering platforms. since 2018, Autodesk released software for generative design development with its Fusion 360 CAD package ( Walia et al .2021) Fusion 360 is a 3D collaboration design tool that allows designers to create and assesses 3D models and drawings. Fusion 360 is a cloud-based 3D modeling that requires setting up inputs and design constraints to start iterating different designs. With all of the inputs the designer gave, its software has simultaneously found design solutions that are converged designs. Then it allows the designer to filter the produced designs to choose the best one and edit its mesh till reaching the desired result. Hayrettin (2012) used Fusion 360 to present 50 generative designs for a bookshelf and 40 generative designs for a TV unit. The design parameters were Structural loads, objectives minimizing mass, and materials. PTC also launched a generative design software called Creo. Creo is a 3D CAD solution that accelerates product innovation to assist designers in creating better results more quickly. All that is required to generate an optimized design is the definition of functional goals, geometry, physics, materials, and production procedures.

A generative design approach could be applied in furniture design for generating numerous design repetitions. That needs previously programmed software according to rules and criteria specified by the designer. It simply transforms requirements into product geometry and design. One of the most innovative furniture pieces that are designed with the generative design method is the "AI chair" designed by "Philippe Starck" (Buonamici .2021). It is designed by Philippe Starck in collaboration with Italian contemporary furniture maker Kartell and the Senior Director of Design Futures Autodesk "Mark Davis". Artificial intelligence is applied to use an algorithm that is programmed according to the structural standards and aesthetic considerations to develop the chair model (fig.2). The AI chair reflects comfort, stability, and simplicity. This chair is one of the first commercial furniture pieces created with generative AI. which could manufacture by plastic injection molding technology.

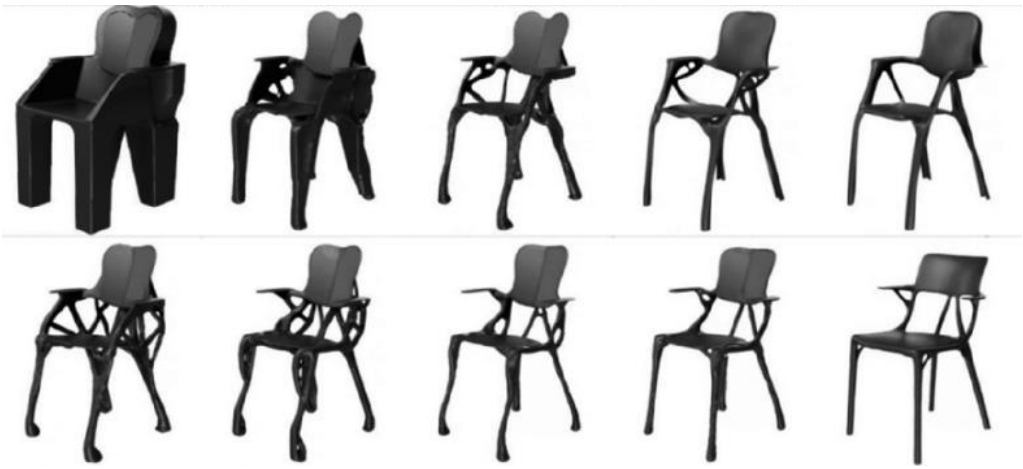

Fig .2 Philippe Starck's A.I. chair for Kartell company by using Generative design. Adapted from https://www.fastcompany.com/90334218/this-is-the-first-commercial-product-made-using-generative-design

Pollák and Török (2022) created a chair design backrest (fig.3) by combining numerous quickly evolving technologies. They digitized the selected backrest of the chair and digitally modified it with the Creo Parametric 7.0 Generative Design system. The included and excluded geometries were specified to apply the required loads and constraints. Hence, they input Structural measurable constraints for moving parts, planar surfaces, and cylindrical surfaces. And also input the Structural loads of force, moment, pressure, centrifugal, and linear Acceleration. This backrest was manufactured by a 3D printing production process with specific parameters.

Fig. 3 shows the chair's design backrest Designed by Martin Pollák and Jozef Török with Creo Parametric 7.0 adapted from (Pollák and Török.2022)

A new method for easily generating designs is the Mid Journey web interface, which produces a proprietary artificial intelligence program that creates images from textual descriptions. The researcher first thought about words to describe the chair design that was imagined. Then typed a direct message in the bot: /imagine plastic chair, wood joints, white, oak legs, art nouveau, octane render, high quality, ultra-realism, 12k, 300 pixels, aspect ratio. In a few seconds, the bot then returns an image with four alternative designs (fig .4), which have never been seen before and were not expected.

Fig .4 shows the image returns from the bot with four alternative furniture designs in my experiment in Midjourney. By the author

Then two rows of buttons appeared: In the top row, the U1 button was chosen to upscale and generate additional details for the first design (up left one) (fig.5). In the bottom row, the V2 button was chosen to create variations for the second design (upright one) to generate four new images, similar to the original design (fig.6).

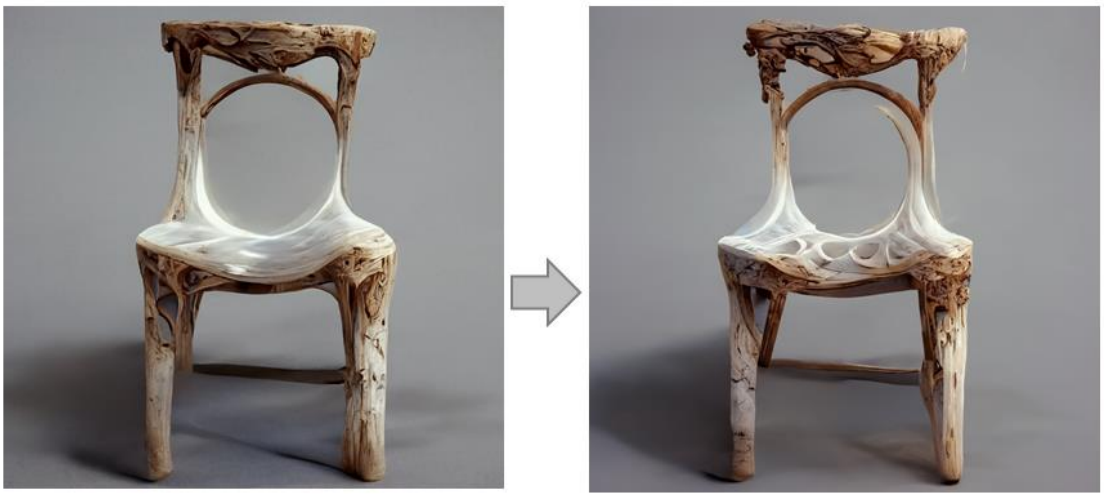


Fig.5 shows the chair design after choosing the U1 button to upscale and generate additional details for the first design. By the author.


Fig .6 shows the chosen chair design from the four resulting designs after choosing the V1 button. By the author.

**3.2 Furniture Layout**

Planning and organizing layouts are the most important interior design stages as all the next steps are based on them. This work can be difficult and time-consuming. The layout must adhere to ergonomic rules, in addition to aesthetics that a user can simply evaluate. The many possible placements, orientations, and combinations of objects that the end user might want to place in the potential space make it more difficult to strike a balance between an interior space. It complies with ergonomic, stylistic rules, and guidelines to fulfill the client's preferences. planning a new space or redesigning an existing one talks much-repeated effort until one reaches the perfect layout for the user and the designer. Therefore, the designer needs to zone the space functionality, select objects that should be laid out, and identify the design relationships between furniture pieces to achieve the best final layout. It has come more complicated when accessibility, visibility, ventilation, and illumination are being taken into consideration. Moreover, the designer needs to present many solutions to meet the user's needs and thoughts. Otherwise, AI technology can help to generate a layout for furniture arrangement within different spaces automatically. By using the power of computation to explore wide design space and identify the best design options. The designer needs only to work closely with the stakeholders and gather unique and critical data about the project. Then transform these data into design constraints

for furniture layout arrangement. This can inform the generative model to perform layouts that provide the highest levels of comfort and usability for users and discover new unexpected results. This ability would generate numerous alternative designs; which the users can compare to select the design they prefer. It helps users to reach more qualified furniture plans than those manually produced by designers. For example, Kan and Kaufmann (2017) used a Markov chain Monte Carlo algorithm as a novel method to select and place the furniture into the room in an iterative way and fully automatically. This optimization process optimizes work on generating furniture configurations according to determinants of functionality and aesthetics. A genetic algorithm is used to optimize multiple dimensions simultaneously to make it applicable in several interiors. This method requires professional programming qualifications to inter the parameters and relationships of the furniture defined by the designer. The genetic algorithm in this experiment provides an effective tool for interior designers and users to obtain many successful arrangements of furniture inside interiors, choose the best furniture plan and save time and effort.

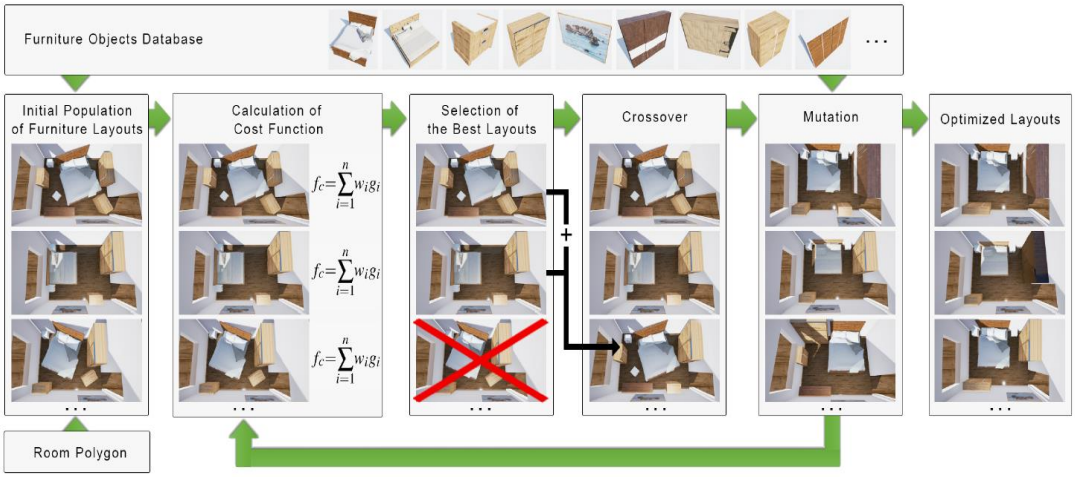


Fig .7 Peter Kan and Hannes Kaufmann experiment in generating bedroom layout. adapted from (Kan and Kaufmann .2017)

In the 2020s, many researchers are studying various approaches, that applied AI to the structuring and designing of furniture layouts. They aim to create opportunities to take advantage of AI applications and develop creative layout concepts (table.1).

Table 1 Furniture layout studies involving artificial intelligence

| Authors | Used Approach | Identify Algorithm by ( method of machine learning ) | design constraints | 2D or 3D /Room type |
|---|---|---|---|---|
| Fu et al (2020) | presented a novel approach called Human-Centric Metrics (HCMs) to well-design indoor layouts according to human-environment factors. | performing statistic models that learned from a floor plan database to evaluate space, then give assessment scores to synthesize plausible indoor scenes. | accessibility, visibility, ventilation, and illumination | 3D/Bedroom, living room, dining room, conference room, and office room. |
| Zhang et al (2021) | presented a data-driven layout framework to adjust relations among three or more objects. | using a non-learning geometric algorithm. | objects should be inside a room, without overlapping, and clear paths should exist for windows and doors. | 3D/Bedroom, Living Room, dining room. |
| Miao et al (2021) | Used an encoder to input the scene information ( windows, walls, doors) and employ a generator to decode the scene layout from the sampled Gaussian noise for conditional new scene generation. | Using a large-scale indoor scene dataset to embed the unstructured furniture into the graph neural network structure to learn the distribution of scene layout. then incorporated the graph into a conditional variational autoencoder. | number of furniture pieces, Placement rules, furniture size, Instance labels of the bounding box and Instance labels for furniture with the same partition size and semantic label | 2D / Bedroom. |
| Sydora and Stroulia (2020) | Used a domain-specific language for interior design rules which evaluated against a BIM model. | Transforming natural language rule to rule language by Subset of the IFC class type hierarchy. | BIM model of a space, a set of objects that should be placed in the space, and a set of design rules. | 3D/ Kitchen and living room |
| Li et al (2020) | presented optimization to obtain the best synthesis scene with the smallest energy functions and proposed 3D gestures to enhance the users' interest in | Using a multi-objective particle swarm optimization algorithm (MOPSO) with the Pareto principle and the adaptive grid method. | five objective energy functions, namely, overlap, pairwise, wall, aisle, and angle. And aesthetic criterion and movement criterion | 3D/ bedroom and living room |

| Authors | Used Approach | Identify Algorithm by ( method of machine learning ) | design constraints | 2D or 3D /Room type |
|---|---|---|---|---|
| | the furniture locations. | | | |
| Yang et al (2021) | designed a data-driven approach layout scheme by dividing rooms into functional areas with furniture according to user preference. | Using conditional generative adversarial networks (CGAN) to train a fully connected network model to place furniture in the functional area. | user-specified furniture, improve the furniture vector, objective function, and training process | 2D,3D/ different areas in the apartment. |
| Arroyo et al (2021) | A novel generative model uses self-attention to model many-to-many relationships between a large number of elements in a layout. which relies solely on bounding box annotations | Using variational autoencoder (VAE) to capture high-level relationships between elements in layouts. | margins, alignments, the correlation between elements, and other global design rules | 3D/ different spaces |
| Zheng and Ren (2020) | developed a specific machine learning neural network to learn and predict design drawings as vectorized data | Optimizing the neural network and data structure through design rule prediction model and generation model based on human-made design data | bedroom boundary, door, and window, | 2D/ bedroom |

### 3.3 Improve the design efficiency

One of the most complex design stages for furniture design is topology optimization (TO). The furniture designers do many experiments, measurements, and evaluations on prototypes to reach the suitable design topology. Topology optimization is a mathematical method to optimize material for a particular combination of loads, boundary conditions, and restrictions. This process takes a lot of effort and time to be done, but with the help of AI technology, it became easier and quicker. There are 3D simulation software that are similar to the generative design that is used for topology optimization such as Ansys Discovery and n Topology. Other software types are used to enable a collaborative workflow between designers and engineers for conventional or additive manufacturing as occurs in CATIA. It enables non-specialist designers the ability to automatically create optimized conceptual pieces from functional specifications.

Topology optimization aims to maximize design performance. This leads to changes in form and size inside the design space. For example, In France in 2004, the EZCT Architecture & Design Research company collaborated with “Marc Schoenauer” who is a French mathematician and computer scientist to mechanize the design process. They worked on a fully automated project called CCD “Computational Chair Design” (fig.8) in which a genetic algorithm is used to evolve a volume by analyzing the forces inflicted upon the chair. The model was programmed in terms of stability, static load, and maximal deformations allowed. Marc Schoenauer based on “Voronoi” diagrams to harmonize between the genotype representation and the phenotype of the real chairs (Feringa .2008).

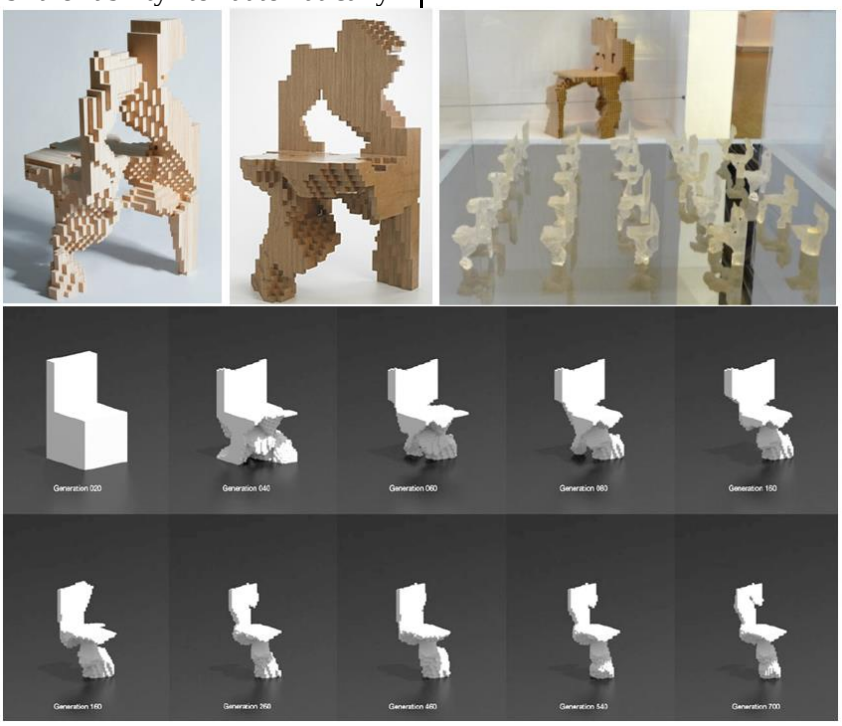

Fig.8 The manufactured chair test number 1-860 and other generations such as 1-20, 1-40, t 1-60, 1-160, 1-260, 1-460, 1-540, 1-600.adapted from (Feringa .2008)

## 5. The role of the furniture designer inside AI systems:

A lot of challenges fall on designers to cope with these sequence changes. Furniture designers will start to transition from human-intensive to AI-centric innovation systems. This required designers to gain new skills out of their experience field. Such as the ability to make design problem-solving loops and conceive design rules to formulate algorithms will be essential for setting up appropriate software through cooperating with AI experts (fig.9). Knowing the methods to learn machines and deal with data infrastructure to deliver improved solutions to a user.

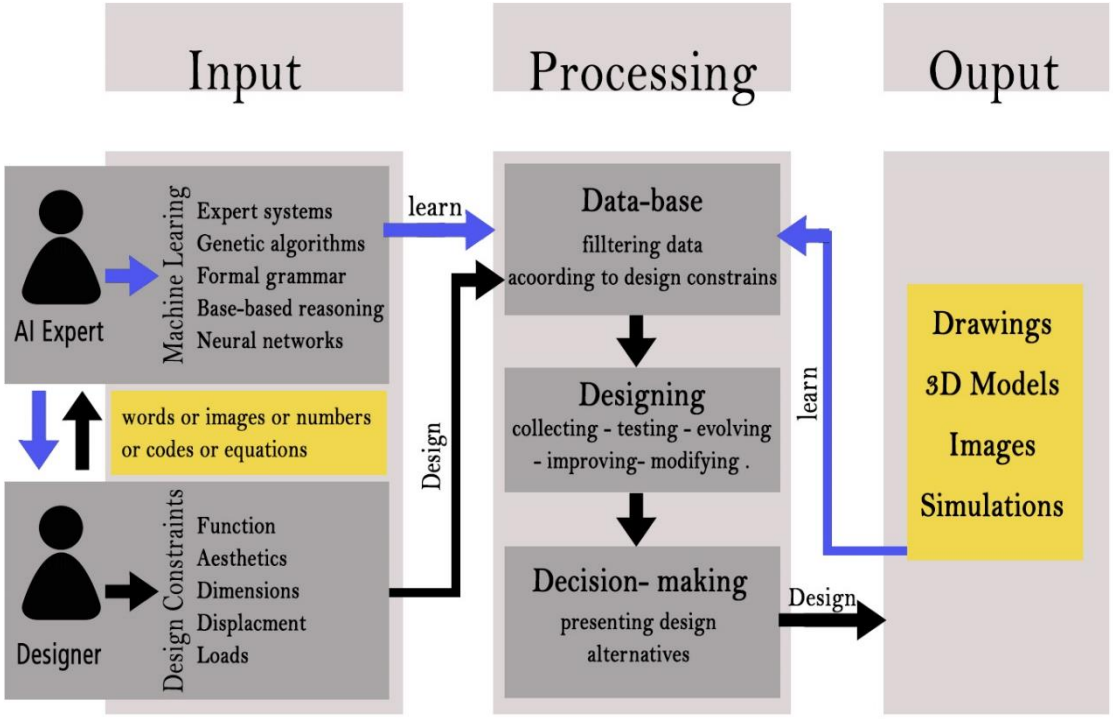


Fig.9 shows the role of the furniture designer inside AI systems for the design process. which draws a model starting from the input, passing by the process, and ending with the output. by the author

## 5. SWOT Analysis

After presenting developed AI techniques that are used in furniture design. This section presents and justifies a SWOT Analysis to extract results from the previous AI applications in the furniture design process. The SWOT analysis is used because it is a simple and powerful tool used in multiple prior research studies for situation analysis (Gurel and Tat .2017). It is used in this research study to identify the most important criteria that could be effective when AI technologies are applied in the furniture design process. This analysis is used to achieve the research aim to help furniture designers to evaluate the ability to use AI technologies, to form a strategy for their future work to grow and succeed during the AI era. It presents the strengths, weaknesses, opportunities, and threats involved in the design process. To make it becomes easier to figure out a strategy or direction to take when it comes to designing.

Table 2 shows the SWOT analysis for using AI technologies in the furniture design process, it clarifies the strengths, weaknesses, opportunities, and threats. by the author

| Strengths (advantages) | Weaknesses(Limitations) |
|---|---|
| • AI technology applications in the furniture design field are considered a leap that helps designers to save time and expand possibilities.<br>• **Saves human resources.:** In the process of its creation and self-improvement, it can realize the automatic configuration and adjustment of parameters without too much intervention from staff.<br>• **Get concept easily:** AI technology provides methods such as mid-journey that can help furniture designers to get and clear the | • **Difficult learning:** Unfortunately, AI needs a large number of samples to achieve learning. Also, furniture designers couldn't program AI systems, they need technicians and specialists.<br>• **Limited integrated:** Some generative design software does not integrate with the existing CAD or CAE platform.<br>• **Need human skills**: Although the great achievements of Ai technology in furniture design, it is not enough to rely on it without human participation. AI was unable to collaborate directly with the project's |

design concept and generate initial ideas easily and quickly.

- **Provide Data:** Also, it provides a huge database that contains many design solutions according to specific design criteria. This would save the furniture designers time in collecting similar design cases related to the project they work on.
- The great ability of AI technology to design and model thousands or millions of furniture designs based on the guidelines that designers have established.
- Furthermore, it can differentiate between the generated designs and choose the better one to approve or redesign in its direction. As a result, it could generate unexpected design mutations.
- **Improve Design:** With the help of some AI systems, designers can locate more sustainable materials and give priority to characteristics like light weighting, part consolidation, and material investigation.
- **Manage Cost:** The AI software also features a cost comparison to uncover part designs that would be expensive to manufacture.

stakeholders and collect specific and vital data, it is human skills.

- **Unreliable :**Cannot be fully implemented in the whole design process.
- **Complexity in manufacturing**: In some instances, linking design with artificial intelligence broke any design boundaries and created complex designs. Some of these designs are impossible to make with traditional manufacturing methods. As The manufacturing limitations are restricting their production of them. Instead, they're built using developed additive manufacturing methods that turn complicated configurations into real products and need specific materials for production. But additive manufacturing required high costs that will be a burden in the final furniture piece price.
- **Unexpected designs**: In some cases, the designer is surprised by the generated design that could be far from the original designer's imagination. That could cause dispersion.

| Opportunities | Threats |
|---|---|
| • In the AI world, furniture designers' work will be a joy and play fun.<br>• Furniture designers will easily interact with users and make them a part of the design process. There will be new connections made between customers and the product. These exchanges will only be the start of a continuing dialogue between businesses and consumers.<br>• AI will be a professional tool to design furniture in VR, AR, and MR environments.<br>• AI will be an essential tool for designing the coming metaverse environments furniture is an important part of it. | • Artificial intelligence can replace the designer role in many design stages. The role of the designer is receding in the design and creative process, as the artificial intelligence system may outperform the designer's mindset. That can cause reliance on artificial intelligence and a lack of design practice.<br>• The designers may lose their identity when using the same AI techniques.<br>• AI could replace a big slice of workers in the furniture design sector such as designers, model makers, analyzers, and executive engineers with few AI experts.<br>• A huge gap will occur in the furniture design sector between the developed countries and companies that have qualifications and the ability to input AI systems in the furniture design process that developed countries don't. |

## 6. The survey study

The survey questionnaire was developed and analyzed online via Google Documents. The online link was sent to many specialists in furniture design. The survey aims to collect their opinions on the impact of AI technology in furniture design. The previous SWOT analysis was used in the survey to measure the role of AI in the development of furniture design. Table 3 shows the questions, the answers available, and the objective of the question. The number of designers who responded to the questionnaire was 47 responses.

Table 3 shows the questions of the survey and the available answers.

| | Questions | The methods of answers and answers | The objective |
|---|---|---|---|
| 1 | What are the Strengths (advantages) of | multiple choices:<br>• Save time and expand possibilities.<br>• **Saves Human Resources**: Provide repetitive | Measure the percentages of the designer's agreement |

| | | | |
|---|---|---|---|
| | applying AI techniques to furniture design? (you can choose more than one answer) | effort in standard operations and modifications during the design process.<br>• Generate initial ideas easily and quickly.<br>• **Data Mining**: Provides a huge database that contains many design solutions according to specific design criteria.<br>• **Fluency in Design**: Model thousands or millions of innovative furniture designs.<br>• **Election:** Differentiate between the generated designs and choose the better one.<br>• **Optimization**: Improve furniture designs' physical and mechanical properties before implementing them, such as lightweight and durability.<br>• **Manage Costs**: develop alternatives to the used materials and quantities | with the Strengths. |
| 2 | What are the other Strengths? | Text box | Collect other views about Strengths. |
| 3 | What are the Weaknesses(Limitations) of applying AI techniques to furniture design?<br><br>( you can choose more than one answer) | •**Learning difficulty**: Furniture designers can't program AI systems, they need technicians and specialists.<br>•**Unsupported Software**: Some generative design software does not integrate with the existing CAD or CAE platform.<br>•**Need human skills**: it is not enough to rely on it without human participation.<br>•**Unreliable** :Cannot be fully implemented in the entire design process.<br>•**Design Complexity**: Sometimes complex designs are produced that require innovative manufacturing methods or expensive raw materials.<br>• **Unexpected designs**: In some cases, the designer is surprised by the generated design far from the original designer's imagination. That could cause dispersion. | Measure the percentages of the designer's agreement with the Weaknesses. |
| 4 | What are the other Weaknesses? | Text box | Collect other views about Weaknesses. |
| 5 | What are the opportunities provided by the application of AI techniques in furniture design?<br><br>( you can choose more than one answer) | • **Design Joy**: furniture designers' work will be a joy and play fun.<br>• **Design Exchanges**: Furniture designers will easily interact with users and make them a part of the design process.<br>• **Professional Design Tool**: AI will be a professional tool to design furniture in VR, AR, and MR environments.<br>• **Metaverse Design**: AI will be an essential tool for designing the coming metaverse environments furniture is an important part of it. | Measure the percentages of the designer's agreement with the opportunities. |
| 6 | What are the other opportunities? | Text box | Collect other views about opportunities. |
| 7 | What are the Threats that face the application of AI | • **Lack of design practice:** AI can replace the role of the designer in many stages of design. This can cause dependency on AI. | Measure the percentages of the designer's agreement |

| | | | |
|---|---|---|---|
| | techniques in furniture design?<br><br>( you can choose more than one answer) | • **Lose identity:** The designers may lose their identity when using the same AI techniques.<br>• **Replace humans:** AI could replace a big slice of workers in the furniture design sector such as designers, model makers, analyzers, and executive engineers.<br>• **Qualifications gap**: A huge gap will occur between developed countries and companies that use AI systems in the furniture design process that developed countries don't. | with the Threats. |
| 8 | What are the other Threats? | Text box | Collect other views about Threats. |

## 7. Analyzing the survey responses:

According to the Analysis of survey responses, the application of AI technology has a great role in the development of the furniture design process. The first question was asked about strengths, and the results in fig10 showed that using AI accelerates the furniture design process with low effort. Almost (78.7%) of participant designers choose the answer: save time and expand possibilities, and (74.5%) choose the answer: save human resources by providing repetitive effort in standard operations and modifications during the design process. AI is effective in the concept design stage; as almost (89.4%) of participant designers assure that AI can generate initial ideas easily and quickly. AI is effective too in the design creation stage, (66%) of the participant designers see that AI Provides a huge database -data mining- that contains many design solutions according to specific design criteria, and (66%) see that AI has fluency in design it can model thousands or millions of innovative furniture designs. As for participant designers' opinions, AI is also effective in the design modification and selection stage. Almost (70.2%) of participant designers choose the answer: election by differentiating between the generated designs and choosing the better one. The lowest percentages were for the optimization design stage; (40.4%) for Improving furniture designs' physical and mechanical properties, and (42.6%) for developing alternatives to the used materials and quantities.

Some of the participant designers wrote down answers for other strengths in the second question as shown in the following points:

- Increase creativity in furniture design.
- Add unusual vision in furniture design.
- Provide a digital bank for helpful ideas.
- Mix design variables to create new designs from the same design constraints.
- Allow the furniture design to cope with the technology innovation.
- Avoid unsuccessful Attempts during the design process.
- Redesign the existing furniture pieces.

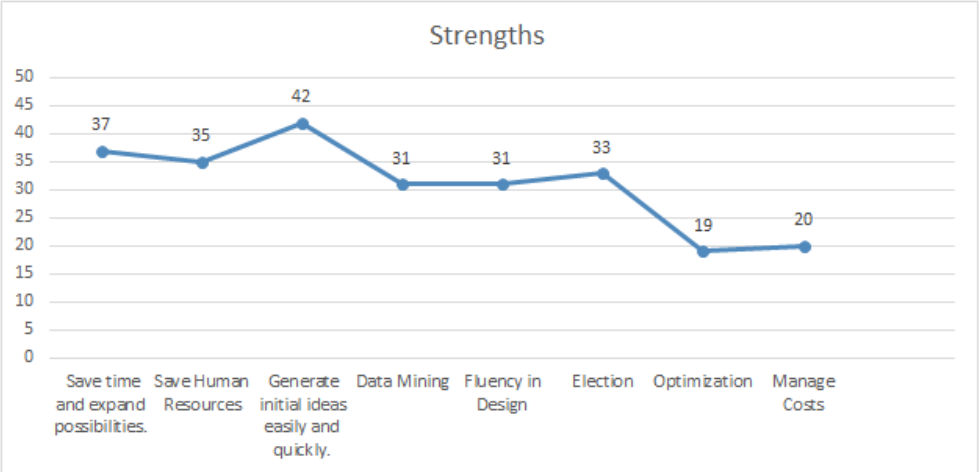


Fig.10 shows the responses for Q1 about the strengths of applying AI techniques to furniture design

The third question was about weaknesses, and the results in fig11 showed that using AI in furniture design has some disadvantages. The participant designers found that using AI required advanced technical skills from the furniture designer. Almost (48.9%) of them choose the answer learning difficulty: furniture designers can't program AI systems, they need technicians and specialists, and (48.9%) choose the answer unsupported Software: Some generative design software does not integrate with the existing CAD or CAE platform. Using AI in the design process is not entirely dependable.

Almost (87.2%) of participant designers choose the answer AI needs human skills: it is not enough to rely on it without human participation, and (66%) choose the answer AI is unreliable and cannot be fully implemented in the entire design process. There are some problems with the resulting furniture designs. Almost (74.5%) of participant designers choose the answer design complexity: sometimes complex designs are produced that require innovative manufacturing methods or expensive raw materials, and (55.3%) choose the answer unexpected designs: In some cases, the designer is surprised by the generated design far from the original designer's imagination. That could cause dispersion.

Some of the participant designers wrote down answers for other weaknesses in the next question as shown in the following points:

- Create un-logical furniture designs that cannot be executed.
- Reduce the furniture designer's role and creativity, and maybe it will disappear over time.
- Reduce the skills of students if they only depend on using AI in the education process.
- Need to input many parameters and design constraints.
- Can be reliable only in generating preliminary ideas.
- Some of the AI software such as mid-journey produce un accurate designs: just present 2d designs without 3d modeling and dimension.
- Allow non-specialists to enter the field of work.
- Loss of intellectual property rights for the furniture designers.

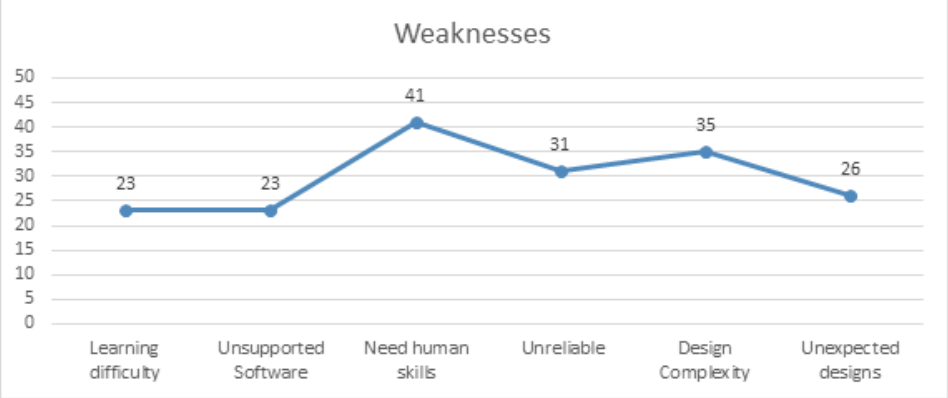


Fig.11 shows the responses for Q3 about the weaknesses of applying AI techniques to furniture design.

The fifth question was about opportunities, and the results in fig12 showed that using AI in furniture design has promising prospects in furniture design. The participant designers see that AI would be an interesting futuristic tool for enhancing interactive design processes. Almost (68.1%) of participant designers choose the answer design joy: furniture designers' work will be a joy and play fun. (72.3%) choose the answer design exchanges: furniture designers will easily interact with users and make them a part of the design process. AI has high-performance techniques that allow designing in virtual environments easily. Almost (72.3%) of participant designers choose the answer professional design tool: AI will be a professional tool to design furniture in VR, AR, and MR environments, and (68.1%) choose metaverse design: AI will be an essential tool for designing the coming metaverse environments furniture is an important part of it.

Some of the participant designers wrote down answers for other opportunities in the next question as shown in the following points:

- AI will cope with new furniture design trends.
- AI will Provide an attractive visualization for furniture designs.
- AI will open new marketing channels for furniture designs.
- AI will innovate furniture design mobile applications.
- AI will enhance the education process for furniture design by expanding the perceptions of beginner designers.

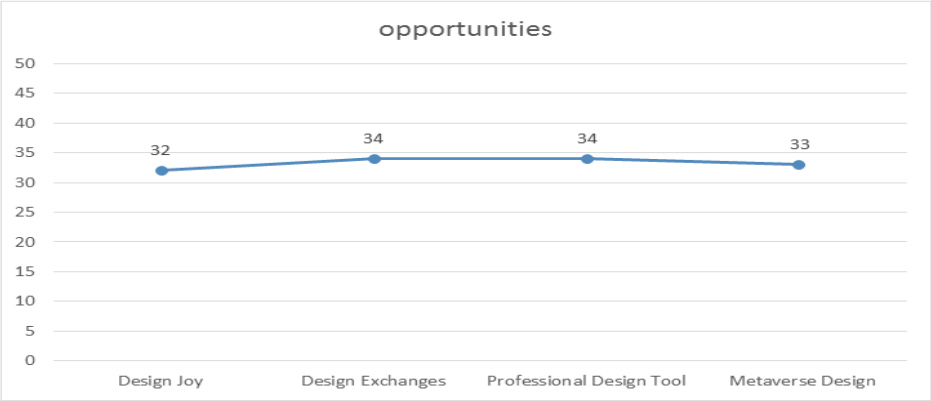


Fig.12 shows the responses for Q5 about the opportunities provided by the application of AI techniques in furniture design.

The seventh question was about threats, and the results in fig13 showed that using AI in furniture design has promising prospects in furniture design. The participant designers see that AI would have a bad effect on furniture designers. Almost (57.4%) of participant designers choose the answer lack of design practice: AI can replace the role of the designer in many stages of design. This can cause dependency on AI, (78.7%) choose the answer: lose identity: The designers may lose their identity when using the same AI techniques. There is an opinion difference among participant designers, almost (55.3%) choose the answer: replace humans: AI could replace a big slice of workers in the furniture design sector such as designers, model makers, analyzers, and executive engineers. The furniture design competition in the international situation will be in critical condition. About (68.1%) of participant designers choose the answer qualifications gap: A huge gap will occur between developed countries and companies that use AI systems in the furniture design process that developed countries don't.

Some of the participant designers wrote down answers for other threats in the next question as shown in the following points:

- Furniture designers will be addicted to using AI, which could affect their natural creativity.
- AI use will be limited to designers who have AI skills or cooperate with AI experts.
- AI could not spread widely due to the expensive price of its techniques and tools, it will be an added value over the design cost.
- Promote the idea that AI could replace humans.

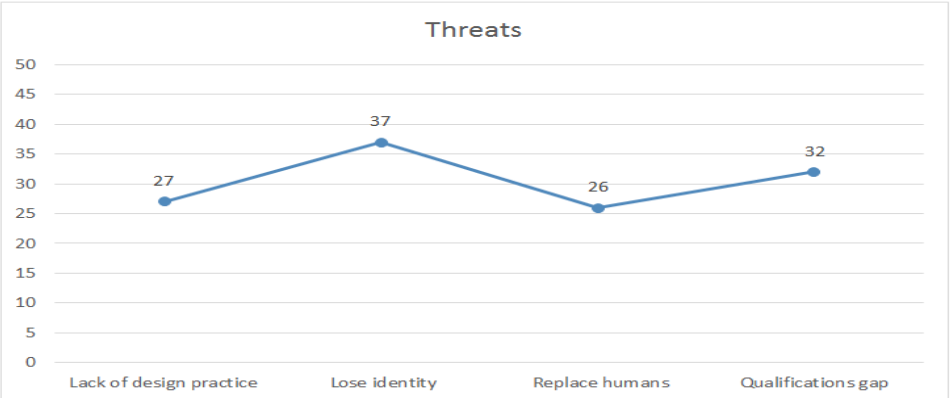


Fig.13 shows the responses for Q7 about the threats that face the application of AI techniques in furniture design.

The SWOT Analysis and the survey analyses provide a framework for AI that helps furniture designers to focus on minimizing weaknesses and taking the greatest possible advantage of opportunities available.

## Results:

1- AI offers the furniture design process great capabilities such as analyzing data, generative designs, modifying models, arranging furniture layouts, optimizing structures, and decision-making.

2- AI is an enhancing design tool or collaborative assistance, especially in complex design tasks.

3- Furniture designers need to gain new skills such as making design problem-solving loops, conceiving design rules to formulate algorithms, identifying the methods to learn machines, and dealing with data infrastructure

4- Furniture designers who participated in the survey see that the strengths of applying AI technology to furniture design are:

- **The highest percentages of responses were:** save time and expanding possibilities, save human resources, generate initial ideas easily and quickly, provide a huge database -data mining, model thousands or millions of innovative furniture designs, and differentiate between the generated designs and choosing the better one. The lowest percentages were: improve furniture designs' physical and mechanical properties and develop alternatives to the used materials and quantities.
- Some of the participant designers wrote down other strengths such as increasing creativity, adding unusual vision in furniture design, providing a digital bank for helpful ideas., mixing design variables to create new designs from the same design constraints, allowing the furniture design to cope with the technology innovation, avoiding unsuccessful Attempts during the design process, and redesign the existing furniture pieces.

5- Furniture designers who participated in the survey see that the weaknesses of applying AI technology to furniture design are:
- **The highest percentages** of responses were: learning difficulty, unsupported Software, need human skills, unreliable, and design complexity. The lowest percentages were: unexpected designs.
- Some of the participant designers wrote down other weaknesses such as Creating un-logical furniture designs that cannot be executed, reducing the furniture designer's role and creativity, and maybe will disappear over time, reducing the skills of students if they only depend on using AI in the education process, need to input many parameters and design constraints, and reliable only in generating preliminary ideas.

6- Furniture designers who participated in the survey see that the opportunities for applying AI technology to furniture design are:
- The same highest percentages of responses were: making design joy, and design in VR, AR, and MR environments professionally. The same lowest percentages were: design exchanges, and design in metaverse design professionally.
- Some of the participant designers wrote down other opportunities such as coping with new furniture design trends, providing an attractive visualization for furniture designs, opening new marketing channels for furniture designs, innovating furniture design mobile applications, and enhancing the education process for furniture design by expanding the perceptions of beginner designers.

7- Furniture designers who participated in the survey see that the threats of applying AI technology to furniture design are:
- The highest percentages of responses were: lack of design practice, loss of identity, and qualifications gap. The lowest percentage was: replace humans.
- Some of the participant designers wrote down other threats such as Furniture designers will be addicted to using AI, which could affect their natural creativity.AI use will be limited to designers who have AI skills or cooperate with AI experts.AI could not spread widely due to the expensive price of its techniques and tools, it will be an added value over the design cost. Promote the idea that AI could replace humans.

## Recommendations:

1- Furniture designers should face the challenges that fall on them to cope with AI technology and make use of its advantages.
2- Scientists and researchers should work on innovating new manufacturing methods and innovative materials suitable for executing upcoming AI furniture designs.
3- It is necessary to integrate the study of AI systems, machine learning approaches, and their applications in applied arts colleges.
4- Developed countries should concern with the new AI technology and establish a clear path to deal with this technological growth.

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