AI-Enhanced Facade Design: Exploring the Synergy of Generative Models and Architectural Creativity

Domenico D'Uva

Abstract

The intersection of artificial intelligence (AI) and architectural design unfolds a transformative potential for traditional design processes. The role of AI can be divided into three different areas: generating initial layouts, optimising form during initial design phases, and improving energy efficiency and sustainability. Generative models can propose innovative layouts and optimise designs for aesthetics, functionality, and structural integrity. Artificial intelligence also helps reduce energy consumption by optimising building designs and integrating sustainable materials. The study involved some of the 100 design school students who Stable Diffusion to generate facades and furniture. The students who used AI methods improved their grades on average than their colleagues who used traditional methods. Future research aims to improve the role of AI in design optimisation and sustainability and to develop workflows to integrate AI-generated projects into BIM-compatible models. This study highlights the potential of AI in revolutionising architectural design with practical and innovative solutions that meet industry standards.

Keywords
Artificial Intelligence, Architectural Design, Generative Models

Generation of night view facade based on Stable Diffusion prompts. Authors of *Bosco Panoramico*: Gloria Di Gregorio, Anna Gaioni, Misia Lingua, Mascia Maestri, Chiara Onofri.

doi.org/10.3280/oa-1180-c487

Introduction

The confluence of artificial intelligence (AI) and architectural design is an emerging research domain that aims to harness AI's potential to transform architectural design processes. This study investigates the multifaceted role of AI in architecture, focusing on three pivotal areas: the inception of layout ideas, the optimisation of form during the early design stages, and resolving energy efficiency and sustainability issues. Each of these areas represents a unique yet interconnected facet of architectural design, where AI can make a significant impact.
The initial phase of architectural design, marked by creating the basic layout idea, is vital for determining the project's trajectory. AI, particularly through generative models, provides a fresh approach to this phase by facilitating the swift generation of diverse design concepts based on specific criteria or design briefs. These AI-powered tools can process vast amounts of data to suggest innovative layout ideas that may not be readily discernible through conventional design methods.
Following the establishment of a basic layout idea, the subsequent step involves refining the design to optimise its form. This optimisation process is multifaceted, involving aesthetic, functional, and structural considerations. AI algorithms, particularly those based on machine learning and optimisation techniques, can assess multiple design variations against a set of predefined objectives. This could expedite the design process but also ensure that the proposed solutions are innovative and feasible, considering factors such as material efficiency, structural integrity, and spatial dynamics.
The final focus area is the application of AI in tackling the critical issues of energy efficiency and sustainability in architectural design. The construction and operation of buildings contribute significantly to global energy consumption and carbon emissions. AI can play a crucial role in mitigating these impacts by optimising building designs for reduced energy consumption and integrating sustainable materials and technologies. Through predictive modelling and simulation, AI can project the energy performance of buildings under various scenarios, guiding architects in making informed decisions that align with sustainability goals. The experimentation in this work only concerns the first section, i.e. support in the initial stages of design, as explained in the following sections.
In conclusion, integrating AI into architectural design processes could revolutionise traditional practices in ways that seem unpredictable today.

State-of-the art

This subchapter analysed the scientific literature dealing with the relationship between artificial intelligence and architectural façade design. The synergy between the study of facades and the study of the volumetric mass connected to them was explored [Wang et al. 2022]. This study allows for an improvement in the artefact's efficiency that would be lost by studying the façade alone. Other studies evaluate the automatic genesis of the architectural façade in relation to its urban context [Sun et al. 2022]. This procedure is conducted with a GAN (generative adversarial network) [Ali & Lee 2023; Karras et al. 2019] and generate designs that show a good level of accuracy, correspondence with reality, and a fair diversity of results.
An interesting approach to the façade design problem is the work of [Sermarini et al. 2022], who changes the point of view. Whereas conventional façade representation is done from the outside, in this research, the problem is examined from the inside. Through Mixed/Augmented Reality and BIM methodologies, a retrofitting of the artefact is implemented. The optimal solution to the façade design problem is thus found through a perceptive approach.
An even more advanced approach of artificial intelligence in façade design in a context was pioneered by [Zhang et al. 2022]. A CGAN (conditional generative adversarial network, an evolution of GAN) by [Mirza & Osindero 2014] technology was used. This research showed the possibility of producing reference frameworks for the construction of buildings of conventional architecture. The development of experimental facades that can fit in syner-

gistically with the existing urban fabric was also experimented with. A field of experiments of particular interest [Hosseini et al. 2020] studies the dynamic position of coloured transparent elements. It uses artificial intelligence methodology to improve the quality of light perceived by the position of the occupants. To this area of study belongs [Takhmasib et al. 2023] work, which developed an electromagnetic hexagonal KF mechanism, and three machine-learning (ML) regressors (eXtreme Gradient Boosting (XGB), Random Forest (RFR), Decision Tree) that predicts light dynamics. A work which works out façade parametric modelling [Son & Huyen 2023] employs dynamism, colour and environmental analysis and generates high precision results. Façade optimisation can follow LEED certification by using a peculiar algorithm called African Vulture Optimization Algorithm', which works through a meta-heuristic approach.
Recent developments in large language models (LLM) and generative AI have unleashed the astonishing capabilities of text-to-image generation systems to synthesise high-quality images that are faithful to a reference text, known as a "prompt". The three prominent text-to-image AI engines are DALL-E, Midjourney, and Stable Diffusion [Xie et al. 2023]. These generative

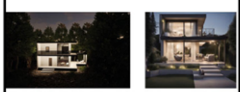
Motto	AI generated / Rendered 3d model	AI text prompt
1. Reflective nook		Front elevation of a one-story building by Raphael Soriano
3.Komorebi		professional photo of the bathroom of a small two-story house, perspective view, 1024.1024 resolution, wabi sabi style effortless, without wall
5.Bosco Panoramico		Night Exterior of a two-storey detached house with balcony and lights'.
6. The Compose		House with two floors, simple and bright with big window
10. Ti House		a. Exterior of a two-storey Scandinavian wooden house with large windows. Geometric and essential architecture. Dominant colours: black, white and brown
		b. Cosy Scandinavian living room with large windows and fireplace. White, black and wooden furniture "
		c. Wooden wardrobe with glass doors and dressing table
		d. Scandinavian-style sofa with wooden frame and soft white cushions

Fig. 1. Generation of architecture and furniture based on the Stable Diffusion Prompts. Comparison of Generated images and 3d modelling. Building 1- 3 - 5 - 6. The image on the left of each building is generated by artificial intelligence. The one on the right represents the 3D model built from the prompt. Building 10 represents respectively: (a) Three top views created by the AI and the two bottom views rendered from the 3D model. (b) Three AI-generated views of the interior of the residence. (c) (d) The top left view is generated by the AI. The rest of the images are modelled and rendered from the original view. Authors of Reflective nook: Zeno Ferrari, Maria Vittoria Finarelli, Costanza Mignemi, Lucia Mancin, Massimo di Castri; Komorebi: Giorgia Maria Di Cato, Rayane Ech Chaibi, Giulia Marelli La Pera, Alice Pagliari, Riccardo Paniccia; Bosco Panoramico: Gloria Di Gregorio, Anna Gaioni, Misia Lingua, Mascia Maestri, Chiara Onofri; The Compose, Davide Furgeri, Michel Guilavogui, Sonia Morselli, Marta Padovani; Ti House: Francesco Detomaso, Alberto Distefano, Irene Dominici, Maria Giulia Ielati, Monica Levi.

models have been developed to process textual input and produce high-fidelity images that correspond to the text descriptions. They leverage advanced neural network architectures, such as diffusion models, to synthesise images through a process that introduces and then gradually removes noise. Integrating these models with large language models has significantly improved their performance, making the generated images nearly indistinguishable from real-world photographs. These models have been utilised in various fields, including game development, architectural design, and the generation of photorealistic images, demonstrating their versatility and the growing interest in AI-driven creative processes.
Midjourney and Stable Diffusion, has revealed their potential to serve as collaborative entities in the ideation phase [Petráková, Šimkovič 2023]. These models can generate preliminary design concepts, thereby facilitating innovation within the design process. Despite their utility, these AI models exhibit certain limitations, including a predisposition towards aesthetic generation over functional comprehension. This observation leads to the development of methodologies for effectively integrating AI into architectural design workflows. The proposed strategies emphasise the critical role of iterative feedback and adaptation in harnessing the capabilities of AI, thereby optimising the design process, and fostering innovation.
The present work aims to explore and explain the potential of machine learning methods in generating building facades, providing a comprehensive analysis of existing techniques, and proposing innovative approaches for future research and practical applications.

Fig. 1. Three top views created by the AI and the two bottom views rendered from the 3D model. Authors: Francesco Detomaso, Alberto Distefano, Irene Dominici, Maria Giulia Ielati, Levi Monica Levi.

Methodology

To effectively test the possibilities of interaction between artificial intelligence and the design of architectural facades, 100 students from the second year of the Bachelor of Design degree were involved. The course is called Space Modelling Tools. These students were provided with the most common digital tools for representing architecture, such as Revit and Rhinoceros. The students were tasked with modelling a simple building and the furniture contained within it. The 100 students, divided into 20 groups, had the option to choose between modelling a building with technical drawings provided by the teaching staff or a building with a facade generated by the AI Stable Diffusion engine. In the latter case, the volumetric design beyond the façade was left to the student's creativity. Six groups chose this option and generated their respective buildings within these given parameters: two floors and a regular shape. The parameters entered for image generation were geometric, both for generating views and for the number of levels. The challenge of this methodology was to make a tool of virtually infinite flexibility and one with the onerous constraints of Building Information Modelling systems interact in a single digital ecosystem. To achieve the required task, Stable Diffusion was asked to generate buildings in the style of architects whose creations were geometrically regular. The groups made text-requests to AI to generate buildings and furniture as detailed in table a. Although students were given the opportunity to generate furniture with the artificial intelligence tool, most of them do not exploit this road, but one group. They followed a creative path of generation, by writing prompts for the whole building, for the interior and for a selection of furniture. This path accomplished a request for coherency given by the teaching staff. Once the style of the whole building was defined, all the elements in it would follow that pattern.

Fig. 2. Three AI-generated views of the interior of the residence. These views were of great importance for coherence. Authors: Francesco Detomaso, Alberto Distefano, Irene Dominici, Maria Giulia Ielati, Levi Monica Levi.

Results

The results of the experimentation, as shown in fig. 1, were very effective; the students who used the Stable Diffusion model to generate their buildings and furniture reported higher ratings on average compared to those who used traditional methodologies. The major difficulty encountered by the students was to reconcile even very interesting ideas from a figurative point of view with stringent functional requirements. In the first phase, in fact, they all needed guidance to create models that had a link with the starting AI image and the possibility of creating habitable spaces in terms of proportions and windows. The Stable Diffusion model has been extensively employed in architectural image generation, but there is still room for improvement in terms of the controllability of the generated image content. This experimentation could provide a foundation for subsequent studies and teaching methods on the generation of architectural images. Stable diffusion-generated facades are a perfect manifestation of this concept, offering a method to generate randomly stunning facades with endless possibilities. By leveraging the inherent randomness of stable diffusion, designers can explore a vast array of possibilities and discover fascinating facades that can leave a lasting impact. The different textual prompts that were used by the students can be grouped into two families: the generation of the building envelope, the generation of the façade alone, and the generation of individual rooms. Of the 6 groups selected for experimentation, four generated the entire building, two the façade alone. One group, fig. 2, completed the work by generating both the envelope and three environments consistent with the style of the building using the AI engine. From these settings, part of the furniture was modelled. Some furniture was instead generated with the same AI engine. Fig. 3 shows this process; AI furniture model is generated, then 3d model was made up, then rendered and inserted into the room. The result seems promising because no guidance has been provided to student in terms of generation procedure.

Discussion and future developments

Integrating artificial intelligence (AI) into architectural design has opened a new chapter in the evolution of the built environment. This study has laid the groundwork for understanding AI's role in the early stages of design, particularly in generating building facades and pieces of furniture. However, the journey ahead is vast and filled with the potential for further exploration and innovation.
Despite promising, this work possesses several limitations: methodological, theoretical and practical. Methodological limitations are a limited sample size, a lack of control group to compare the result with traditional design methods, and a limited proper interaction with BIM systems. Theoretical limitations embrace the need for a full exploration of the underpinning of AI role in architectural design, in terms of transformation and outcomes; an exploration of AI's potential design in later design phased would be advisable. Practical limitations are the connected to the difficulty of translating all the findings into real-world buildings. The limit in providing information about the dataset from where images are extracted could be improved with an ad hoc array of images to make the set. All these limitations can be overcome through an in-depth study of each individual aspect with targeted research that improves sample size, control group, contextualisation and, above all, control in both theoretical and digital terms.
Future research will aim to extend AI's involvement beyond the initial design stages. By incorporating AI into the optimisation of form and function, it is possible to develop systems that not only suggest aesthetically efficient manufactures, but also ensure their practicality and compliance with building codes and regulations. Integrating AI in later design phases could lead to a more holistic approach, where AI assists in material selection, structural analysis, and even construction planning. Another promising direction is the use of AI to address energy efficiency and sustainability challenges. Future developments will focus on creating AI tools can predict and optimise the energy performance of buildings in the design phase. By simula-

Fig. 3. The top left view is generated by the AI. The top centre view is modelled in Rhinoceros. The top right view is rendered. The large image at the bottom represents the rendered view in which the furniture is placed. Authors: Francesco Detomaso, Alberto Distefano, Irene Dominici, Maria Giulia Ielati, Levi Monica Levi.

ting various environmental scenarios, these tools will help architects design buildings that are not only energy efficient but also resilient to changing climate conditions.
Generative models like Stable Diffusion have shown promise in creating interesting examples of facades. Future iterations will aim to enhance the controllability and specificity of these models, allowing for the generation of images that adhere to more detailed and complex design briefs. This will involve training models on diverse architectural styles and contexts, ensuring that the AI can cater to a wide range of cultural and environmental considerations.
The interaction between AI-generated designs and BIM systems presents a unique challenge. Future research will develop workflows that allow for the smooth transition of AI-generated concepts into BIM-compatible models. Among these digital tools, text-to-BIM seems to be one of the most promising road for evolution. This will enable the detailed planning and execution of AI-assisted designs, ensuring that they are not only innovative but also buildable and compliant with industry standards.

Conclusions

AI integration in architectural design processes has the potential to revolutionise traditional practices. It offers a new paradigm where AI and architectural creativity work together to push design innovation boundaries. This study focuses on AI's role in architectural design, specifically in generating building facades and furniture. It also sets the stage for future research and practical applications that can further utilise AI's potential in architecture. An even more compelling road lies in the interaction between AI-generated designs and BIM systems. Future research will develop workflows that allow for the smooth transition of AI-generated concepts into BIM-compatible models, enabling the detailed planning and execution of AI-assisted designs. This will ensure that AI-generated designs are not only innovative but also buildable and compliant with industry standards. The potential of AI in architectural design extends beyond the initial design stages. By incorporating AI into the optimisation of form and function, it is possible to develop systems that not only suggest aesthetically efficient designs but also ensure their practicality and compliance with building codes and regulations. Integrating AI in later design phases could lead to a more holistic approach, where AI assists in material selection, structural analysis, and even construction planning.

Acknowledgements

Figures have been produced by the following authors:
Reflective nook: Zeno Ferrari, Maria Vittoria Finarelli, Costanza Mignemi, Lucia Mancin, Massimo di Castri.
Komorebi: Giorgia Maria Di Cato, Rayane Ech-Chaibi, Giulia Marelli La Pera, Alice Pagliari, Riccardo Paniccia, Bosco Panoramico, Gloria Di Gregorio, Anna Gaioni, Misia Lingua, Mascia Maestri, Chiara Onofri.
The Compose: Davide Furgeri, Michel Guilavogui, Sonia Morselli, Marta Padovani.
Ti House: Francesco Detomaso, Alberto Distefano, Irene Dominici, Maria Giulia Ielati, Levi Monica Levi.

References

Ali A. K., Lee, O. J. (2023). Facade Style Mixing Using Artificial Intelligence for Urban Infill. In *Architecture*, vol. 3, n. 2, pp. 258–269. <https://doi.org/10.3390/architecture3020015>

Hosseini S. M., Mohammadi M., Schröder,T., Guerra-Santin O. (2020). Integrating interactive kinetic façade design with colored glass to improve daylight performance based on occupants' position. In *Journal of Building Engineering*, n. 31. <https://doi.org/10.1016/j.jobe.2020.101404>

Karras T., Laine S., Aila, T. (2019). A style-based generator architecture for generative adversarial networks. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 4401-4410.

Mirza M., Osindero S. (2014). Conditional Generative Adversarial Nets <http://arxiv.org/abs/1411.1784> (last accessed on 06/08/2024)

Petráková L., Šimkovič V. (2023). Architectural alchemy: Leveraging Artificial Intelligence for inspired design – a comprehensive study of creativity, control, and collaboration. In *Architecture Papers of the Faculty of Architecture and Design STU*, vol. 28, n. 4, pp. 3–14. <https://doi.org/10.2478/alfa-2023-0020>

Sermarini J., Michlowitz R. A., LaViola J. J., Walters L. C., Azevedo R., Kider Jr., J. T. (2022). BIM Driven Retrofitting Design

Evaluation of Building Facades. In *Proceedings of the 2022 ACM Symposium on Spatial User Interaction*, pp. 1–10. <https://doi.org/10.1145/3565970.3567688>

Son P. V. H., Huyen, V. T. B. (2023). Optimizing daylight in west-facing facades for LEED V4.1 Compliance using metaheuristic approach. In *Scientific Reports*, vol. 13, n. 1 <https://doi.org/10.1038/s41598-023-49025-0>

Sun C., Zhou Y., Han Y. (2022). Automatic generation of architecture facade for historical urban renovation using generative adversarial network. In *Building and Environment*, n. 212. <https://doi.org/10.1016/j.buildenv.2022.108781>

Takhmasib M., Lee H. J., Yi H. (2023). Machine-learned kinetic Façade: Construction and artificial intelligence enabled predictive control for visual comfort. In *Automation in Construction*, n. 56. <https://doi.org/10.1016/j.autcon.2023.105093>

Wang, L., Zhang, H., Liu, X., & Ji, G. (2022). Exploring the synergy of building massing and façade design through evolutionary optimization. In F*rontiers of Architectural Research*, vol. 11, n. 4, pp. 761–780. <https://doi.org/10.1016/j.foar.2022.02.002>

Xie Y., Pan Z., Ma J., Jie, L., Mei Q. (2023). A Prompt Log Analysis of Text-to-Image Generation Systems. In *Proceedings of the ACM Web Conference 2023*, pp. 3892–3902. <https://doi.org/10.1145/3543507.3587430>

Zhang L., Zheng L., Chen Y., Huang L., Zhou S. (2022). CGAN-Assisted Renovation of the Styles and Features of Street Facades - A Case Study of the Wuyi Area in Fujian, China. In *Sustainability*, vol. 14, n. 24. <https://doi.org/10.3390/su142416575>

Author
Domenico D'Uva, Politecnico di Milano, domenico.duva@polimi.it

To cite this chapter: Domenico D'Uva (2024). AI-Enhanced Facade Design: Exploring the Synergy of Generative Models and Architectural Creativity. In Bergamo F., Calandriello A., Ciammaichella M., Friso I., Gay F., Liva G., Monteleone C. (a cura di). *Misura / Dismisura. Atti del 45° Convegno Internazionale dei Docenti delle Discipline della Rappresentazione/Measure / Out of Measure. Transitions. Proceedings of the 45th International Conference of Representation Disciplines Teachers.* Milano: FrancoAngeli, pp. 355-362.

 Isbn 9788835166948