

# From Science Fiction to Science Facts: Digital Architects

Prasasto Satwiko<sup>1,\*</sup> Brigitta Michelle<sup>1</sup>

<sup>1</sup> Department of Architecture, Faculty of Engineering, Universitas Atma Jaya Yogyakarta, Yogyakarta, Indonesia

\*Corresponding author. Email: [prasasto.satwiko@uajy.ac.id](mailto:prasasto.satwiko@uajy.ac.id)

## ABSTRACT

The current development of artificial intelligence (AI) may encourage the digital architect emergence. It is an artificial-intelligence-powered software that approaches the architectural design process from upstream to downstream in an integrated and comprehensive manner and works autonomously. This paper reviews research in the field of AI to discuss the development of the concept of the digital architect. The result explained the presence of digital architect software as a necessity to bring more efficient and holistic architectural design. Furthermore, we concluded that the final development of the digital architect might be only a matter of time, considering the advancements of intelligent robot technology.

**Keywords:** *Architecture design, Artificial intelligence, Autonomous robot, Digital architect.*

## 1. INTRODUCTION

The future of computers with equal capacity as humans in creative work may become less fictional, considering the rapid advances in artificial intelligence (AI) technology and artificial awareness. The emergence of these creative computers is also a high possibility in architecture. Digital technology has been in the architecture world since the 1960s [1]. In the beginning, digital technology was solely a tool for drawing. Today, digital technology has been used in the architectural design process [2,3]. It also becomes an essential tool that aids design decisions with interdisciplinary approaches [4,5] as the need for a more efficient, effective, and holistic design increases.

Devising architect-friendly applications to aid the design process has been a long-sought interest. They should consider how architects think and present their work to prevent difficulties that can hinder the project altogether. Currently, there are various applications that aid architects in the design process. However, many are solely for modeling or analyses, not both. For instance, Andrew Marsh's Ecotect is an application that solely helps analyze the environmental performances of buildings [6]. Because it does not support detailed architectural designs, architects need another application as a drawing tool.

Some applications unify the design environment for architects, engineers, and contractors with BIM

(Building Information Modeling) software such as Revit and Archicad. Although architectural BIM applications are becoming an industry standard [7], they are still partial in providing a more integrated workflow.

Meanwhile, the development of comprehensive and integrated architectural design applications is increasing. Those applications can unite the architectural design processes in various stages, from the conceptual to the final design. For instance, SketchUp allows users to model architectural drawings and analyze the environmental performances using plugins (such as Sefaira and OpenStudio). These multi-functional applications may encourage the emergence of more sophisticated applications as both a drawing and analyzing tool. Moreover, AI technology can also help further these applications as a thinking tool for architects.

This paper presents the theoretical concept of the realization of a digital architect. We define the digital architect as artificial-intelligence-powered software that can provide both design tools and multi-disciplinary design thinking for architects. Its emergence is just a matter of time with the increasing development of powerful processors and AI. People used to believe that computers could never imitate and supersede the role of architects regarding creativity and imagination. However, the defeat of the world chess champion (Garry Kasparov) by Deep Blue (IBM) [8] and game

champion Go (Lee Sedol) by Alpha Go [9] shake the monopoly of imagination as uniquely human property. Those two games represent the superiority of humans in imagination and creativity. Indeed, the wins are still under debate. Many argue that the advantage of computers is only in their ability to process information faster. However, a study showed that generating floor plans with AI is possible [10]. Another study showed developing 3D building designs with the generative adversarial network was also attainable [5]. How can computers provide creative solutions? Algorithms help the software process data and determine the most mathematically plausible solutions in both cases. Now, perhaps, the answer lies in a more philosophical question: what is creativity? Is the creative process independent from the standard logic? Consequently, the answers may aid in providing more groundbreaking software for architects.

## 2. THEORETICAL REVIEW

### 2.1. Robot

Humans have long dreamed of a machine with whom they can communicate. Robots (now, computers in general) fulfill the description somehow. We can parallel the conception of how humans build robots and how God formed humans according to the Genesis creation narrative. Both creations represent the creator's image. Moreover, both are born to work. The Bible views humans as God's workers to rule over the earth [11]. Meanwhile, the word robot means forced labor, first introduced by Karel Čapek in 1921 [12]. Thus, the idea of robots as helpers for humans has existed since the beginning.

### 2.2. Digital Architecture

The term *digital architecture* refers to digital technology usage in architectural practice [13]. The presence of digital technology fills the gaps in the conventional design process. Further digital architecture explorations have made how previously unimaginable building forms can come to life, such as Zaha Hadid Architects' Heydar Aliyev Center and Galaxy Soho. It is now also possible to build unconventional architectural forms because of digital fabrication technology [14].

Digital architecture is maturing. Currently, digital technology usage in architecture is no longer limited to an architectural presentation tool, solely as added hands for architects [2]. Instead, digital technology has become a tool for thinking, now as added brains for architects [3]. Computers can currently be involved in the architect's thinking process, becoming like an external brain. Thus, the process does not occur entirely in the architect's brain.

### 2.3. Architecture Design Process

An architect requires relevant data and processes them appropriately to produce excellent architectural works. Even an ordinary residential building demands plenty of information to deliver a desirable design. In that case, however, the architect and the client may decide to ignore some data that they are considered a hassle and not worth their time. Of course, ignoring such data reduces the accuracy of the design.

In large-scale buildings, ignoring data that seemed lowly relevant may potentially affect design accuracies throughout the building's life cycle [15]. A design process begins from data collection and proceeds to data selection, per-data analysis, cross-analysis, etc. This profoundly detailed design process is complex, lengthy, and tiresome. Although several applications are available for design analysis, architects still need to integrate the separated analysis result into one design. The process is tedious as the results are interrelated and affect other elements. For instance, increasing the total glazing area for natural light may impact the indoor air temperature [16]. Computer processors can process humongous data integrated and comprehensively with the appropriate algorithms. Moreover, they can also provide design solutions, as shown by several AI technologies [5,10]. It initiates opportunities for more integrated architectural applications, and in effect, leads to the emergence of computers as digital architects.

### 2.4. Artificial Intelligence in Architecture

Kurzweil predicted that in 2045 there would be technological singularity [17]. It also hypothesized that computers become independent entities and thinkers with abilities that surpass the human brain [18]. Hollywood movies such as *Transcendence* and *CHAPPiE* have also prophesied the future with a digital entity that is independent, creative, and conscious without human interventions. If technological singularity indeed happens, then it will be Hollywood fiction coming to life. Meanwhile, AI development in architecture now allows design generation [5], analysis [4], and creativity [19]. It is now possible to generate a 2D or 3D design for architecture with AI technology.

In contrast to the use of robots in the industrial world, their use in the world of architecture is quite late. But this depends on which side we look at the role of the robots. Robots are widely used in industrial objects that will later be used in buildings. It means the robot has been involved indirectly. Currently, robots are also involved in the fabrication of buildings. However, robots involved in the planning process, let alone autonomous entities, are still in the form of promising ideas [20].

Separately, artificial intelligence has been applied to aspects related to architecture, such as landscape design. The study found that using artificial intelligence in landscape design has many advantages over manual methods. Artificial intelligence scores are relatively high [21]. In other fields, such as product design, artificial intelligence is also beneficial in finding new forms through the parameters set [22].

### 3. METHODS

This paper reviews research in the field of AI published in reputable journals and surveys on the

internet about the trending phenomenon of using AI to replace human thinking processes. The trend forces humans to be aware of AI's impact in many areas of life. Thus, replacing the activity of human architects with computers (digital architects) may entirely be a matter of time.

### 4. RESULTS

We gathered data literature review based on the design process focus and the implemented AI technology below in Table 1.

**Table 1.** Literature review

Ref	Year	Topic	Focus	Technology
[23]	1999	Automatic design synthesis with artificial intelligence techniques	Design generation	Neural networks and genetic algorithms
[4]	2014	Modeling heating and cooling loads by artificial intelligence for energy-efficient building design	Design analysis	Support vector regression (SVR), artificial neural network (ANN)
[5]	2018	Artificial intelligence in architecture: Generating conceptual design via deep learning	Design generation	Deep learning, generative adversarial networks (GAN)
[24]	2018	Does AI make PD obsolete? exploring challenges from artificial intelligence to participatory design	Design approach	Machine learning
[19]	2019	An artificial intelligence-based data-driven approach for design ideation	Design ideation	GAN
[10]	2019	Generation of Floor Plan Variations with Convolutional Neural Networks and Case-based Reasoning	Design generation	Convolutional Neural Networks (CNN)
[25]	2019	Deep learning architect: Classification for architectural design through the eye of artificial intelligence	Design analysis	Deep learning (deep convolutional neural network), computer vision
[26]	2020	Inference of drawing elements and space usage on architectural drawings using semantic segmentation	Design preparation	Deep learning

Table 1 shows how AI can benefit most processes, from design preparation to design generation. Various neural networks technology can help architects to make creative decisions.

Both in 2D and 3D, design generation is now possible with AI technology. The intended purpose of the technology was for design in general, shown by Vico et al. using neural networks and genetic algorithms for designing a telephone handset [23]. Currently, generative adversarial networks (GAN) [5] and convolutional neural networks (CNN) [10] can generate 2D and 3D architectural designs.

Design creativity is also achievable with GAN. Chen et al. studied the possibility of generating images with two distinct concepts [19]. It can aid architects in the initial and conceptual visualization of a project.

Meanwhile, the artificial neural network (ANN) and CNN can aid design analysis. For example, Chou and Bui used ANN to estimate buildings' heating and cooling loads [4]. Yoshimura et al. used CNN for detecting similarities of different architectural works [25].

Design preparation is also possible with deep learning. For example, Seo et al. studied how deep learning technology can label images for automatic

design [26]. Meanwhile, a design approach with machine learning is also feasible. For example, Bratteteig and Verne showed it might help to process data in the participatory design approach [24].

## 5. DISCUSSION

Architectural design is a rational process that systematic arrangement is possible. In the past, Vitruvius divided architectural aspects into three, namely *firmitas* (strength), *utilitas* (utility), and *venustas* (beauty). Today, these three aspects remain valid but have grown more complex and detailed. Although said to be logical, architectural design involves tangible-intangible and concrete-abstract matters. These features, in return, affect the position of architecture education in many universities. Some include the discipline in the engineering field, while some include it in the arts. Engineering relates to the exact mathematical science, relatively straightforward with numbers. Meanwhile, art is subjective and less obvious to value.

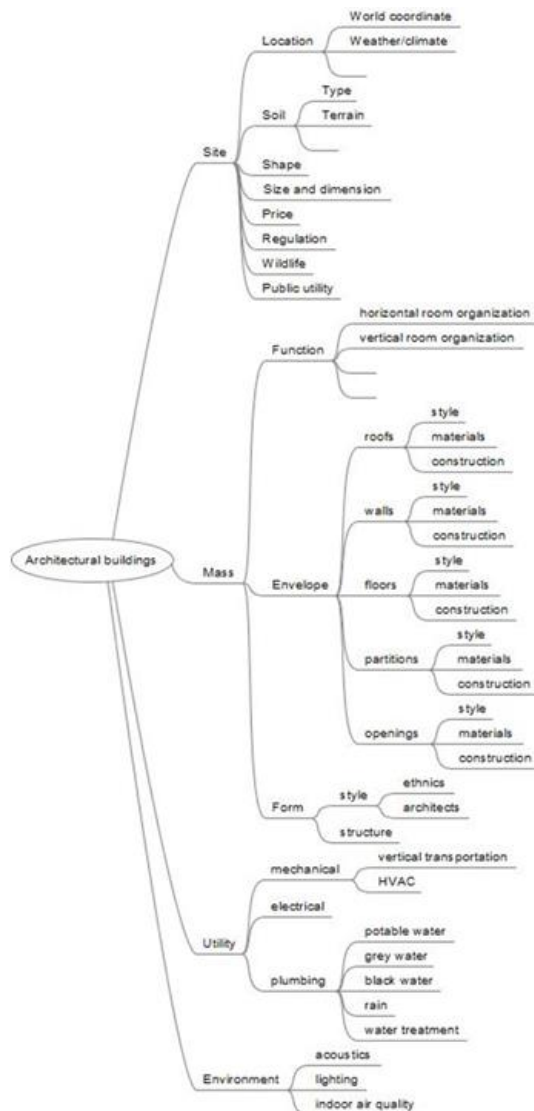
Architecture's aesthetic aspect (*venustas*) may involve art driven by emotions [27]. Often considered as a uniquely human trait, the emotion-influenced aesthetic is irreplaceable by machines. Human emotions are closely related to psychological matters [28,29], currently nonexistent in computers. It has been the subject of studies and debates whether robots can have the emotions required to create works of art [30]. Further discussion can ask the meaning of an aesthetic work of art. Computers may have the capacity to produce images or music, for example, that seems or sound appealing [31,32].

On the other hand, not all humans can create beautiful works of art. Meanwhile, computers can produce something considered artistic by humans [2]. Computational creativity is still a matter of debate. Currently, AI is used for analysis and synthesis as a tool in building environment design; not integrated and autonomous in the creative process [33]. The involvement of AI in the art world continues to grow, such as in interactive installation art [34], so that the role of AI in the art aspect in the context of architecture is not impossible. If AI cannot replace human creativity, at least AI can increase human creativity [35].

The digital architect algorithms should start from the most basic design process flow. Consequently, they can proceed one step at a time, indicated by the increasing completeness and complexity of the design. The architectural design also follows a pattern like the production process in general: input → process → output. In detail, the flow starts from the design objectives (the input), namely identifying the desired design to meet the needs (the output). The design objectives need to be processed correctly to obtain a suitable architectural design. Thus, the workflow becomes more detailed: formulation of clients' needs → design process → product design that meets clients' needs. The process is repeatable (iterations) until convergence occurs, resulting in an optimal architecture form.

Organizing each fundamental stage into sub-processes (similar to modules) that account for different aspects is possible. These sub-processes communicate their input-output to each other to achieve the main result. Each sub-process may involve highly complex calculations. In effect, it demands a vast capacity of processors and memory to perform complicated computations quicker. The presence of high-speed and large-capacity computers has accelerated these calculations.

The main obstacle of creating the digital architect is to unify all elements of the design process. Figure 1 shows the aspects of architectural design elements. Each part may have many variations depending on its context. Combining them creates complex combinations that can be potentially incompatible together. For instance, several variables may determine the decision for developing the spatial organizations of a residential house: the number of occupants, their hierarchical status, their customs/cultures/habits, the climate, the location of public roads, the cost set, and the land area. This issue can be solved by, for one, priority. For example, the customs of a nation may have specific architectural guidelines that govern the spatial organization of a dwelling [36,37]. If this priority is selected, for instance, then other elements will follow. Likewise, if the focus is the upper limit of costs, the remaining variables will attend variations closest to that limit.



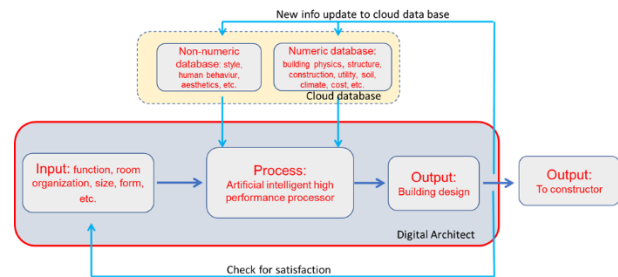
**Figure 1** Exploring aspects of architecture design elements (source: authors).

## 6. CONCLUSIONS

The literature review shows how AI can be valuable in most design processes, from preparation to production (design generation). It also displays how the digital architect is a high possibility in the future. Applications that comprehensively unite data analysis for architectural design will be a big help for architects. Those applications allow architects to focus on more issues above what algorithms can solve. Figure 2 shows how the digital architect is possible with varying functions. The architecture design process can be automated if design thinking and computational thinking can be harmonized [38].

Theoretically, the presence of a digital architect makes a lot of sense. However, when an independent digital architect is present, is highly dependent on the development of digital technology, maybe a few decades [39]. To be sure, architectural education must

be prepared for the changes that AI brings in the world of architecture [40]. The combination of building information modeling and blockchain is one example of how management in the complex construction world can be handled [41].



**Figure 2** Schematic concept of the digital architect (source: authors).

## REFERENCES

- [1] K. Pierce Meyer, "Technology in Architectural Practice: Transforming Work with Information, 1960s–1990s," *Inf. Cult.*, vol. 51, no. 2, pp. 249–266, Mar. 2016.
- [2] N. Gu and P. Amini Behbahani, "A Critical Review of Computational Creativity in Built Environment Design," *Buildings*, vol. 11, no. 1. 2021.
- [3] R. Martin, N. Bredella, and C. Höfler, "Material networks: architecture, computers, and corporations," *Archit. Res. Q.*, vol. 21, no. 1, pp. 74–80, 2017.
- [4] J.-S. Chou and D.-K. Bui, "Modeling heating and cooling loads by artificial intelligence for energy-efficient building design," *Energy Build.*, vol. 82, pp. 437–446, 2014.
- [5] I. As, S. Pal, and P. Basu, "Artificial intelligence in architecture: Generating conceptual design via deep learning," *Int. J. Archit. Comput.*, vol. 16, no. 4, pp. 306–327, Nov. 2018.
- [6] K. Mehaoued and B. Lartigue, "Influence of a reflective glass façade on surrounding microclimate and building cooling load: Case of an office building in Algiers," *Sustain. Cities Soc.*, vol. 46, p. 101443, 2019.
- [7] Y. Lu, Z. Wu, R. Chang, and Y. Li, "Building Information Modeling (BIM) for green buildings: A critical review and future directions," *Autom. Constr.*, vol. 83, pp. 134–148, 2017.
- [8] G. Mani, "Artificial Intelligence's Grand Challenges: Past, Present, and Future," *AI Mag.*, 2021.

- [9] S. Byford, "AlphaGo, a project of Google AI subsidiary DeepMind," Quartz, 2016. .
- [10] V. Eisenstadt, C. Langenhan, and K.-D. Althoff, "Generation of Floor Plan Variations with Convolutional Neural Networks and Case-based Reasoning - An approach for transformative adaptation of room configurations within a framework for support of early conceptual design phases," in *Architecture in the Age of the 4th Industrial Revolution - Proceedings of the 37th eCAADe and 23rd SIGraDi Conference - Volume 2*, 2019, pp. 79–84.
- [11] J. Cohen, *Be fertile and increase, fill the earth and master it: the ancient and medieval career of a Biblical text*. Ithaca: Cornell University Press, 1989.
- [12] Preceden, "History Of Robots Timeline | Preceden," 2021. [Online]. Available: <https://www.preceden.com/timelines/625227-history-of-robots>. [Accessed: 18-Oct-2021].
- [13] A. Picon, "Beyond Digital Avant-Gardes: The Materiality of Architecture and Its Impact," *Archit. Des.*, vol. 90, no. 5, pp. 118–125, Sep. 2020.
- [14] P. Schumacher, "Tectonism in Architecture, Design and Fashion: Innovations in Digital Fabrication as Stylistic Drivers," *Archit. Des.*, vol. 87, no. 6, pp. 106–113, Nov. 2017.
- [15] T. Di Noia, M. Mongiello, F. Nocera, and U. Straccia, "A fuzzy ontology-based approach for tool-supported decision making in architectural design," *Knowl. Inf. Syst.*, vol. 58, pp. 83–112, 2019.
- [16] R. Amini, A. Ghaffarianhoseini, A. Ghaffarianhoseini, and U. Berardi, "Numerical investigation of indoor thermal comfort and air quality for a multi-purpose hall with various shading and glazing ratios," *Therm. Sci. Eng. Prog.*, vol. 22, p. 100812, 2021.
- [17] R. Kurzweil, *The singularity is near: When humans transcend biology*. New York: The Viking Press, 2005.
- [18] B. Nicolescu, "Technological Singularity: The Dark Side BT - Transdisciplinary Higher Education: A Theoretical Basis Revealed in Practice," P. Gibbs, Ed. Cham: Springer International Publishing, 2017, pp. 155–161.
- [19] L. Chen et al., "An artificial intelligence based data-driven approach for design ideation," *J. Vis. Commun. Image Represent.*, vol. 61, pp. 10–22, 2019.
- [20] A. Picon, F. Roche, and T. Verebes, *Made by robots*. 2014.
- [21] B. Zhu, "Influence of Computer Intelligence on Landscape Design," in *Journal of Physics: Conference Series*, 2021.
- [22] W. Yang, J. N. Su, S. Zhang, K. Qiu, and X. Zhang, "Intelligent Design of Product Forms Based on Design Cognitive Dynamics and a Cobweb Structure," *Comput. Intell. Neurosci.*, 2021.
- [23] F. J. Vico, F. J. Veredas, J. M. Bravo, and J. Almaraz, "Automatic design synthesis with artificial intelligence techniques," *Artif. Intell. Eng.*, vol. 13, no. 3, pp. 251–256, 1999.
- [24] T. Bratteteig and G. Verne, "Does AI Make PD Obsolete? Exploring Challenges from Artificial Intelligence to Participatory Design," in *Proceedings of the 15th Participatory Design Conference: Short Papers, Situated Actions, Workshops and Tutorial - Volume 2*, 2018.
- [25] Y. Yoshimura, B. Cai, Z. Wang, and C. Ratti, "Deep Learning Architect: Classification for Architectural Design Through the Eye of Artificial Intelligence," in *Computational Urban Planning and Management for Smart Cities*, S. Geertman, Q. Zhan, A. Allan, and C. Pettit, Eds. Cham: Springer International Publishing, 2019, pp. 249–265.
- [26] J. Seo, H. Park, and S. Choo, "Inference of drawing elements and space usage on architectural drawings using semantic segmentation," *Appl. Sci.*, 2020.
- [27] G. Gernot, M. Pelowski, and H. Leder, "Empathy, Einfühlung, and aesthetic experience: the effect of emotion contagion on appreciation of representational and abstract art using fEMG and SCR," *Cogn. Process.*, vol. 19, pp. 147–165, 2018.
- [28] M. Hiebler-Ragger, J. Fuchshuber, H. Dröschner, C. Vajda, A. Fink, and H. F. Unterrainer, "Personality Influences the Relationship Between Primary Emotions and Religious/Spiritual Well-Being," *Front. Psychol.*, vol. 9, p. 370, 2018.
- [29] D. Furnes, H. Berg, R. M. Mitchell, and S. Paulmann, "Exploring the Effects of Personality Traits on the Perception of Emotions From Prosody," *Front. Psychol.*, vol. 10, p. 184, 2019.
- [30] O. Nocentini, L. Fiorini, G. Acerbi, A. Sorrentino, G. Mancioffi, and F. Cavallo, "A Survey of Behavioral Models for Social Robots," *Robotics*, vol. 8, no. 3, 2019.
- [31] M. Ragot, N. Martin, and S. Cojean, "AI-Generated vs. Human Artworks. A Perception Bias Towards Artificial Intelligence?," in *Extended*

Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, 2020, pp. 1–10.

- [32] J. Wu, X. Liu, X. Hu, and J. Zhu, “PopMNet: Generating structured pop music melodies using neural networks,” *Artif. Intell.*, vol. 286, 2020.
- [33] N. Gu and P. Amini Behbahani, “A critical review of computational creativity in built environment design,” *Buildings*. 2021.
- [34] Y. Cao, Z. Han, R. Kong, C. Zhang, and Q. Xie, “Technical Composition and Creation of Interactive Installation Art Works under the Background of Artificial Intelligence,” *Math. Probl. Eng.*, 2021.
- [35] K. German, M. Limm, M. Wölfel, and S. Helmerdig, “Towards Artificial Intelligence Serving as an Inspiring Co-Creation Partner,” *EAI Endorsed Trans. Creat. Technol.*, 2019.
- [36] I. B. A. Wicaksana, “The art of space and architecture; Asta Kosala Kosali and Asta Bumi,” *Bali Tour. J.*, vol. 2, no. 1, pp. 14–18, 2018.
- [37] N. S. Steinhardt, *Chinese Architecture: A History*. Princeton, NJ: Princeton University Press, 2019.
- [38] N. Kelly and J. S. Gero, “Design thinking and computational thinking: A dual process model for addressing design problems,” *Des. Sci.*, 2021.
- [39] J. Kołata and P. Zierke, “The decline of architects: Can a computer design fine architecture without human input?,” *Buildings*. 2021.
- [40] D. Trabucco, “Will artificial intelligence kill architects? An insight on the architect job in the AI future,” *TECHNE - J. Technol. Archit. Environ.*, pp. 128–132, Mar. 2021.
- [41] Z. Liu, L. Jiang, M. Osmani, and P. Demian, “Building information management (BIM) and blockchain (BC) for sustainable building design information management framework,” *Electron.*, 2019.