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Evolution of AI role in architectural design: between parametric exploration and machine hallucination

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Abstract

The integration of Artificial Intelligence (AI) into architectural design has revolutionized the building industry. AI offers a wide range of algorithmic approaches that can be used to explore abstract conceptual designs and generate an unlimited number of design ideas based on mathematically defined parameters. This paper provides an exploratory study that critically reviews the evolution of AI in architectural design. The study highlights the potentials, limitations, and future vision of this technology within the context of architectural design. AI has transitioned from a tool for functional optimization to an unprecedented resource for design inspiration based on machine intelligence. However, the authors emphasize the importance of a balanced approach that ensures AI-generated designs are human-centric, environmentally responsible, and culturally sensitive. The study concludes that AI has the potential to inspire and enhance architectural design but must be used ethically and responsibly to avoid negative impacts on human creativity and design ethics.

Keywords: Conceptual design, Architecture, Artificial Intelligence, Image Generation.

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1. Finding the perfect balance: Aesthetics and functionality in architectural design

To reconcile the tension between aesthetics and function in architectural design, architects should consider the needs and preferences of the building's users and the broader cultural, historical, and environmental context in which the building will be located. This includes considering the existing architectural styles and cultural norms of the area, as well as the unique physical characteristics of the site. For example, a building designed to be a school should have aesthetic features that enhance the learning environment, such as natural light and open spaces, while also providing necessary functional features like classrooms and offices. By considering these factors, architects can design buildings that are aesthetically pleasing and functional, while also being sensitive to their surroundings and context.

A fine example of architecture that embodies both aesthetics and function can be found in the Sydney Opera House in Sydney, Australia (Fig. 1). Designed by Danish architect Jørn Utzon and completed in 1973, the Sydney Opera House is a world-renowned cultural icon and one of the most recognizable buildings in the world. The Sydney Opera House is an excellent example of how aesthetics and function can be combined in a single architectural design. The building's distinctive sail-like shape is aesthetically striking, and its iconic silhouette has become a symbol of Sydney and Australia. At the same time, the building is highly functional, providing a state-of-the-art performing arts venue with multiple theaters, rehearsal spaces, and other facilities.


Fig. 1 Sydney Opera House, reflecting a fine set of design aesthetics in order, shapes, and rhythms, while on the other hand offer a highly function spaces and a sound structural system. [1]

2. Digital technology and AI in architecture: The future of conceptual design

2.1. Impact of digital technology on the conceptual design phase in architecture

One of the early examples of utilizing digital technology to serve the architectural design imagination was in Frank Gehry’s design for the Guggenheim Bilbao Museum. The building's distinctive curved surfaces and flowing lines are a signature feature of Gehry's architecture, and they posed a significant challenge for traditional architectural design methods. To overcome this challenge, Gehry turned to digital technology. He used a computer-aided design (CAD) program called CATIA, which was originally developed for the aerospace industry to design fighter jets. Using CATIA, Gehry was able to visualize and materialize the complex curved surfaces of his design, creating a 3D model that could be used to guide the construction of the building (Fig. 2). The steel frame for the Guggenheim Bilbao Museum is composed of hundreds of individual steel members, each of which was designed using CATIA, which allowed to precisely control the shape, size, and location of each member, ensuring that the frame well before the construction process. This early adoption of digital technology allowed Gehry to achieve his ambitious design for the Guggenheim Bilbao Museum, pushing the boundaries of architectural design and creating a truly iconic building.

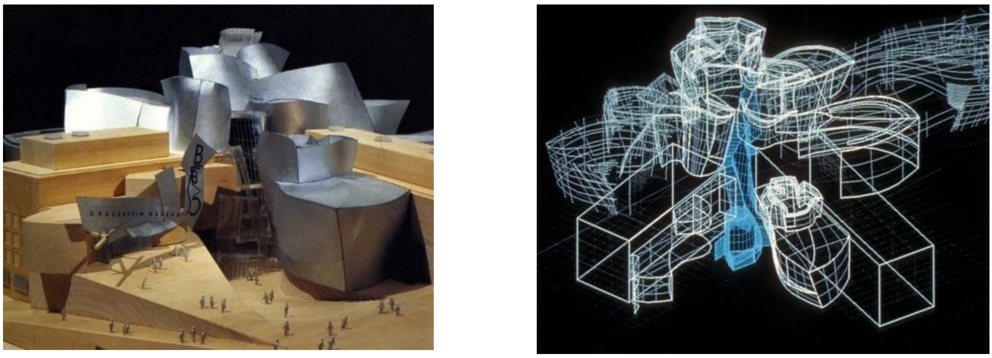

Fig. 2 (Left) The free-form scale model of Guggenheim Bilbao Museum. (Right) Vector representation of the museum’s form in CATIA. [2]

3. The historical evolution of AI in architecture: From modularity to machine learning

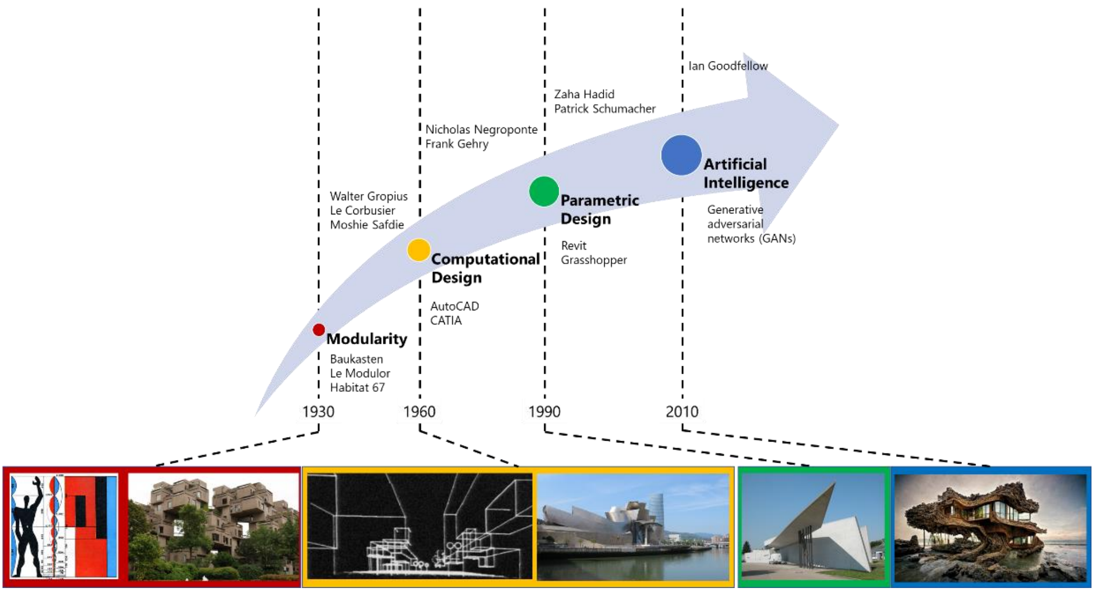

Fig. 3 Evolution of AI predecessors in impacting architectural theories and practices. Images from left to right: Le Modulor concept by Le Corbusier [3], Habitat 67 by Moshie Safdie [4],

URBAN 5 by Negroponte [5], Guggenheim Museum Bilbao Museum by Frank Gehry [6], Vitra Fire Station by Zaha Hadid [7], and GAN generated architecture by Midjourney [8]. Illustration by authors based on a historical analysis by [9].

According to Chaillou [9], the application of AI into the architectural realm didn't happen as a sudden disruption, but rather as a natural progression and accumulation of preceding concepts that used related technologies. This historical evolution of using AI in architecture can be divided into four main steps: modularity, computational design, parametric design, and AI (Fig. 3). Modularity involves using standardized, interchangeable parts in design to allow for flexibility and adaptability in construction. Computational design uses computers to assist in the design process, allowing for more precise and complex designs. Parametric design uses algorithms and variables to generate design options based on specific criteria. AI takes these concepts even further by using advanced machine learning algorithms to assist in the design process and create even more complex and optimized designs.

3.1. Modularity

Modularity in architecture is often linked to the concept of using prefabricated units or repeating elements that can be assembled to form buildings in a flexible, evolutionary way. This approach gained popularity in the modernist movement, with famous architects such as Le Corbusier espousing the idea that "a house is a machine for living" and advocating for the use of standardized, modular units in construction. However, the concept of modularity in its essence is much older than this modernist approach. When approached through the context of rhythm, harmony, order, and repetition, it can be found deeply embedded in classical architecture, such as that of the Greek, Roman, and ancient Egyptian cultures. These styles emphasized the aesthetic and functional value of modularity through the use of architectural orders, such as columns and other elements, to create a sense of unity and harmony in the design. Modularity, whether approached through the use of prefabricated units or through the repetition of formal elements, has been an important principle in architecture throughout history (Fig. 4).

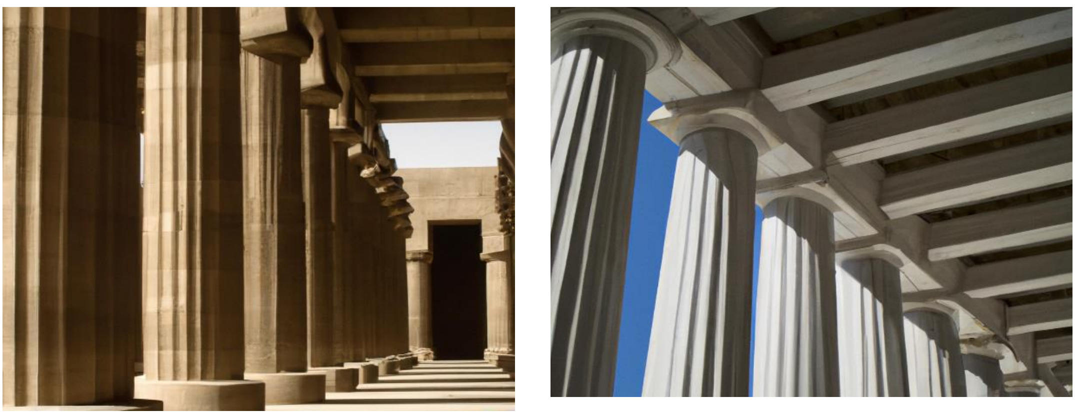

Fig. 4 Examples of modularity features in ancient Egyptian and Greek architectural styles.

Modularity was popularized by Walter Gropius for the Bauhaus in 1920 and focused on the idea of technical simplicity and affordability in architecture. This concept was further developed by Le Corbusier, who applied the principles of modularity to the human scale with his "Modulor" system. Modularity also evolved to include building systems within the module, as exemplified by Buckminster Fueller's Dymaxion House (Fig. 5). A notable example of modulariry in city planning was the “Plugin City” concept, which is a project by the British architectural group Archigram that explores the idea of modular, adaptable cities that can be easily added to or removed from an existing urban environment. The project envisions a three-dimensional structural matrix that can accommodate a variety of modular units, including housing, office, and public spaces. These units can be assembled and disassembled as needed to accommodate changes in population or urban growth. The idea behind Plugin City is to create a more flexible and adaptable approach to urban planning, allowing cities to evolve and grow in response to changing needs and conditions (Fig. 6).

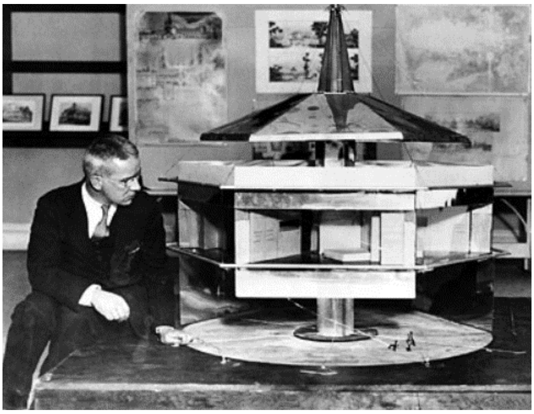

Fig. 5 Buckminster Fueller's Dymaxion House. [10]

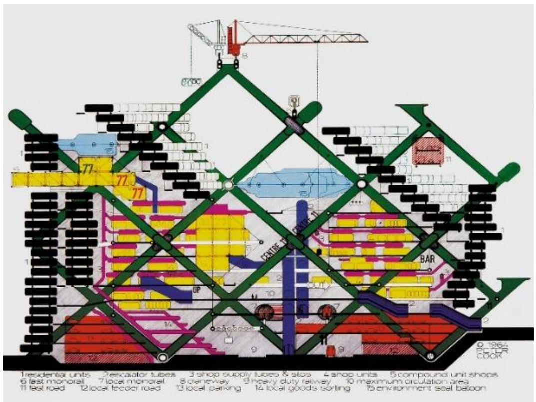

Fig. 6 “Plugin City” concept by Archigram group. [11]

3.2. Computational design

Nicholas Negroponte was a pioneer of computational design in architecture. He was the founder and leader of the Architecture Machine Group (AMG) at MIT, where he and his team worked on investigating the potential of machines to enhance the creative process in architectural production. The group's projects, including URBAN II and URBAN V, demonstrated the value of computation in architecture and paved the way for the widespread adoption of 3D design software in the field [5]. Furthermore, Frank Gehry was a particularly vocal advocate for the use of computation in architecture. He founded Gehry Technologies, where he used early CAD-CAM software to tackle complex geometric problems, setting a precedent for the use of computational design in architecture.

Fig. 7 An aerial view for Frei Otto's Munich Olympic Stadium. [12]

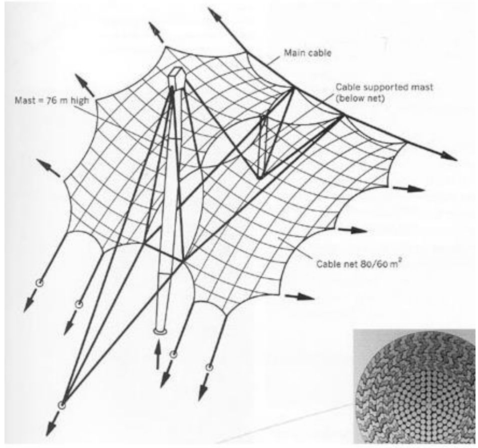

Fig. 8 An orthographical view for a section of the tensile structure. [13]

Frei Otto was another architect and engineer who was known for his use of computational design to create innovative and unique architectural forms. In particular, he was known for his work with tensile structures, such as the roof of the Munich Olympic Stadium (Fig. 7). Frei Otto used computer simulations to design the roof of the Munich Olympic Stadium. To create the complex and efficient form of the roof, it was necessary to calculate the exact geometry using specialized computer programs. These programs were developed by Professors K. Linkwitz and JH Argyris specifically for this purpose and were used to determine the optimal form and material distribution for the roof (Fig. 8) [13].

3.3. Parametric design

Parametricism is an approach to architectural design that uses computational algorithms to create dynamic and responsive forms. It was introduced by architect Patrick Schumacher, who believes it represents the next step in the evolution of architecture. Famous architects who have used Parametricism in their work include Zaha Hadid, Daniel Libeskind, and Rem Koolhaas. Examples of Parametricism in architecture include Zaha Hadid's design for the Guangzhou Opera House in China (Fig. 9), which features interlocking panels that move in response to changes in the environment, and Rem Koolhaas's design for the CCTV Headquarters in Beijing, which has an innovative and highly functional form created using computational design techniques (Fig. 10).

Fig. 9 Guangzhou Opera House in China. [14]

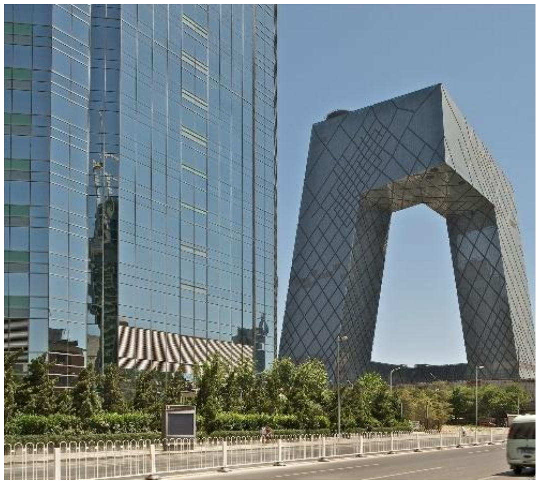

Fig. 10 CCTV Headquarters in Beijing. [15]

3.4. Artificial Intelligence

AI in the context of machine learning refers to the ability of a computer or machine to simulate human cognitive abilities such as learning and problem-solving through the use of algorithms and statistical models. This allows the machine to learn from data and improve its performance over time, without explicit programming. Machine learning is a key component of modern AI and has been applied in various fields, including natural language processing, image and speech recognition, and decision making. In architecture, AI can be used to assist in the design process by analyzing design data and suggesting solutions or variations based on statistical distributions of that information. Potential applications of AI in architecture include generating initial design concepts, optimizing design layouts, predicting building performance, analyzing the effects of design decisions on energy efficiency or occupant comfort, and generating building simulations or visualizations.

An example of using AI objectively in architectural design could be found in the study conducted by As et al. [16], where they presented a deep neural network (DNN) approach using graphs to generate conceptual designs in architecture. They showed that their system can evaluate and score designs, decompose them into essential building blocks, and recombine them into novel compositions (Fig. 11). The authors also demonstrated how to use generative adversarial networks (GANs) to generate new designs not seen in the training set. The study showed how DNNs can be used to discover interesting building blocks in design data, merge them in a mathematically principled manner to yield new compositions, and generate interesting design variations using GANs. The preliminary results were promising, but the authors noted limitations and constraints in the scope of the designs, the limited number of design samples, and the lack of evaluation of the generated designs.

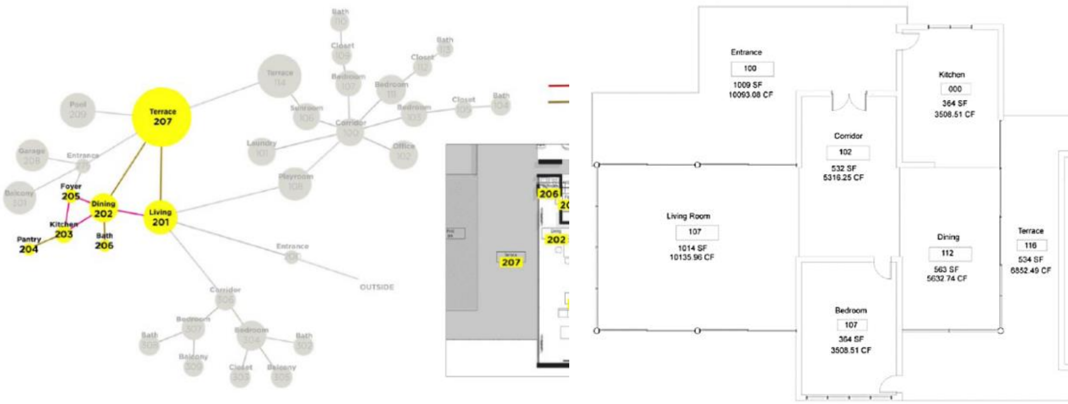

Fig. 11 (Left) DNN concluding zoning relationships from the dataset provided (Right) A floor plan generated by AI using the concluded zoning rules [16]

4. Methods and applications of AI in conceptual design

In their extensive review study, Castro Pena et al. [17] provided an overview of major research projects that use artificial intelligence in architectural conceptual design. The authors identified five categories of AI techniques used in the design process: evolutionary algorithms, artificial neural networks, fractals, swarm intelligence, and cellular automata. These techniques utilize various methods such as optimization, machine learning, self-similar patterns, collective behavior, and rules-based interactions to generate design ideas and assist in tasks such as initial concept generation, design optimization, building performance prediction, analysis of design effects on energy efficiency or occupant comfort, and building simulation and visualization. (Fig. 12). In the following section, a brief review of each area of application will be discussed:

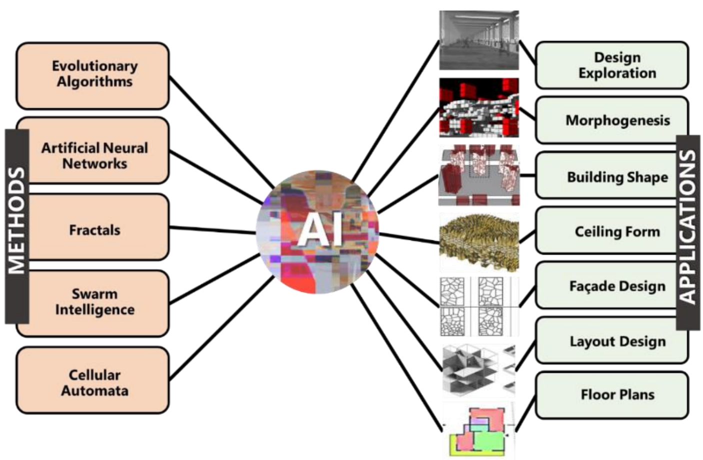

Fig. 12 Classification of methods and applications of artificial intelligence in architectural conceptual design. (Illustration by authors based on the study by Castro Pena et al., 2021)

4.1. Design exploration

One example of using AI for design exploration could be found in the works of Mueller & Ochsendorf [18] where they proposed a computational approach to space exploration design that allows designers to control the evolutionary parameters of mutation rate, generation size, and parent selection (Fig. 13). This approach, which uses interactive evolutionary algorithms, allows designers to prioritize performance, qualitative preferences, diversity, or some combination of these objectives. They demonstrated the potential of their approach through a parametric study and case studies, showing that their method can be used to explore design space in a variety of ways and can accommodate a range of design goals and constraints.

Fig. 13 (Left) Design exploration of structural frames for airport hall design based on performance. (Right) a visual illustration for the structure conceptual design based on algorithmic exploration. [18]

4.2. Morphogenesis

Morphogenesis in architecture is the study of the processes and patterns that shape the form and structure of buildings and other architectural elements. It involves understanding how these forms emerge over time and exploring ways to control and manipulate them. Morphogenetic approaches often use computational tools and techniques and can draw inspiration from natural systems. This field combines computational techniques with design thinking to understand and shape the built environment. One example for this application could be found in the study by (Herr & Ford, 2016 [19] in their exploration of cellular automata (CA) in as generic generative design tools (Fig. 14). In their case study, they suggested using a CA machine to generate forms that could be examined and modified by a designer. The designer would have a collaborative and evaluative role in the design process alongside the CA system.

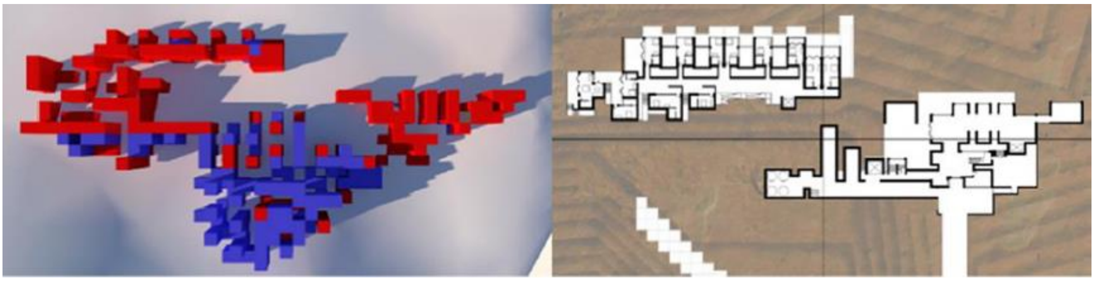

Fig. 14 Design morphogenesis between cellular automata and architectural layout. [19]

4.3. Building shape

The study by Yi & Kim [20] shows an example of using AI in optimizing building shape. In their study, they proposed a method that uses an agent-based geometry control system that sets parameters to control a building in a hierarchical manner, which introduces relatively fewer control points than the typical parameters used in Genetic Algorithm (GA) optimization (Fig. 15). This method reduces the computational cost and time required to determine a solution and allows for the integration with computational simulation tools that provide the ability to find a more accurate and objective performance value.

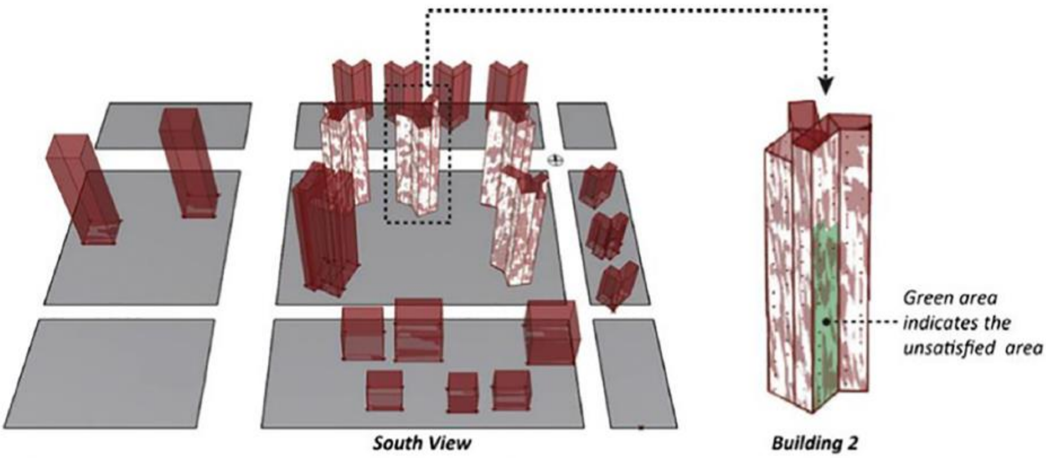

Fig. 15 The developed system showing attention-needed areas within the building shape in which not enough sunlight. [20]

4.4. Ceiling form

One example of using AI in optimizing ceiling shape for architectural spaces could be found in the study by (Rakha & Nassar [21], where they developed develop a method to generate and evaluate various ceiling forms in order to maximize daylight uniformity (Fig. 16). This was done using a genetic algorithm and simulation software, which allowed for the calculation of daylighting performance and visualization of the results. The results of the study suggest that this approach provides a robust and precise method for architects to evaluate and choose ceiling forms that provide optimal daylighting performance.

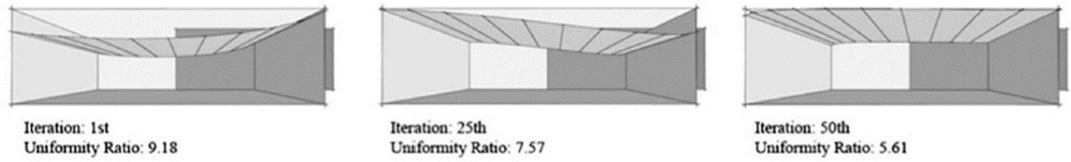

Fig. 16 Ceiling form alternative based on the GA explorations to fulfill daylighting objectives. [21]

4.5. Façade design

Agirbas [22] explored the use of swarm intelligence, a natural principle based on three mathematical rules, in architectural façade design (Fig. 17). The study introduced a conceptual design method using multi-agent-based swarm intelligence algorithms. The method combines morpho dynamic and morphogenetic design approaches by defining the external agents of a swarm intelligence model as solid and void elements in the building façade. The study evaluated the properties of the resulting façade variations and compares the results based on relative daylight intake.

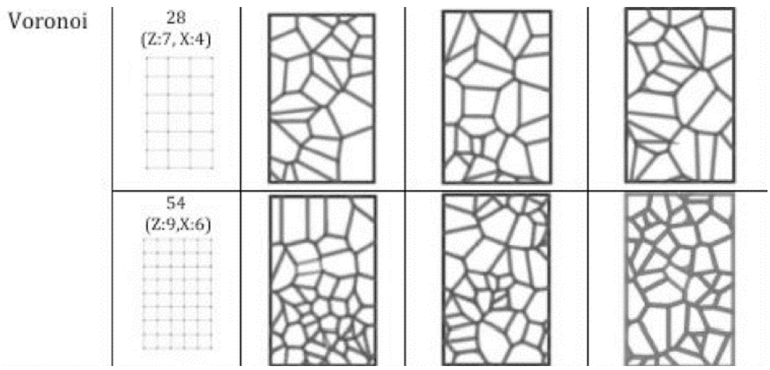

Fig. 17 Swarm intelligence-based design alternative using Voronoi patterns. [22]

4.6. Layout design

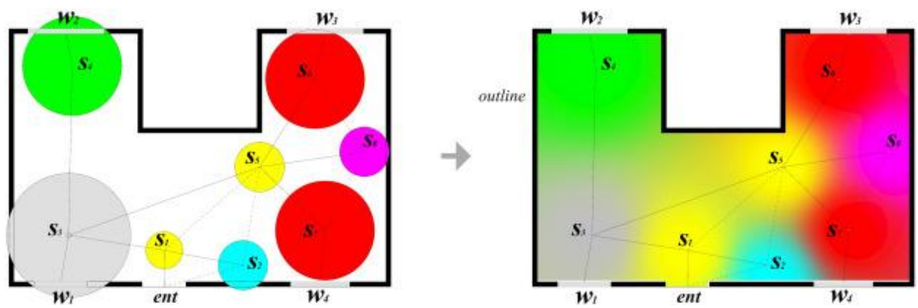

Fig. 18 Arranging layout spaces based on zoning relationship using deep learning [23]

In an recent study by Rahbar et al. [23], a new way of generating automated 2D architectural layouts by fusing agent-based modeling with deep learning algorithms is proposed (Fig. 18). The hybrid approach consists of two methods: first, using agent-based modeling, a bubble diagram that satisfies topological conditions is generated, which is then converted into a heat map by a rule-based algorithm. Second, the pix2pix algorithm uses the heat map to produce an architectural layout as a conditional GAN and deep learning approach. The results indicate improved computational accuracy in generating synthetic architectural layouts compared to previous studies.

4.7. Floor plans

Nisztuk & Myszkowski [24] presented a method for generating floor plans using a combination of evolutionary and greedy algorithms. The method uses architectural design guidelines and user requirements as constraints to generate floor plans that meet the specified requirements. The proposed approach is tested using real-world data and is shown to produce results that are better than those produced by a greedy-based algorithm. The article suggests that further research could be done to improve the effectiveness of the approach.

Fig. 19 An example of the generated floor plans using Nisztuk & Myszkowski ‘s method [24]

5. Machine hallucinations: the creative potential of AI in architecture

Machine hallucination is a term that has been used to describe the ability of a machine or computer program to generate sensory experiences that do not correspond to any real-world input. This could include visual, auditory, or other sensory experiences that are not based on any actual input, but rather are generated entirely by the machine itself. Machine hallucination is not a well-defined term, and it is not clear how it might be achieved or used in practice. The term itself has recently gained a notable momentum in the architectural realm, motivated by the growing interest in AI creative potential in design and how this reflects on rationalism of conceptual decisions and resulted forms and structures.

The term had a notable appearance in the book by architectural theorists Neil Leach and Matias del Campo, entitled “Machine Hallucinations: Architecture and Artificial

Intelligence”[25]. As discussed in the book, originally, the "Machine Hallucinations" is a series of art projects by Refek Anadol that seeks to create an immersive experience that feels like being in the mind of a machine-brain that hallucinates based on the data it perceives (Fig. 20). This is achieved by using machine learning algorithms trained on large datasets to uncover unrecognized layers of external realities and create a self-regenerating element of surprise for the audience. In the special edition created for ARTECHOUSE's New York City location, machine-learning algorithms were used on over 100 million photographic memories of the city to create a data universe in 1,025 latent dimensions (Fig. 21).

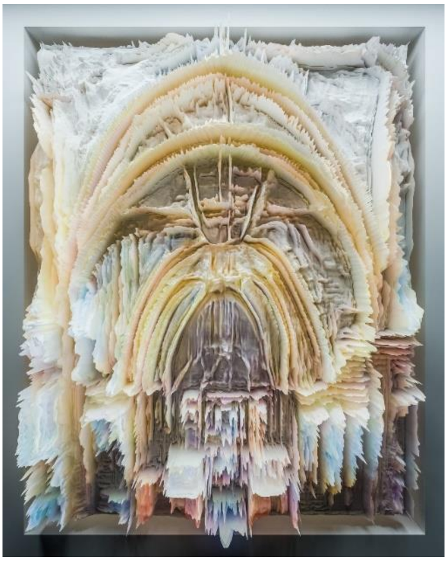

Fig. 20 Machine Hallucinations – Latent Study II exhibition [26]

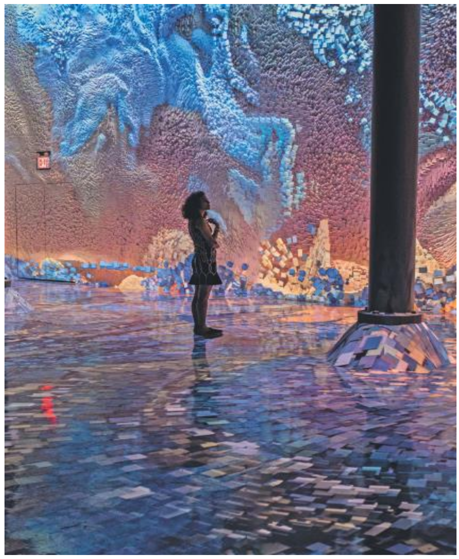

Fig. 21 Machine Hallucination: NYC, ARTECHOUSE, New York City [25]

In their discussion of the concept of machine hallucination in the architectural context, the authors argue that the brain's process of making predictions based on "perceptual expectations" is like the controlled hallucinations of a (GAN). They suggest that backpropagation, a process used to correct errors in neural networks, is similar to the brain's prediction error minimization. They also suggest that the way architects perceive and interpret the world may be similar to how neural networks are trained to interpret images, with architects "architecturalizing" the world and being inspired by non-architectural objects in a way that is similar to how a neural network is trained on a specific dataset. They argue that this highlights the connection between the brain's perception and machine intelligence in art and architecture.

5.1. AI-image generation

AI image generation is a form of machine learning that involves training a computer to create original images based on a set of instructions or a set of training data. This is typically done using a type of algorithm called a Generative Adversarial Network, or GAN. A GAN consists of two parts: a generator and a discriminator. The generator is a neural network that takes in a random noise signal as input and produces an image as output. The discriminator is also a neural network that takes in an image as input and attempts to classify it as either real or fake. The two networks are trained together in a competitive process. The generator produces images, and the discriminator evaluates them, providing feedback to the generator about how well it is doing (Fig. 22). Over time, the generator learns to create images that are more and more like the training data, allowing it to produce highly realistic images.

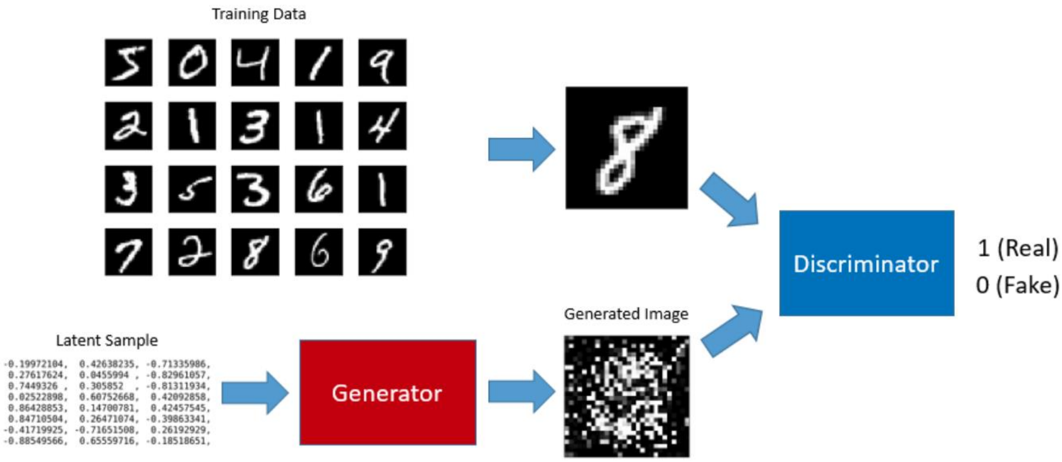

Fig. 22 Workflow of Generative Adversarial Network [27]

One way that AI image generation could be applied to architecture is by using a technique called style transfer [28]. This involves using a neural network to learn the style of a particular reference image, and then applying that style to a new image to generate a version of the new image that has the same aesthetic qualities as the reference image. In recent years, there has been a proliferation of tools for AI image generation. These tools, which are largely based on the conceptual framework of (GANs), offer unique artistic styles and varying levels of comprehension of text prompts. This has made them particularly appealing to the field of architectural design, where they have garnered significant attention. Despite their shared foundation in GANs, these tools differ in their results and capabilities. Some can create highly detailed and realistic images, while others focus on more abstract or stylized outputs. Still others can understand and incorporate natural language instructions in their generation process, allowing for greater control and flexibility. In the following section, we will explore several tools that have garnered significant attention in the field of architectural design.

5.1.1. DALL-E

DALL-E is a deep learning model introduced by OpenAI in 2021 that generates images from text prompts. It can generate photorealistic and stylized images and add components to images based on visual context. DALL-E 2, an improved version of the original model, was released in April 2022 and is capable of producing highly coherent architectural environments based on a user's description. [29]. A notable application of DALL-E 2 in architecture could be seen in the exploratory work done by Zaha Hadid Architects. In this work, DALL-E 2 was used as a source of inspiration for the conceptual design of various projects, and as a starting point for the 3D modeling of corresponding designs. For example, in Fig. 23, DALL-E 2 was used to explore design ideas for a museum building, combining the terms “Zaha Hadid” and “Organic” as the visual attributes of image generation. The resulting images show a range of possible designs for a museum building, with flowing, organic forms and bold, futuristic shapes.

Fig. 23 A set of generated images as a result of the text prompt “Zaha Hadid museum aerial view organic, high quality” [29].

5.1.2. Midjourney

Fig. 24 An imagination to a fluid form of ancient Egyptian architecture.[30]

Fig. 25 A surreal visualization of ultra-detailed Islamic style Majles. [31]

In July 2022, Midjourney was released as an artificial intelligence system that generates from natural language descriptions [32]. The tool is available through the social platform "Discord" where users can input text prompts as messages describing their scene of choice. Afterwards, the system generates four suggested images that matches the text description, with further options to iterate or detail the outcomes. Unlike similar systems such as DALL-E and Stable Diffusion, Midjourney has been distinct since its inception as a more "artistic" AI image generator than other alternative, being able to generate highly aesthetically pleasing results with wide understanding of art styles and composition. Unsurprisingly, by being artist-oriented system, Midjourney has been vastly used in exploratory approaches to produce fluid, dreamy forms of architecture, including façade and interior design. A notable use case of façade design generation in Midjourney could be found in using the system to explore free flowing façade lines smoothly fused into biomimetic shapes, with a touch of architectural identity emphasis (Fig. 24, Fig. 25).

5.1.3. Stable diffusion

Stable diffusion is another deep learning model that generates images from text prompts. Unlike most of the other popular tools, Stable diffusion adopts an open-source approach. In other words, it's freely available and its source code is accessible for modification and improvement. In addition, Stable diffusion works locally on user's device, in contrary to other proprietary tools which often use cloud processing to generate the outcomes. Being a newly introduced tool, Stable Diffusion is still in gaining the attention of architects and designers as a tool of choice for generating imaginative architecture illustrations (Fig. 26 and Fig. 27).

Fig. 26 An interior for Arabian style architecture generated in Stable diffusion using the following text-prompt "high resolution photography interior design, Arab style, multicolored ceramic floor, Arabic large windows opening onto the garden, Arabic furniture and decoration, high ceiling, beige blue salmon pastel palette, interior design magazine, cozy atmosphere" [33]

Fig. 27 An illustration for a futuristic ancient Egyptian architecture, generated in Stable Diffusion using the following prompt: "the inside of a monument with Egyptian motifs, by Tim Blandine and Arthur Haas and Bruce Pennington and john Schoenherr, big windows architecture by Zaha Hadid, octane render, modernism, futuristic, trending on artstation, sci - fi, high detail, high quality,

sharp focus, close up angle, people walking”
[33]

6. AI-image generation for design exploration: use cases

6.1. Abstract forms

One of the predominant potential uses for AI image generation is the ability to easily imagine radical, futuristic, and highly abstract forms. This allows for the generation of images that feature unusual and abstract designs, often with a highly aesthetic composition and feel. These results are achieved by crafting a text prompt that mixes various concepts, architectural styles, and emphasizes terms such as "sci-fi" and "futuristic" elements within the prompt. For instance, Tim Fu, a designer at Zaha Hadid Architects, has demonstrated a variety of design explorations that mix organic forms and naturally inspired patterns in aesthetic architectural representations that reflect futuristic concepts and materials [34]. These designs showcase the potential of AI image generation to create highly imaginative and abstract forms that can be used in the exploration of new architectural concepts and styles (Fig. 28).



Fig. 28 Variety of design exploration studies generated by Midjourney showing nature oriented and futuristic concepts. [34]

6.2. Reimaging biomimicry architecture

In the field of biomimicry architecture, AI image generation can be used to create designs that mimic the forms, functions, and behaviors of natural systems, due to its ability to abstract elements and mix styles homogenously. For example, a building designed using biomimicry principles might use materials and structures inspired by the shells of mollusks or the leaves of plants, allowing it to blend seamlessly into its surroundings and function more efficiently. In this context, El Sayary [35] used Midjourney to generate a variation of imaginative forms that directly depict structures inspired by natural phenomena, such as ant colonies (Fig. 29) and forests (Fig. 30). The author argued that the generated designs not only reflect nature but also the identity of the place, by using natural local materials in the forms as well. Midjourney was able to generate highly detailed, fluid forms with relatively convincing structural and aesthetic orders.

Fig. 29 Generated design inspired by ant colonies in terms of structure, forms, and materials. [35]

Fig. 30 Tree-like design inspired by African foliage nature. [36]

6.3. Revisiting traditional architecture

AI image generation can be used to revisit traditional architectural styles by combining them with newer styles or using the design elements from traditional styles in more futuristic and fluid forms through crafting text prompts. An example of this use case could be seen in a design study trial by Soliman [37] to use Midjourney as a tool for reimagining traditional architecture in Alexandria city, Egypt. Soliman, where several elements of parametric design with the Renaissance style in Alexandria were combined, in over 2000 variations. The study showed that Midjourney was able to repeat details and windows of the traditional styles in a modular way, even on curved surfaces and from different perspective points (Fig. 31), as well as its potential to transform Renaissance buildings in Alexandria by blending them with parametric design elements.

Fig. 31 A re-imagination for traditional design elements in various facades in Alexandria city, Egypt generated by Midjourney. [37]

6.4. Augmenting architectural sketches

AI image generation also showed a potential use for augmenting architectural sketches and ideas in several ways, where an AI image generation system could be trained to complete unfinished sketches or to create new variations of a design based on a set of input sketches. This could be useful for quickly generating a range of design options for architects to choose from, or for helping architects to explore different design ideas more easily without the need to furtherly visualize each idea (e.g., using 3D modelling and rendering tools). An example of this use case could be seen in the exploitation of img2img- an implementation of Stable Diffusion- by AbdelShakour [38] to generate façade design visualizations based on student's simple sketches. the generated images were reported as closely aligned with the original sketches in terms of camera angles, building masses, and heights (Fig. 32). The author also notes that while generation time for these images is relatively fast, they do require a high level of GPU compute to be generated quickly.

Fig. 32 An example of img2img output visualization from student's sketch. [38]

7. Limitations of AI-generated conceptual design

7.1. Limited controls and customization

Text-prompt based AI image generators work by inputting a text prompt or description into a machine learning model that has been trained on a large dataset of images and their corresponding text descriptions. The model uses this input to generate an image that it thinks best matches the given text prompt. In traditional conceptual modeling, and even in parametric design tools, architects have a high level of control over the final outcome and its fine details because they can specify every aspect of the design. They can choose the specific materials, textures, and colors to use, as well as the exact dimensions and proportions of the various elements in the design. They can also make creative decisions about the overall composition and layout of the design.

On the contrary, text-prompt based AI image generators do not give users as much control over the final outcome, as the model is only able to generate images based on what it has been trained o and within the context of the text prompt, which makes the architect limited to the types of images that the model is capable of producing without the ability to fine tune the results or transfer to other tools to do so.

7.2. Lack of consideration for structural design feasibility

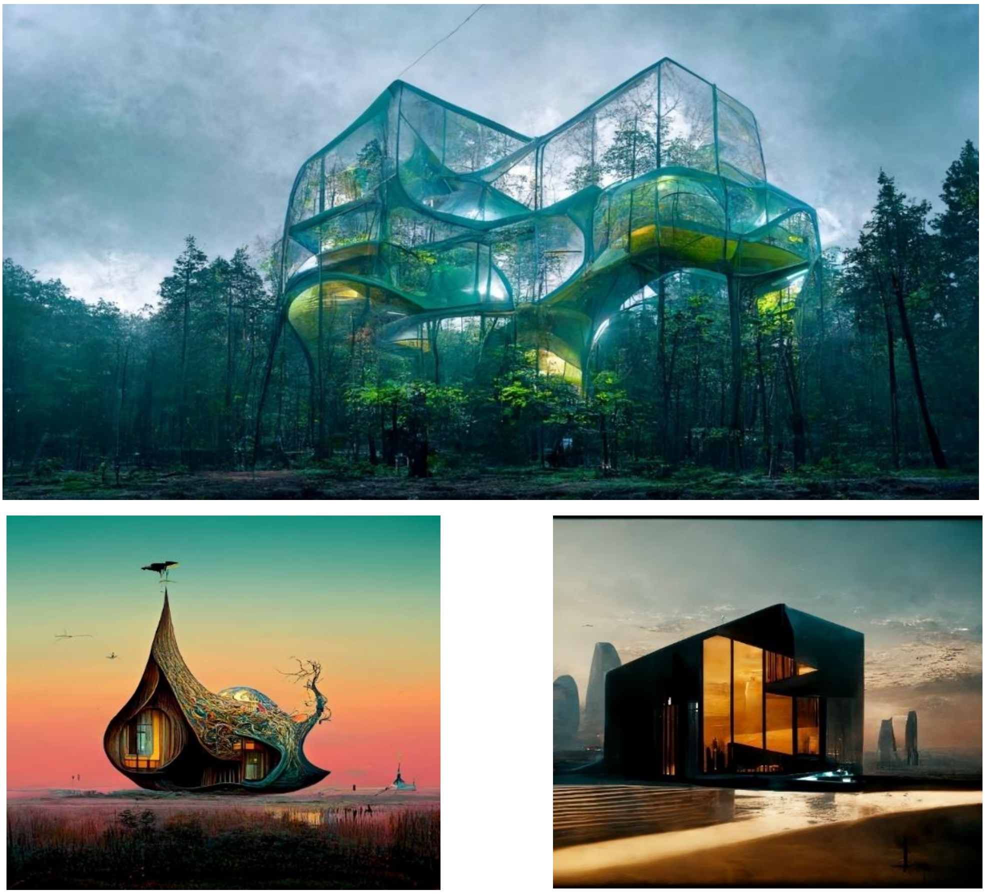

Fig. 33 Several examples of Ai-generated designs where structural consistency is not adequately considered. This can be seen in the bypassing of realistic material representations, structural elements representation, or correct understanding of proportions and third dimension. [39]

AI image generators, particularly those that are designed to produce artistic or stylized images, may produce results that are biased towards highly fluid or structurally challenging forms. This is because these models are often trained on datasets that include a wide range of images and may not be specifically designed to consider structural considerations or construction feasibility. As a result, the images generated by these models may not always be realistic or feasible to construct in the real world. They may be too complex or require materials or construction techniques that are not currently available or practical to use (Fig. 33). This can be a limitation when using AI image generators as a source of inspiration for architects, as it may be necessary to simplify or modify the generated images in order to make them more feasible to construct.

7.3. Inconsistency of outcomes

In architectural projects, it is important to have a consistent and unified conceptual design to realize the general feel of the design in 3D space and to further improve upon it. AI-image generators are often used to produce a set of iterations for a given text prompt, which can provide a range of ideas and concepts for architects and other professionals to consider. However, these iterations may not always be unified in terms of architectural style elements and may visualize different designs that are not necessarily consistent with each other. While it is possible to use input images to generate variations in these tools, the resulting variations are not always consistent with the input designs (Fig. 34). As a result, it can be difficult to use AI image generators to create a unified set of visualizations for a single project, and they are more commonly used as a source of inspiration, like a mood board, rather than a comprehensive design tool.

Fig. 34 (Left) A façade design for mixed-use tower fed to DALL-E as an input image. (Right) four design iterations (variations) generated based on the input design, reflecting the inconsistency of elements, dimensions, and order.

8. Discussion and conclusions

This study offered an exploratory approach to the trend of AI image generation as a form of machine hallucination, examining its unpredictable or predictable results and its implications on conceptual architectural design. The study highlighted the criticism of conceptual design as a delicate balance between aesthetics and functionality, leading to the increasing incorporation of digital technology into architecture to help architects realize and visualize their creative imagination into feasible design forms. The relationship between AI and architecture is not new, with the use of modularity in the past and the evolution of more powerful applications and implications with the advent of computational and parametric design tools. More recently, the emergence of AI-based design has presented a new approach to machine-aided design for architects. While there has always been debate among architects on the topic of technology in architecture, with some being hardcore supporters and others being more skeptical, the dialogue on how architects should handle the integration of AI into the architectural design realm has not been widely covered. At this moment in history, it is crucial for architects to understand the technology and to evolve their skills to incorporate AI capabilities into their workflows rather than resisting it.

There are numerous applications of AI in architecture, including the use of genetic algorithms to optimize environmental performance, explore performance-based iterations of design, and explore morphogenesis and rule-based form finding. The new image generation tools provide a new horizon as an inspirational tool and a fast lane for generating conceptual ideas. However, these tools also have limitations, including a lack of technical abilities specifically related to architecture and a focus on image generation that limits their benefit in the conceptual and post-conceptual process. These limitations may be overcome in the future as AI technology continues to improve exponentially, with AI tools already available that can generate video footage [40] and 3D models [41]. Soon, it is expected that AI platforms will be able to produce fully 3D usable conceptual designs and, with the incorporation of language models, even computable files for 3D modelling and building information modelling software, which would revolutionize architecture.

References

[1] Deezen, Sydney Opera House concert hall reopens after extensive renovation, Dezeen. (2022). https://www.dezeen.com/2022/09/02/sydney-opera-house-concert-hall-renovation/ (accessed December 3, 2022).

[2] Marcos Martínez, How do you build a Guggenheim museum? - Ferrovial’s blog, Ferrovial. (2017). https://blog.ferrovial.com/en/2017/10/guggenheim-museum-construction/ (accessed December 3, 2022).

[3] Forgemind ArchiMedia, Corbusier Modulor color.jpg, 2010. https://www.flickr.com/photos/eager/5031911411/ (accessed December 4, 2022).

[4] Wladyslaw, Deutsch: Montreal: Habitat67, 2008. https://commons.wikimedia.org/wiki/File:Montreal_-_QC_-_Habitat67.jpg (accessed December 4, 2022).

[5] E. Pertigkiozoglou, 1973: Nicholas Negroponte and Architecture Machine Group MIT, Medium. (2020). https://eliza-pert.medium.com/1973-a1b835e87d1c (accessed December 4, 2022).

[6] Samuel Medina, Gallery of Paul Goldberger: “Frank Gehry Really Doesn’t Want To Be Remembered as Somebody Who Just Did a Few Iconic Buildings” - 8, ArchDaily. (2015). https://www.archdaily.com/778151/paul-goldberger-frank-gehry-really-doesnt-want-to-be-remembered-as-somebody-who-just-did-a-few-iconic-buildings/565f0003e58ece20b4000229-paul-goldberger-frank-gehry-really-doesnt-want-to-be-remembered-as-somebody-who-just-did-a-few-iconic-buildings-photo (accessed December 4, 2022).

[7] Z. Hadid, Marsupium, Vitra Fire Stationlabel QS:Lit,"Vitra Fire Station", 1993. https://commons.wikimedia.org/wiki/File:Vitra_Campus_-_Hadid_Fire_Station_-_full_view,_blue_sky.jpg (accessed December 4, 2022).

[8] Sunena V Maju, Midjourney: in the middle of the universe and multiverse of AI imagination, (2022). https://www.stirworld.com/see-features-midjourney-in-the-middle-of-the-universe-and-multiverse-of-ai-imagination (accessed December 4, 2022).

[9] S. Chaillou, The Advent of Architectural AI, Medium. (2020). https://towardsdatascience.com/the-advent-of-architectural-ai-706046960140 (accessed December 4, 2022).

[10] Gili Merin, AD Classics: The Dymaxion House / Buckminster Fuller, ArchDaily. (2019). https://www.archdaily.com/401528/ad-classics-the-dymaxion-house-buckminster-fuller (accessed December 4, 2022).

[11] Benedict Hobson, Archigram’s Plug-In City shows that “pre-fabrication doesn’t have to be boring” says Peter Cook, Dezeen. (2020). https://www.dezeen.com/2020/05/12/archigram-plug-in-city-peter-cook-dennis-crompton-video-interview-vdf/ (accessed December 4, 2022).

[12] Evan Rawn, Spotlight: Frei Otto, ArchDaily. (2020). https://www.archdaily.com/511689/happy-birthday-frei-otto (accessed December 4, 2022).

[13] Tensinet, OLYMPIC GAMES 1972 (MUNICH): OLYMPIC STADIUM, (2010). http://www.tensinet.com/index.php/projects-database/companies?view=project&id=3779 (accessed December 4, 2022).

[14] Iwan Baan, Guangzhou Opera House / Zaha Hadid Architects, ArchDaily. (2011). https://www.archdaily.com/115949/guangzhou-opera-house-zaha-hadid-architects (accessed December 4, 2022).

[15] Alyn Griffiths, OMA’s CCTV Headquarters redefined the skyscraper, Dezeen. (2022). https://www.dezeen.com/2022/05/12/cctv-headquarters-oma-deconstructivism/ (accessed December 4, 2022).

[16] I. As, S. Pal, P. Basu, Artificial intelligence in architecture: Generating conceptual design via deep learning, International Journal of Architectural Computing. 16 (2018) 306–327. https://doi.org/10.1177/1478077118800982.

[17] M.L. Castro Pena, A. Carballal, N. Rodríguez-Fernández, I. Santos, J. Romero, Artificial intelligence applied to conceptual design. A review of its use in architecture, Automation in Construction. 124 (2021) 103550. https://doi.org/10.1016/j.autcon.2021.103550.

[18] C.T. Mueller, J.A. Ochsendorf, Combining structural performance and designer preferences in evolutionary design space exploration, Automation in Construction. 52 (2015) 70–82. https://doi.org/10.1016/j.autcon.2015.02.011.

[19] C.M. Herr, R.C. Ford, Cellular automata in architectural design: From generic systems to specific design tools, Automation in Construction. 72 (2016) 39–45. https://doi.org/10.1016/j.autcon.2016.07.005.

[20] Y.K. Yi, H. Kim, Agent-based geometry optimization with Genetic Algorithm (GA) for tall apartment’s solar right, Solar Energy. 113 (2015) 236–250. https://doi.org/10.1016/j.solener.2014.11.007.

[21] T. Rakha, K. Nassar, Genetic algorithms for ceiling form optimization in response to daylight levels, Renewable Energy. 36 (2011) 2348–2356. https://doi.org/10.1016/j.renene.2011.02.006.

[22] A. Agirbas, Façade form-finding with swarm intelligence, Automation in Construction. 99 (2019) 140–151. https://doi.org/10.1016/j.autcon.2018.12.003.

[23] M. Rahbar, M. Mahdavinejad, A.H.D. Markazi, M. Bemanian, Architectural layout design through deep learning and agent-based modeling: A hybrid approach, Journal of Building Engineering. 47 (2022) 103822. https://doi.org/10.1016/j.jobe.2021.103822.

[24] M. Nisztuk, P.B. Myszkowski, Hybrid Evolutionary Algorithm applied to Automated Floor Plan Generation, International Journal of Architectural Computing. 17 (2019) 260–283. https://doi.org/10.1177/1478077119832982.

[25] N. Leach, M. del Campo, eds., Machine Hallucinations: Architecture and Artificial Intelligence, 1st edition, Wiley, Oxford, 2022.

[26] Refik Anadol, Refik Anadol: Machine Hallucinations – Latent Study II – ACM SIGGRAPH ART SHOW ARCHIVES, (2019). https://digitalartarchive.siggraph.org/artwork/refik-anadol-machine-hallucinations-latent-study-ii/ (accessed December 8, 2022).

[27] Naoki, Understanding Generative Adversarial Networks, Medium. (2022). https://naokishibuya.medium.com/understanding-generative-adversarial-networks-4dafc963f2ef (accessed November 29, 2022).

[28] Neural style transfer | TensorFlow Core, TensorFlow. (2022). https://www.tensorflow.org/tutorials/generative/style_transfer (accessed December 4, 2022).

[29] DigitalFUTURES Talk: The AI Design Revolution: DALLE vs MidJourney, 2022. https://www.youtube.com/watch?v=ButDfjQohB0 (accessed November 29, 2022).

[30] A. E. C. Magazine, Midjourney architecture: Hassan Ragab, AEC Magazine. (2022). https://aecmag.com/ai/midjourney-architecture-hassan-ragab-conceptual-ai-rtist/ (accessed November 29, 2022).

[31] The mind circle, Midjourney Architecture: Intricate Architecture Designs by AI, Themindcircle. (2022). https://themindcircle.com/midjourney-architecture-concepts-by-ai/ (accessed November 29, 2022).

[32] Midjourney, Midjourney, Midjourney. (2022). https://www.midjourney.com/#about (accessed November 29, 2022).

[33] PromptHero, Stable Diffusion prompt: high resolution photography interior design, ar..., PromptHero. (2022). https://prompthero.com/prompt/a217e1053c6 (accessed December 3, 2022).

[34] Tim Fu, The new paradigm of A.I. generated design, (2022). https://www.linkedin.com/feed/update/urn:li:activity:7003021512785940480/ (accessed December 14, 2022).

[35] Samer El Sayary, What if homo sapiens were able to hire ant builders to construct human habitats?, (2022). https://www.facebook.com/samersayary/posts/pfbid0s2tSC2JfL7BADngMMCTAxNm75sFsLiLXsGzfQpkt5AuuCz6RAjCFJ5p4SyWnxyMJl (accessed December 14, 2022).

[36] Samer El Sayary, The future of Africa, exploring the AI concept art of biomorphic construct-built architecture, (2022). https://www.facebook.com/samersayary/posts/pfbid0Zwv2d1qhJfTb11uFMi9ERYbk3EeiuxeKA1NGuuVv7Ndd92jgHGiy1iq1BupkPCXTl (accessed December 14, 2022).

[37] Mai Abdelsalam Soliman, Dr, Mai Abdelsalam Soliman, Rethinking Alexandria, Linkedin.Com. (2022). https://www.linkedin.com/feed/update/urn:li:activity:7008110675952570369/ (accessed December 14, 2022).

[38] Mohamed AbdelShakour, AI in Architecture: Working with Stable Diffusion, Facebook.Com. (2022). https://www.facebook.com/mshakour/posts/pfbid0aU4HiBnbNkHNXD94ctQJij2YmRpEhK7r4TQ1m53kNFNrxZJSJ651ovXAexZDbWNNl (accessed December 14, 2022).

[39] PromptHero, Midjourney prompt: architecture, PromptHero. (2022). https://prompthero.com/prompt/e36886c22a2 (accessed December 19, 2022).

[40] J. Ho, W. Chan, C. Saharia, J. Whang, R. Gao, A. Gritsenko, D.P. Kingma, B. Poole, M. Norouzi, D.J. Fleet, Imagen video: High definition video generation with diffusion models, ArXiv Preprint ArXiv:2210.02303. (2022).

[41] J. Gao, T. Shen, Z. Wang, W. Chen, K. Yin, D. Li, O. Litany, Z. Gojcic, S. Fidler, GET3D: A Generative Model of High Quality 3D Textured Shapes Learned from Images, ArXiv Preprint ArXiv:2209.11163. (2022).