# Utilizing Machine Learning Algorithms for Architectural Design

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**Abstract.** With the development of digital technology, artificial intelligence has brought a paradigm shift in numerous fields. Machine learning is used as a decision making tool to analyze large data and produce output data with similar characteristics. This paper aims to explore and analyze the influence of artificial intelligence on the architectural designing process. In the second section, traditional methods of architectural design are observed. The third section explains the methodology of machine learning and its current limitations. The fourth section investigates several real world applications of machine learning in designing architecture, and the last section speculates on the potential directions that the field of architectural design could take as machine learning continues to advance.

**Keywords:** Machine Learning, architectural design.

## 1. Introduction

The field of architectural design holds an essential role in shaping the built environment, harmonizing aesthetics, functionality, and sustainability. For decades, architects have wielded their creativity to craft spaces that align with human experiences. Traditionally, architectural design has been approached through manual drafting and physical models, where architects meticulously transform their visions onto paper and materials. This craftsmanship, guided by experience and artistic skills, has been the cornerstone of architectural design.

However, as technology develops, the investigation into Artificial Intelligence (AI) and its diverse applications has brought a paradigm shift in their traditional approaches. Its indispensability in modern times arises from its remarkable ability to address intricate problems that require substantial time and effort. Functioning as a versatile tool, AI advances the process of integrating information, analyzing data, and generating solutions to everyday problems. This technology has been integrated with a variety of sectors, which includes areas such as healthcare and smart cities. Amid this expansive landscape, one particularly promising application lies in the realm of architectural design. Currently, about seven percent of the world's labor force is in the construction industry. However, it has fundamentally been one of the least technologically advanced industries due to the complexity of designing progress. This juxtaposition creates an opportune arena for the convergence of AI with architecture, a partnership that holds the potential to streamline design procedures and significantly enhance overall efficiency.

Hence, this paper aims to closely examine how AI can influence architectural designs and how it might transform the construction industry in the next decade. It evaluates both the traditional methods and new machine learning algorithms used for architectural design and discusses the potential directions that the field of architectural design could take as machine learning continues to advance.

## 2. Traditional Methods

Some of the traditional methods such as manual drafting, physical models, and trial-and-error methodologies have historically formed the bedrock of architectural creation.

Manual drafting involves the painstaking process of transforming conceptual ideas onto paper using precision instruments. These skills often require extensive knowledge of the history of architecture as well as culture to achieve the desired outcome. This method, though emblematic of craftsmanship, is fraught with challenges such as human error and time-intensive modifications. The second method, physical models, provides tangible representations of architectural concepts. Architects construct scaled-down models to showcase spatial relationships and aesthetics of buildings. However, this method demands considerable time and resources, hindering the rapid exploration of multiple design variations. The third approach, the trial-and-error method, allows architects to produce an outcome that satisfies the consumer's needs. However, the process is often resource-consuming, which limits the exploration of design alternatives.

Eventually, the handcraft approach has evolved into a digital one. By the 1980s, the traditional methods were replaced by the digital approach (Donaldson, 2023). Architects' tools transitioned from sheets of paper to software that can generate drawing outputs. This major shift has greatly impacted the field and will hold as advanced technologies have replaced the simplicity of the pen. According to Bill Kwon, vice president of IT at the architecture firm CallisonRTKL, "there are many inefficiencies within the traditional architecture process in terms of design, delivery and simulation" (Brodsky, 2020). He believes that AI will improve those problems through optimized methods that can create efficiency.

## 3. Methodology

The term "Artificial Intelligence" was coined by John McCarthy in 1956. He characterized it as "the discipline and engineering of creating intelligent machines" (McCarthy, 1990). It leverages computers and algorithms to comprehend human intelligence and can thus be applied to tasks involving problem-solving and decision-making. AI ought to possess the capability to execute the design process and fulfill consumers' preferences. It can serve as a tool for clients to pinpoint the most appropriate design that aligns with their desires. Imdat As, an architect specializing in digital design and holding the position of assistant professor of architecture, elucidates that deep-learning machines and AI have the potential to alter the longstanding patterns in architectural design (Imdat, 2018). AI could potentially expand upon these patterns, encompassing functional and programmatic considerations while incorporating additional variables such as geographical and climatic factors that influence the built environment. Through AI, machines can scrutinize the optimal patterns for a given problem and substantiate their findings. The design process stands to significantly benefit from heightened intelligence and efficiency. Early research relating to the use of machine learning in architectural design focused on design generation, shape recognition, and space organization (Tamek, 2018).

### 3.1 Machine Learning

Machine Learning is a multidisciplinary field that focuses on the development of algorithms and statistical models that enable computer systems to improve their performance through learning from data, without being explicitly programmed. This paper will focus on neural networks.

A neural network is a computational system composed of algorithms that aims to uncover hidden patterns within a dataset by imitating the way the human brain functions. Whether made up of biological neurons or artificial counterparts, these networks can adjust to varying inputs, allowing them to produce optimal outcomes without the need for a complete redesign of their output rules.

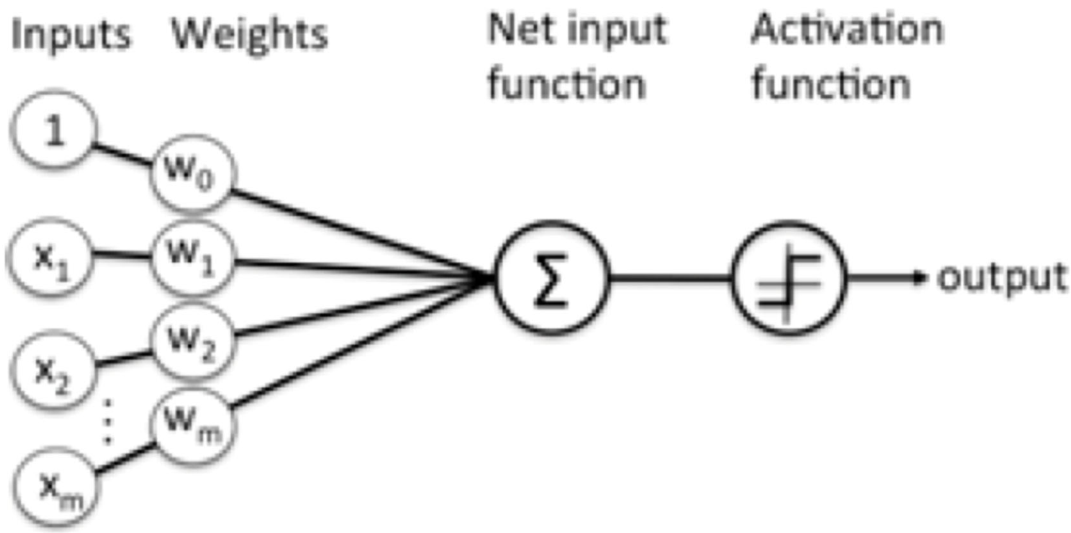


Figure 1: Neural Networks

### 3.2 Types of machine learning used in architectural design

#### 3.2.1 Generative adversarial networks (GAN)

Generative adversarial networks (GAN) is a model framework that can learn from input data and generate outputs with similar characteristics. There are two components in the model, the Generator and the Discriminator, which allow the model to operate in a feedback loop to refine the model's ability to generate outputs. While the Discriminator is used to recognize images from data, the Generator can create images that are similar to the ones in the data. In response, the Discriminator then provides feedback for the Generator to improve on. As this process continues, a GAN is trained to create synthetic images (Goyal, 2019).

GANs are useful in generating new architectural designs and adapting existing ones to different styles, offering architects creative inspiration and flexibility. They contribute to interior design by generating layouts and decor suggestions and aid in parametric design optimization. Moreover, GANs create high-quality 3D models and immersive VR/AR experiences, enhancing design communication.

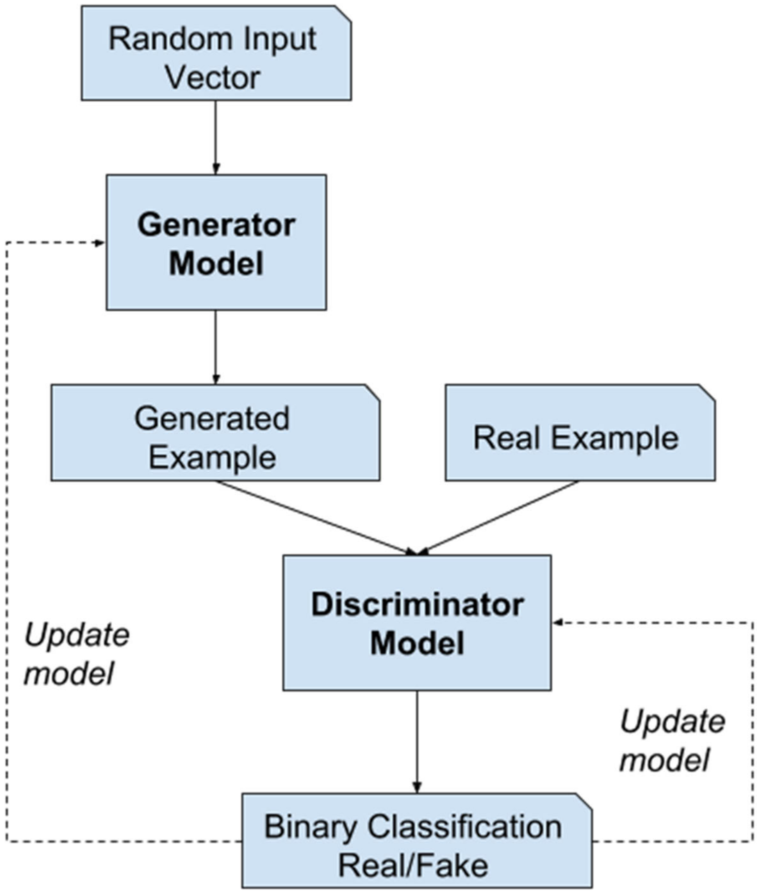


Fig.2 Generative Adversarial Network Model Architecture
Source: Mohamed, et al. (2022)

#### 3.2.2 Convolutional neural network (CNN)

Convolutional Neural Networks (CNNs) are integral to modern architectural design processes.. It is a multilayer neural network that’s often used in image-processing applications. Essentially, CNN is made up of multiple layers of feature extraction and classification processes. When inputting an image, the image is divided into areas that feed into a convolutional layer, which extracts features from it. Then, the pooling process reduces the dimension of the extracted features. The next stage involves another round of convolution and pooling, which then connects to a fully connected multilayer perceptron. This network's ultimate output layer consists of nodes that recognize specific characteristics within the image. Training the network is accomplished through the iterative process of back-propagation (IBM Developer, 2023).

CNN enables image recognition and classification, aiding architects in categorizing styles and features of existing architectures. It also offers design inspiration by analyzing architectural images and suggesting elements aligned with project goals. In design optimization, they help fine-tune layouts and materials for enhanced sustainability and functionality. CNNs recognize materials and textures, ensuring suitable choices, and can even assess environmental impact. They also contribute to safety compliance by identifying hazards in designs.

### 3.3 Limits of machine learning in its current state

Architectural processes using AI need constant supervision. Hence, one of the limitations is the possible occurrence of human error in the process, which can be reduced by hiring experts to supervise the work. Some of the drawbacks of using AI in architecture include dependence on technology, potential job loss, as well as privacy and security risks (Asri).

# 4. Evaluation

## 4.1 Architectural AI

With the growing power of artificial intelligence, many corporations have been conducting research on AI's potential to transform urban spaces. Ravi Bedi, Technology Innovation Principal Director at Accenture, highlights two fundamental changes that make AI important in the future, which are the growing trend of digitization and the reduction in the cost of processing data (Dhawan, 2020). During the designing process, architects review past designs and the data prepared throughout the making of the building. AI will analyze data and give insights which the architects will be able to do testing in a faster way. There are several ways AI can shape future architecture. For example, it uses geometry programming with complex algorithms that allow architects to change parameters to create innovative designs (Reddy, 2020). Moreover, it can save an architect's time and energy to plan by analyzing the whole data in milliseconds and creating foundation models so that the architects can add details to it (Kai, 2019).

According to statistics, "About seven percent of the world's labor force is in the construction industry", however, "it has traditionally been one of the least technologically advanced industries" (Kai, 2019). Nevertheless, experts believe that there is great potential for the integration of AI in the architecture industry as it could reduce the building and designing costs by up to twenty percent. "There are many inefficiencies within the architecture process in the realms of design, delivery, and simulation," Bill Kwon, vice president of IT and digital transformation at the architecture firm CallisonRTKL, said in an email interview. "AI will inevitably wean out the waste through optimized and predictive modeling, create efficiencies, and reduce errors through automation and continuous learning" (Brodsky, 2020).

Research has been conducted using a deep neural network (DNN), which is a deep learning application that "extracts design into essential building blocks - based on functional performance criteria - and recombines them into new designs" (As, 2018). DNNs are not bound by rules or original algorithms but can learn patterns through training, which is different from conventional approaches. In architecture, a project goes through several phases, including conceptual design, schematic design, design development, construction documents, procurement, construction administration, and operations. Deep learning can help shorten the conceptual design process. It can use graphs to generate conceptual designs. This tool can evaluate design models, input them into building blocks, and yield them into new design compositions.

## 4.2 Generative design

Stanislas Chaillou, a designer, worked on a project at Harvard aiming to apply machine learning in architectural practice. He focused on the area of AI-generated floor plans and developed training models aligning to specific architectural styles: Baroque, Row House, Victorian Suburban House, & Manhattan Unit. The study of the style is essential as it demonstrates how a particular style can "define mechanics and space" and "control the internal organization of the plan" (Chaillou, 2019). Next, he used a framework, Pix2Pix, which is a standard generative adversarial neural network (GAN) model. There are two components in the model, the Generator and the Discriminator, which allow the model to operate in a feedback loop to refine the model's ability to generate floor plans. While the Discriminator is used to recognize images from data, the Generator can create images that are similar to the ones in the data. In response, the Discriminator then provides feedback for the Generator to improve on. As this process continues, a GAN is trained to create synthetic images.

Chaillou adopted the model from this project in a large-scale housing development project located in Manhattan's Lower East Side. This project explores the potential of AI in floor plan design: firstly, it can aid architects in creating cohesive room arrangements and furnishings; secondly, it can reconstruct all apartment units into a preliminary floor plan; and thirdly, transform floor plans from one style to another.

## 5. Conclusion and Future Work

As AI technology advances, the architectural design field will continue to be affected. Emerging technologies, such as real-time simulation, augmented reality, and integrative design, hold the promise of reshaping the future of architectural practice. Fueled by advanced machine learning algorithms, real-time simulation can provide architects with dynamic, interactive models that respond to real-world conditions, facilitating more accurate design decisions. Augmented reality, seamlessly integrated with architectural workflows, could offer architects immersive experiences, allowing them to visualize and modify designs on-site, enhancing precision and client engagement. Integrative design, propelled by machine learning's data-driven insights, encourages cross-disciplinary collaboration, ensuring that architecture evolves in harmony with other domains like sustainability, engineering, and urban planning. These technological advancements, coupled with the creative ingenuity of architects, herald an era where design becomes more efficient, adaptable, sustainable, and attuned to the evolving needs of society.

The direction of AI in architectural development is not certain, but multiple researches have been conducted to collect the opinions of designers and researchers with expertise in artificial intelligence regarding the future development of architectural design. Imdat As, an assistant professor of architecture with expertise in digital design, believes that AI can drastically improve our built environment since architects have more time to "reach a much wider audience and provide access to quality design to a broader portion of the public" (As, 2018). However, some interviewees believe that AI still lacks accessibility in architecture because of the lack of data and technology. Nonetheless, experts agree that artificial intelligence "will be highly useful for professional practice over the next ten years" (Gallo, 2020). To facilitate this transformation, AI integration into the workflows of modern design firms is imperative, and architects must acquire the necessary skills to effectively employ these tools, ensuring they remain at the forefront of their field.

## References

[1] Asri, Youne. AI in Architecture: Exploring the Benefits, Drawbacks, and Innovative Differences. https://bootcamp.uxdesign.cc/ai-in-architecture-exploring-the-benefits-drawbacks-and-innovative-differences-b1a5a719a2bc.

[2] Brodsky, S. (2020, December 9). How AI is Changing Architecture. Lifewire. Retrieved April 13, 2022, from https://www.lifewire.com/how-ai-is-changing-architecture-5090676

[3] Chaillou, Stanislas. "AI Creates Generative Floor Plans and Styles with Machine Learning at Harvard | ArchDaily." ArchDaily, ArchDaily, 5 June 2019, https://www.archdaily.com/918471/ai-creates-generative-floor-plans-and-styles-with-machine-learning-at-harvard.

[4] Dhawan, Vidushi. "Artificial Intelligence Will Have a Direct Impact on Future Urban Planning – OpenGov Asia." OpenGov Asia, 2 Mar. 2020, https://opengovasia.com/artificial-intelligence-will-have-a-direct-impact-on-future-urban-planning/.

[5] Donaldson, James E. With or Without AI; The Architect's Methodology. 20 June 2023, https://www.linkedin.com/pulse/without-ai-architects-methodology-james-jed-donaldson/.

[6] Dr. Kai Oberste-Ufer. "7 Ways Artificial Intelligence Is Revolutionizing Architecture." EN - Dormakaba Blog, https://www.facebook.com/dormakabaGLOBAL/, 2 Sept. 2019, https://blog.dormakaba.com/7-ways-artificial-intelligence-is-revolutionizing-architecture/.

[7] Eltay, Mohamed, et al. "Generative Adversarial Network Based Adaptive Data Augmentation for Handwritten Arabic Text Recognition." PeerJ Computer Science, PeerJ, Jan. 2022, p. e861. Crossref, doi:10.7717/peerj-cs.861.

[8] Gallo, Giuseppe, and wirz. "(PDF) The Role of Artificial Intelligence in Architectural Design: Conversation with Designers and Researchers | Giuseppe Gallo and Fulvio Wirz - Academia.Edu." Academia.Edu - Share Research, 1 Jan. 2020, https://www.academia.edu/44902106/The_role_of_Artificial_Intelligence_in_architectural_design_conversation_with_designers_and_researchers.

[9] Goyal, Shweta. “GANs — A Brief Introduction to Generative Adversarial Networks | by Shweta Goyal | Analytics Vidhya | Medium.” Medium, Analytics Vidhya, 2 June 2019, https://medium.com/analytics-vidhya/gans-a-brief-introduction-to-generative-adversarial-networks-f06216c7200e.

[10] “IBM Developer.” IBM Developer, https://developer.ibm.com/articles/cc-machine-learning-deep-learning-architectures/. Accessed 22 Sep. 2023.

[11] Mahesh, Batta. “Machine Learning Algorithms - A Review.” International Journal of Science and Research , Jan. 2020.

[12] McCarthy, John. Formalizing Common Sense. Intellect Books, 1990.

[13] Reddy, Vinod. “How Is Artificial Intelligence (AI) Changing the Future of Architecture?” AiThority, https://www.facebook.com/AiThority, 16 Jan. 2020, https://aithority.com/guest-authors/how-is-artificial-intelligence-ai-changing-the-future-of-architecture/.

[14] Tamke, Martin, et al. “Machine Learning for Architectural Design: Practices and Infrastructure.” International Journal of Architectural Computing, June 2018