APPLICATION OF ARTIFICIAL INTELLIGENCE IN SUPPORTING THE GENERATION AND EVALUATION OF RESIDENTIAL ARCHITECTURAL DESIGN OPTIONS

ỨNG DỤNG TRÍ TUỆ NHÂN TẠO HỖ TRỢ TẠO SINH VÀ ĐÁNH GIÁ PHƯƠNG ÁN THIẾT KẾ KIẾN TRÚC NHÀ Ở

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ABSTRACT

This paper presents a study on the application of Generative Artificial Intelligence (Generative AI) in the field of residential architectural design in Vietnam. The research focuses on two principal dimensions: the automation of design variant generation through advanced Generative AI tools; and the multi-criteria evaluation of design alternatives based on aesthetic, functional, economic, sustainability, and local cultural appropriateness criteria. The paper proposes an AI-integrated design workflow tailored to the practical conditions of small and medium-sized architectural firms in Vietnam.

Keywords: Architectural design, design option evaluation, generative design, Generative AI.

Bài báo này trình bày nghiên cứu về việc ứng dụng trí tuệ nhân tạo tạo sinh (Generative AI) trong lĩnh vực thiết kế kiến trúc nhà ở tại Việt Nam. Nghiên cứu tập trung vào hai khía cạnh chính: tự động hóa quá trình tạo sinh phương án thiết kế thông qua các công cụ Generative AI tiên tiến; đánh giá đa tiêu chí các phương án thiết kế dựa trên yếu tố thẩm mỹ, công năng, chi phí, tính bền vững và phù hợp văn hóa địa phương. Bài báo đề xuất quy trình thiết kế tích hợp AI phù hợp với điều kiện thực tế của các văn phòng kiến trúc vừa và nhỏ tại Việt Nam.

Từ khóa: Generative AI, thiết kế kiến trúc, tạo sinh, đánh giá phương án thiết kế.

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1. INTRODUCTION

Residential architectural design is a field that demands high creativity, integrating aesthetic, functional, economic, sustainable, and cultural factors. Against the backdrop of rapid urbanization in Vietnam, the demand for housing is continuously rising, placing significant pressure on architects to meet multiple client requirements simultaneously within increasingly tight schedules. This is precisely the context in which Generative Artificial Intelligence (Generative AI/Gen-AI/AI) tools can play a vital supporting role.

Around the world, the application of Gen-AI in the construction sector has attracted broad research interest. Key research directions include the use of AI in architectural design, construction supervision, risk management, resource optimization, and construction waste reduction. In recent years, several notable studies have been published, including applications of Gen-AI in architectural modeling [1,2]; surveys of Gen-AI's potential in construction engineering [3,4,5]; AI-assisted optimization of operational performance and cost reduction in construction [6,7]; and comprehensive analyses of Gen-AI's current capabilities in the construction industry [8]. In Vietnam, interest in this field is also growing significantly among the research community and designers. Notable works include a study on an AI application model for the stages of architectural design [9] and a study on the impact of artificial intelligence on human resource training in architecture in Vietnam [10]. However, these studies are still at a general level, lacking specific guidelines on the application of artificial intelligence in generating and evaluating multi-criteria options in the field of residential architectural design. This research aims to fill this gap in the fields of architecture and interior design.

2. RESEARCH METHODOLOGY AND CURRENT RESIDENTIAL ARCHITECTURAL DESIGN PROCESS

2.1. Research methodology

This study employs a combination of qualitative and quantitative research methods to comprehensively evaluate

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the application of generative artificial intelligence in the field of residential architectural design, comprising: the Literature Review Method, the Experimental Method, the Expert Consultation and Analytic Hierarchy Process (AHP) Method, and the Analytical and Comparative Method.

2.2. Traditional design process

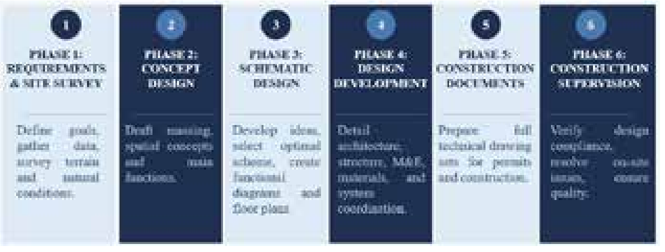

Figure 1. Traditional six-stage design process [9]

The traditional six-stage process possesses numerous significant practical advantages. The requirements gathering and site survey stage enables architects to comprehensively understand the investor's needs - from lifestyle and family size to the natural conditions of the plot. The progressive development of ideas through the conceptual and preliminary design stages allows clients to gradually envision their future home without being overwhelmed by technical information at the outset. The schematic design and construction drawing stage ensures close coordination among architecture, structure, and M&E systems, thereby minimizing errors during construction. Finally, construction supervision plays a pivotal role in ensuring that the building is executed in accordance with the design, protecting the interests of both the client and the design team.

However, this process reveals several significant limitations when applied to residential design. Since clients typically have specific expectations but limited technical knowledge, architects must go through multiple rounds of manual sketching to transform vague ideas into visual representations, which often leads to misunderstandings that persist across multiple stages. Furthermore, the lack of rapid visualization tools means clients must wait considerable time to grasp the overall appearance of the project, reducing their motivation to engage and hindering timely decision-making. At the material selection and interior finishing stage, simulating color schemes, material combinations, and layout options is time-consuming, while clients increasingly expect immediate visual experiences. Moreover, the current process relies heavily on the individual experience of the architect, lacking a platform capable of synthesizing data from similar projects to propose optimal solutions regarding function, lighting, and ventilation suited to specific terrain and climatic conditions.

2.3. Integration of Generative AI into the design process

Generative AI can intervene at multiple points in the design process. During the conceptual design stage, AI can generate exterior and interior perspective sketches from text descriptions within minutes. During the preliminary design stage, AI can suggest spatial zoning and floor plan layouts. During the schematic design stage, AI tools integrated with BIM can optimize structure, natural lighting, and energy efficiency. Within the scope of this study, the research group investigates the application of AI in architectural and interior design for individual residential buildings such as townhouses and villas.

The authors propose a five-step AI integration process (Figure 2), in which the architect plays the role of quality control and creativity, while AI is responsible for generating a large volume of design options.

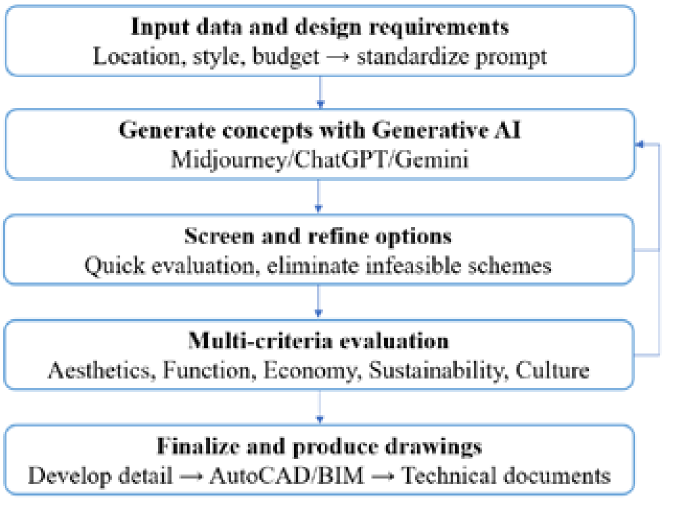

Figure 2. Generative AI-Integrated design process

The proposed Generative AI-integrated design process offers several advantages. First, its 5-step structure is clear, logical, and easy to implement, suitable even for architects unfamiliar with AI. AI is introduced at precisely the right point - the option generation stage - where it has the greatest advantage in terms of speed and volume, while the architect retains a central role in quality control and creative direction. The 5-criterion evaluation framework, particularly the Local Culture criterion, is highly appropriate for Vietnamese residential design practice. The intermediate screening step helps eliminate low-feasibility options early, avoiding resource waste. Finally, concluding the process with AutoCAD/BIM technical documentation demonstrates a clear practical orientation, ensuring the deliverables can be deployed on actual construction sites.

3. RESEARCH ON THE APPLICATION OF GENERATIVE AI IN SUPPORTING DESIGN OPTION GENERATION AND EVALUATION

3.1. Generative AI tools used in the study

The rapid development of generative artificial intelligence has ushered in a new era in the fields of architectural and interior design, where the creative process is significantly supported and expanded by intelligent tools. Several prominent tools currently available - Midjourney, ChatGPT, and Gemini - allow architects and interior and exterior designers to quickly visualize spatial concepts through natural language descriptions, generating high-quality perspective renderings from the very early stages of conceptual sketching. Notably, Gemini enables the simultaneous integration of text, images, and technical data, thereby supporting the assessment of feasibility and proposing comprehensive design solutions. In addition, numerous other AI tools can be used for architectural and interior design, including Maket.ai, Finch, Architechtures, and ArkDesign.ai. The combination of these tools transforms AI into an intelligent creative partner, enhancing quality and expanding creative potential across all projects.

3.2. Method of Design option Generation

The process of option generation is carried out through clearly structured prompts (prompt engineering). Depending on the purpose of option generation, each prompt contains different elements, including: overall spatial description; site conditions (plot, orientation, Vietnam climate); functional requirements; style references (Indochine architecture, Vietnamese modern architecture, tropical, etc.); technical parameters (image ratio, level of detail, viewing angle); and weather conditions (sunny, rainy, morning, evening), among others.

Gen-AI has many applications in architecture and interior design. It can be used to perform the following tasks: Generating concepts from text to 3D floor plans; Generating 3D exterior perspectives from preliminary SketchUp models; Generating 3D exterior perspectives from photos of unfinished buildings; Generating 3D exterior renovation perspectives from photos of existing buildings; Generating 3D interior perspectives from existing images in SketchUp.

3.3. Method of Design option evaluation using the AHP

To demonstrate the design option evaluation phase using the Analytic Hierarchy Process (AHP) [11,12], the research team conducted pairwise comparisons of 5 main criteria through a survey questionnaire administered to several experienced architectural experts with over 10 years of experience. Table 1 presents the pairwise comparison matrix between criteria and the final weights (consistency ratio CR = 0.0152 < 0.1, ensuring the consistency of the evaluation).

Table 1. AHP pairwise comparison matrix and criterion weights

Criterion	Aesthetics	Function	Economy	Sustainability	Culture	Weight (W_i)
Aesthetics	1	1/2	2	3	3	**0.228**
Function	2	1	3	4	4	**0.384**
Economy	1/2	1/3	1	2	2	**0.152**
Sustainability	1/3	1/4	1/2	1	2	**0.121**
Culture	1/3	1/4	1/2	1/2	1	**0.115**

The calculation results show that the Functionality criterion has the highest weight (W_2 = 0.384), reflecting the experts' view that in Vietnamese housing design, comfort and spatial organization are prioritized. Architectural Aesthetics ranked second (W_1 = 0.228), followed by Economy (W_3 = 0.152), Sustainability (W_4 = 0.121), and Cultural Appropriateness (W_5 = 0.115). To evaluate the options (Oi), the following scoring formula was used for each option:

$$W = \sum_{i=1}^{n} PA_i \times W_i$$

Where: W is the total score of all criteria used to evaluate the design; Oi is the score of the architectural design calculated according to criterion i on a 10-point scale; Wi is the weight of criterion i, which are the 5 criteria as shown in Table 1.

3.4. Experimental results

3.4.1. Generation of conceptual design options

Using a text file and Gen-AI software to generate design concepts.

Prompt: Please generate a 3D rendered floor plan of a single-storey house in modern Vietnamese architectural style, with a building footprint of 10 m × 25 m, incorporating the following spaces: 1 garage, 1 living room, 1 kitchen combined with a dining area, 2–3 bedrooms, and 1 full bathroom with shower.

Option 1: 2 bedrooms *Option 2: 3 bedrooms*

Figure 3. Initial conceptual design options generated using ChatGPT

Based on AHP evaluation and criterion weighting, the total weighted score for Option 1 is W_{O1} = 7.46, while that of Option 2 is W_{O2} = 7.92. These results indicate that Option 2 demonstrates superior performance in the Functionality criterion, which carries the highest weight (W_2 = 0.384), making it particularly suitable for the spatial needs of multi-generational Vietnamese families. However, if budget constraints are a consideration, Option 1 represents the more economical choice.

3.4.2. Generating 3D exterior perspectives from SketchUp

SketchUp Model

Option 1 (O1)

Option 2 (O2)

Figure 4. 3D Design options generated from SketchUp preliminary model

Two exterior design options generated from a preliminary SketchUp model were evaluated against five AHP criteria. The AHP assessment results indicate that O1 achieved a total weighted score of WO1 = 7.86, surpassing O2 (WO2 = 7.79). O1 demonstrated superiority in functional performance and economic efficiency - two criteria carrying the highest weights and is therefore proposed as the preferred selection. O2 performed better in terms of aesthetic quality and cultural compatibility, making it a more suitable choice when the investor prioritizes a contemporary architectural image that reflects local identity.

3.4.3. Generating 3D exterior perspectives from an unfinished building

Unfinished Building

Option 1 (O1)

Option 2 (O2)

Option 3 (O3)

Figure 5. Using AI to generate 3D options from an unfinished building

The AHP evaluation results show that O1 achieved the highest total score at W_{O1} = 7.94, followed by O2 (W_{O2} = 7.87) and O3 (W_{O3} = 7.75). O1 leads due to its stronger performance in the two highest-weighted criteria - functional usability and economy. O3, while superior in aesthetics, is less economically optimal.

3.4.4. Generating 3D Exterior renovation perspectives from an existing building

Actual Building Photo

Option 1 (O1)

Option 2 (O2)

Option 3 (O3)

Figure 6. Using AI to generate 3D renovation options

The AHP evaluation results reveal that O1 achieved the highest total weighted score of W_{O1} = 7.89, followed by O2 (W_{O2} = 7.64) and O3 (W_{O3} = 7.41). O1 demonstrated a distinct advantage owing to its assured structural integrity, lower renovation costs, and greater compatibility with local cultural identity. O3, while excelling in contemporary architectural aesthetics, demands a considerably higher level of investment and is better suited for investors seeking to establish a strong and distinctive personal architectural statement.

3.4.5. Generating 3D interior perspectives

SketchUp Model

Option 1 (O1)

Option 2 (O2)

Option 3 (O3)

Figure 7. Using AI to generate 3D interior design options

The AHP evaluation results indicate that O1 achieved the highest total weighted score of WO1 = 8.12, followed by O3 (WO3 = 7.81) and O2 (WO2 = 7.66). O1 demonstrated clear superiority by virtue of its high scores in functional performance and economic efficiency, the two criteria carrying the greatest weightings, alongside notable advantages in sustainability and cultural compatibility. O2, while presenting the most refined aesthetic quality, exhibited comparatively lower cultural appropriateness.

3.4.6. Discussion

This study evaluates the application of generative AI in architectural design through five real-world case studies. AI has the ability to analyze space, quickly generate 3D models, shorten initial concept sketching time, and support visual communication with clients. When integrated with SketchUp, AI improves materials, lighting, and landscaping, reducing rendering time from weeks to hours at a lower cost. Furthermore, AI can create finished images from real-world building photos, suggest facade solutions for home renovations, and enhance interior rendering quality with realistic lighting and materials.

However, generative AI still requires architect intervention to ensure technical feasibility, and when guided by detailed prompts, AI can recreate local identity elements, contributing to the preservation of Vietnamese architectural heritage.

4. CONCLUSION

This study successfully developed a five-step AI-integrated architectural design workflow for residential buildings, accompanied by a multi-criteria evaluation framework, tailored to the practical conditions of small and medium-sized architectural practices in Vietnam. The findings affirm that AI functions as an effective creative support tool that augments rather than replaces the role of the architect. The study opens up a practical avenue of application for the domestic design community. These outcomes establish a foundational basis for subsequent research into prompt standardization and AI-BIM integration, with a view to modernizing the working processes of Vietnamese architectural offices in the context of digital transformation.

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