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A study on the path of Lingnan architectural style in China based on AI generation technology

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Abstract

This paper explores the application of AI-generated content in architectural design, focusing on the Lingnan architectural style. Using Stable Diffusion and LoRA fine-tuning models, this study simulates and generates typical design features of Lingnan architecture by training on architectural images. Conditional control methods, such as ControlNet, are incorporated to enhance spatial structure recognition and architectural detail, ensuring precise outputs. Additionally, the study examines a hybrid generation approach, blending traditional Lingnan and modern architectural styles to evaluate potential style transitions and innovations. Findings suggest that AI generation technology effectively captures Lingnan architectural details while fostering style integration and evolution. This research provides a valuable technical and theoretical foundation for the digital preservation of Lingnan architecture and contemporary design.

Keywords: AI generation techniques, Lingnan architecture, LoRA, Stable Diffusion.

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1. Introduction

With the swift advancement of Artificial Intelligence (AI) technology, Generative Artificial Intelligence (AIGC) has demonstrated significant potential in the field of architectural design. Deep learning models, including Stable Diffusion and GAN, have been extensively employed in the fields of design innovation, style simulation, and image generation in recent years. The digital and intelligent process of architectural style research is supported by these techniques, which are capable of extracting and reconstructing specific architectural style features and generating architectural design solutions from text or images.

In China, Lingnan is a significant region (Figure 1), and its traditional architecture is renowned for its distinctive aesthetic style, regional culture, and climatic adaptability [1]. Through the utilization of elements such as terraces, mounted structures, and grey carvings, Lingnan architecture exhibits both practical and artistic architectural characteristics. Lingnan architectural style, however, is confronted with the challenge of preservation and inheritance as urbanization continues to advance at a rapid pace. This traditional architectural style has become a popular topic of concern in modern architectural design, as it is necessary to both inherit and innovate.

The primary methods of traditional architectural style research are field research, hand-drawing, and 3D modeling. However, these methods have certain limitations in terms of innovative design and detail portrayal. In contrast, AI generation technology is capable of rapidly producing high-precision architectural images through extensive data training, and it exhibits exceptional creativity and adaptability in the areas of hybrid generation and style extraction. Thus, the architectural style research that is based on AI generation technology offers a novel approach to investigating the inheritance and innovation of the Lingnan architectural style. This paper aims to investigate the potential of AI generation techniques to simulate and reconstruct Lingnan architectural styles through the training and generation of Lingnan architectural images. We will employ the Stable Diffusion model with the LoRA fine-tuning technique and the ControlNet conditional control method to ensure the precise generation and style synthesis of Lingnan architectural styles. In the interim, this paper will also investigate the hybrid progeny of Lingnan traditional architectural styles and modern architectural styles, and it will evaluate their potential for use in contemporary architectural projects.

Figure 1.
Map of the Lingnan region.

2. Literature Review

2.1.Typical Research Perspectives

2.1.1. Analysis of Chinese and Foreign Research Perspectives

In the field of "architectural style research based on AI generation technology," academicians in China, Europe, and the United States possess distinct research methodologies and perspectives, which are indicative of the disparities in research content and technology application between the two. A list of five authoritative academicians in China, Europe, and the United States is provided below, along with their typical representatives and research perspectives (Table 1).
Present the following text in a table according to the table style.
Research perspectives of Chinese scholars:

A scholar in particular, Xu [2], concentrates on the preservation and modernization transformation of Lingnan architectural styles Xu [2], with a particular emphasis on the utilization of digital technology to facilitate the virtual reconstruction and presentation of traditional Lingnan architecture. In the digital era, he suggests that AI generation technology can effectively inherit the historical and cultural elements of Lingnan architecture, circumvent the constraints of traditional manual methods, and foster the innovation of Lingnan architectural styles.

The integration of traditional Chinese architecture with modern architectural designs is the primary focus of Lu, et al. [3]. In his opinion, AI generation technology has the potential to identify and extract elements of traditional architectural styles, such as roof structures and decorative details, through model training. This technology can then recombine and apply these elements in modern architectural design, thereby significantly enriching the diversity of architectural aesthetics.

Conversely, Song Jian concentrates on the digital replication of damaged buildings in the Lingnan region, with an emphasis on the preservation and restoration of historical urban buildings [4]. The findings of her research indicate that the cultural significance of these structures is not only preserved by AI generation technology but also encouraged to be continued and applied in future urban development. This innovation offers a novel approach to the regeneration of traditional buildings in contemporary settings.

The research of Wang, et al. [5] is centered on the application of Generative Adversarial Networks (GANs) to the generation of traditional Chinese architectural forms, with a particular emphasis on Guangzhen, et al. [6] architecture [5].He noted that AI technology can produce architectural images that are characterized by traditional aesthetics and exhibit the deep learning capabilities of architectural styles in innovative applications through a data-driven approach.

In particular, Yin, et al. [7] is dedicated to the preservation and transmission of Chinese architectural heritage through the use of AI and 3D modeling technologies [7]. She is particularly interested in utilizing these technologies to replicate the stylistic details of Lingnan architecture. She proposes that AI generation techniques provide a novel approach to the preservation of architectural heritage, particularly in the context of traditional structures with intricate styles. This approach can assist in the development of a more refined expression of architectural styles.

Research perspectives of European and American scholars:

Pena, et al. [8] research underscores the significance of AI in parametric design, particularly in the production of intricate architectural forms [8]. He contends that AI generation techniques can transcend the constraints of conventional architectural design to generate more intricate and innovative architectural styles, thereby bolstering the automation and intelligence of architectural design.

In the field of architectural design, Ghannad and Lee [9] are pioneers in the application of Generative Adversarial Networks (GAN) [9]. Their research demonstrates that GANs can produce images of architectural styles from various eras and even simulate the shape of future structures. This capability provides architects with the ability to incorporate architectural styles from various cultural influences, thereby encouraging the development of more experimental design concepts.

Baduge, et al. [10] concentrate on the incorporation of AI generative technologies with sustainable building design [10]. The research posits that architectural design can be more effectively tailored to environmental and social requirements by utilizing AI-generated technologies. She posits that AI can assist in the design of structures that are both sustainable and aesthetically appealing in modern architecture, particularly in urban landscape design, in order to achieve an equilibrium between traditional and contemporary styles.

Masciotta, et al. [11] research is particularly focused on the digital preservation of historic structures in Europe Masciotta, et al. [11], with a particular emphasis on the restoration of architectural styles through AI-generated technologies. In the virtual reconstruction of historic buildings, he underscores the significant advantages of AI techniques, which enhance the accuracy and adaptability of the digital conservation of architectural styles.

In particular, Shafaghat and Keyvanfar [12] research is dedicated to the automatic generation of architectural forms through the use of AI generation techniques Shafaghat and Keyvanfar [12], with a particular emphasis on the generation of classical European façade designs. Their research demonstrates that AI has the ability to simulate intricate architectural styles and seamlessly transition between them, thereby offering novel solutions for the advancement of stylistic innovation and the diversification of architectural design.

The research perspectives of these ten Chinese and foreign scholars demonstrate the extensive array of applications and potentialities of AI-generated technologies in the examination of architectural styles. They investigate the ways in which AI can facilitate the integration and innovation of traditional and modern architectural styles from a variety of perspectives. These studies serve as a critical reference for the preservation and reinterpretation of Lingnan architectural styles in the digital era.

Table 1.
Summary of views of Chinese and foreign scholars.

Serial number	academia	discuss a paper or thesis (old)	Core ideas relevant to this study	periodicals	Number of citations or downloads
1	Xu [2], Chinese-American physicist, astronomer and mathematician	Ecological Implications and Practical Challenges of Traditional Lingnan Architectural Culture	AI generation technology can effectively inherit the historical and cultural elements of Lingnan architecture and promote its innovation.	Journal of Nanjing Forestry University: Humanities and Social Sciences Edition	389 (downloads)
2	Lu, et al. [3], Chinese diplomat and Catholic monk	Research progress in building structure design methods from simulation-based to artificial intelligence-based	The AI generation technology recognizes and extracts traditional architectural elements through model training to enrich architectural aesthetics.	engineering mechanics	2543 (downloads)

Serial number	academia	discuss a paper or thesis (old)	Core ideas relevant to this study	periodicals	Number of citations or downloads
3	Song and Huang [4], dynasty writer and poet	Restoration and Examination of the Land and Water Post Roads in the Xianggui Corridor during the Yongzheng Period.	AI technology preserves and facilitates the restoration and regeneration of damaged historic buildings.	Canal Studies	141 (downloads)
4	Wang, et al. [5], one of the Gang of Four	Generative Adversarial Network-based Detection of New Buildings on the Ground	AI technology generates architectural images of traditional aesthetic features, demonstrating deep learning capabilities.	computer application	895 (downloads)
5	Indo-Subo	Quadrant and Set - Zhiguai Technology Center, Xiangjiang New District, Changsha, Hunan Province.	AI technology is helping to achieve a refined representation of complex architectural styles and is becoming a new approach to heritage preservation.	World Architecture Herald	61 (downloads)
6	Pena, et al. [8]	Artificial intelligence applied to conceptual design. A review of its use in architecture.	AI technology breaks through traditional design limitations to support building design automation and intelligence.	Automation in Construction	153 (cited)
7	Ghannad and Lee [9]	Automated modular housing design using a module configuration algorithm and a coupled generative adversarial network (CoGAN).	GAN generates architectural styles from different cultural backgrounds to stimulate experimental design.	Automation in construction	46 (cited)
8	Baduge, et al. [10]	Artificial intelligence and smart vision for building and construction 4.0: machine and deep learning methods and applications.	AI-generated technology to design buildings that are both aesthetically pleasing and sustainable.	Automation in construction	469 (cited)
9	Masciotta, et al. [11]	A digital-based integrated methodology for the preventive conservation of cultural heritage: the experience of HeritageCare project.	AI technology improves the accuracy and flexibility of digital preservation of historic architectural styles.	International Journal of Architectural Heritage	86 (cited)
10	Shafaghat and Keyvanfar [12]	Dynamic façades design typologies, technologies, measurement techniques, and physical performances across thermal, optical, ventilation, and electricity generation outlooks.	AI simulates complex architectural styles and provides solutions for stylistic innovation in design.	Renewable and Sustainable Energy Reviews	24 (cited)

2.1.2. Analysis of Chinese and Foreign Literature Search

To gain a more comprehensive understanding of the application of AI generation technology in architectural styles and related research on Lingnan architecture (Figure 2), we conducted literature searches using "China Knowledge Network (CNKI)" and "Google Scholar," respectively, and searched through the keywords "AI generation technology" and "Lingnan architecture." We conducted a literature search using "China Knowledge Network (CNKI)" and "Google Scholar," and we queried using the keywords "AI generation technology" and "Lingnan architecture." The results of the literature search analysis, which was conducted using these two keywords, are as follows.

"AI Generation Techniques" Literature Search Analysis:

The keyword "AI generation technology" yielded 159 results in the China Knowledge Network (CNKI). The research content primarily concentrates on "generative AI, artificial intelligence technology, ChatGPT, AI image generation technology," among other fields. The majority of the literature is related to "automation technology, information economy and postal economy, computer software and computer, news and media," and other related disciplines. This indicates that the domestic research in the field of AI generation technology is relatively extensive, encompassing a diverse range of industries and application fields. However, the integration with architecture is relatively modest, particularly in the context of the research of AI technology in architectural style generation, which has not yet become mainstream. The majority of the literature concentrates on the development of AI generative technology and its application in the disciplines of media, communication, and information economy, which offers a theoretical foundation for comprehending the core principles and development trends of AI generative technology.

The keyword "AI generation technology" yielded 37,400 results in Google Scholar, with the majority of the associated literature occurring within the past three years. This demonstrates that AI generation technology, an emerging field, has incited a significant amount of research and application discussions on a global scale in recent years. These literatures are extensively associated with the application of Generative Adversarial Networks (GAN), Deep Learning, Stable Diffusion, and other techniques in image generation. They encompass a diverse range of application scenarios, including image synthesis, video generation, and text generation. The innovation of AI generation technology in the generation of complex image styles, particularly in architectural design, is the primary focus of foreign studies. For example, the use of AI to generate European classical architecture or modern architectural style provides technical references for the study of Lingnan architectural style.

An analysis of the literature search on "Lingnan architecture":

The keyword "Lingnan architecture" yielded 1,487 results in the China Knowledge Network (CNKI). The subject matter encompasses "Lingnan architecture, architectural design, Lingnan architectural culture, traditional architecture," among others, and the disciplines involved include "building science and engineering, industrial economy, tourism, archaeology." As one of the representatives of Chinese traditional architecture, this demonstrates the widespread popularity of Lingnan architecture in China. Lingnan architecture has garnered significant attention from a variety of sectors in China, including tourist development, cultural heritage protection, and architecture. There has been a significant amount of research conducted on the historical development of Lingnan architecture, its architectural components (such as terraces and mounted structures), and its significance to the regional culture of Lingnan. These literatures offer a comprehensive theoretical and historical foundation for an in-depth comprehension of Lingnan architectural styles and their preservation and inheritance. Nevertheless, there are still a limited number of studies that address the integration of Lingnan architecture with AI technology.

Using the keywords "Lingnan architecture" in Google Scholar, a total of 9,580 results were identified, with the pertinent literature primarily concentrating on the past five years. This indicates that the study of Lingnan architecture has also piqued the interest of scholars in the international arena, particularly in recent years. With the ongoing trend of digitization in the preservation of cultural heritage, there has been an increase in the number of studies that have begun to investigate the use of modern technology to preserve and propagate the Lingnan architectural styles. Not only do these literatures examine the architectural characteristics of Lingnan architecture, but they also emphasize its cultural significance and its preservation and repurposing in the context of globalization. From the standpoint of cultural heritage preservation, the majority of foreign studies commence with the restoration and replication of Lingnan architecture through the use of digital tools, virtual reality (VR), and 3D modeling. This approach offers both technical and cultural references.

A comparative analysis of Chinese and foreign literature:

Domestic and foreign research on "AI generation technology" and "Lingnan architecture" have distinct foci, as evidenced by searches of Chinese and foreign literature. In the domestic context, the research on AI generation technology is primarily focused on its application in the fields of information economy and news dissemination, with a relatively low emphasis on architectural design. Conversely, the research on Lingnan architecture is primarily concerned with its cultural background, historical inheritance, and architectural details. The application of AI generation technology in architectural style generation has garnered increased attention abroad, particularly in recent years. It has been extensively employed in architectural design and the preservation and restoration of cultural heritage. Even though there are relatively few foreign studies on Lingnan architecture, their global research on the integration of traditional architecture and modern technology offers technical references and theoretical support for the application of AI generation in the Lingnan architectural style.

In general, there has been a significant increase in the trend of AI generation technology research both domestically and internationally. In recent years, the implementation of this technology in the preservation of cultural heritage and architectural design has progressively emerged. New avenues for the digital conservation and modern design innovation of Lingnan architecture can be investigated by combining AI generation technology and Lingnan architectural styles. Introducing more recent results of AI generation technology can further enrich and expand the application scenarios of Lingnan architectural styles in future research.

Figure 2.
Literature search analysis chart.

2.2. Current Research Status of Lingnan Architecture

Lingnan architecture is a significant component of the architectural culture of southern China, exhibiting both practical and aesthetic characteristics. Its historical origin and architectural style are characterized by distinct regional features. Lingnan architecture, which is rooted in regional culture, exhibits distinctive technical advantages in terms of protection against wind, rain, moisture, and lightning, as well as a variety of architectural forms, such as jockeyed towers, Xiguan huts, bamboo huts, watchtowers, ancestral halls, and other architectural forms, as per Du, et al. [13] study in "The Status of Typical Residential-use Historical Buildings in Lingnan" [13].

2.2.1. Historical Background and Regional Characteristics of Lingnan Architecture

Lingnan architecture encompasses the architectural style that is located south of the Five Ridges, and it is more specifically defined as the architecture of the Pearl River Delta region. Since the Ming and Qing dynasties, Lingnan architecture has been created to accommodate the local climatic conditions. This includes the protection of buildings against wind, rain, corrosion, and fire, as well as the ventilation and cooling of the interior through innovative layouts (e.g., patios, corridors) to establish a comfortable microclimate for habitation. In addition to fulfilling the practical requirements of daily life, this design imbues Lingnan architecture with a distinctive cultural and aesthetic significance. The architectural style of Lingnan, which combines Chinese and Western elements, was gradually integrated with the combination of local dwellings, particularly after the Opium War. This resulted in the incorporation of Roman columns, long windows, and other Western designs.

2.2.2. The Status of Residential-Type Historic Buildings in Lingnan

The "Residential Historic Buildings" are a unique category of Lingnan architecture. These structures are traditional in design and aged, yet they continue to serve as residences or public services. These structures are predominantly situated in villages and municipalities throughout the Lingnan region and are currently utilized for residential, public, or commercial purposes. The structures of these historic buildings have gradually deteriorated over time, resulting in dilapidated exteriors and outdated interiors. This is particularly true for those with brick and timber structures, which are less durable and less stable. As a result, they are a high-risk group in the event of natural disasters, such as earthquakes.

Studies have demonstrated that residential-type Lingnan historic structures are not only susceptible to the danger of cultural inheritance belt fissures, but also suffer from structural harm and inadequate seismic capacity. The literature notes that numerous historic buildings in the Lingnan area have corrosion and fissures on their wall surfaces as a result of inadequate maintenance, erosion of load-bearing walls, and a substantial decrease in the seismic performance of the overall building structure. This is supported by field surveys. The emergency rescue of these structures in the event of abrupt calamities is more challenging due to the fact that they are primarily coexisting with modern buildings, which have congested passageways and limited space.

2.2.3. Protection Measures and Seismic Performance

The seismic performance of Lingnan historic buildings is generally feeble, particularly for brick, wood, and masonry buildings, which have hybrid structures that perform inadequately in earthquakes, as noted in the literature. Consequently, it is imperative to improve the seismic performance of Lingnan buildings by implementing scientific reinforcement and conservation measures. The study underscores the importance of adopting the principles of "authenticity, integrity, legibility, and sustainability" in the conservation of residential historic buildings, which should not be restricted to the building itself but should be conducted holistically within the context of the surrounding historic environment. The incremental implementation of seismic reinforcement and reasonable repairs of historic structures should be conducted through scientific disaster risk assessment to guarantee the preservation of their cultural significance and public safety.

2.2.4. The Challenges of Modernization and the Architectural Culture of Lingnan

The conflict between modern development and cultural preservation is a challenge that Lingnan architecture is currently facing as urbanization continues to accelerate. The traditional Lingnan architecture has been significantly altered by the development of modern architecture, and certain historical buildings have been damaged or homogenized during the development process, resulting in the progressive loss of their original cultural characteristics. This situation is associated with inadequate macro-integrated planning and insufficient knowledge of cultural heritage preservation among decision-makers, as noted in the literature. In order to resolve this issue, it is imperative to fortify the enforcement of laws and regulations regarding the preservation of historical structures, as well as to develop a more sophisticated protection program that guarantees the preservation of the cultural identity and patrimony of Lingnan architecture.

2.2.5. Utilization of AI Generation Technology and Digital Preservation

Modern technology provides novel solutions for the preservation and perpetuation of traditional Lingnan architecture, despite the numerous cultural and structural obstacles it encounters. It is anticipated that the future will introduce innovative solutions for the preservation of Lingnan architecture through the integration of AI-generated technology and digital means. Researchers can accomplish innovation and continuity of Lingnan architectural styles in modern urban development by recreating the distinct styles of Lingnan architecture through digital modeling and AI generation of architectural structures and styles. In addition to demonstrating the cultural appeal of Lingnan architecture through virtual reality (VR) and other technological means, digital conservation can also provide accurate data support for the repair and restoration of buildings, thereby enhancing public awareness and conservation.

3. Research Tools and Methodology

3.1. Research Tools

The accuracy and diversity of Lingnan architectural styles in the generation are guaranteed by the fundamental instruments of the AI generation technique, which include Stable Diffusion, the LoRA fine-tuning model, and ControlNet, in this study.

(1) Stable Diffusion: This AI image generation tool is based on the latent diffusion model (Zhang, et al. [14]) and is capable of effectively extracting and reproducing the details of complex architectural styles by progressively generating images from random noise. The instrument is capable of producing high-quality Lingnan architectural style images, particularly in the areas of style extraction and representation, and is well-suited for the generation of large-scale architectural styles.

(2) Fine-tuned model with LoRA: LoRA (Low-Rank Adaptation) is a lightweight model fine-tuning technique (Hu, et al. [15]) that can be employed to perform rapid style migration and generation using small-scale data based on existing large models (e.g., Stable Diffusion). To guarantee that the architectural images generated accurately reflect the regional characteristics of Lingnan architecture, the Stable Diffusion model is fine-tuned in this study to accommodate the unique stylistic elements (e.g., mounted structures, terraces, etc.). LoRA is employed to achieve this.

(3) ControlNet: ControlNet is an additional instrument for the conditionally controlled generation of models (see [16]). It allows the model to be provided with additional conditions, such as edge maps and depth maps, during the generation process to guarantee the accuracy of the generated results. In this investigation, ControlNet is implemented to optimize the management of spatial information associated with Lingnan buildings, including the façade structure, roof shape, and door and window layouts. This guarantees that the images produced are both spatially reasonable and stylistically consistent.

3.2.Mathematical Modelling Formulas

3.2.1. Stable Diffusion Image Generation Process

Stable Diffusion uses Latent Diffusion Model (LDM) for image generation. The key equation for the diffusion process is:

Forward diffusion processes:

Forward diffusion adds noise to the data step by step and Equation 1 is as follows:

$$q(x_t|x_{t-1}) = \mathcal{N}\left(x_t; \sqrt{1-\beta} x_{t-1}, \beta_t I\right) \qquad (1)$$

Among them:

-xt denotes the image representation at step t.

-βt is the noise increment factor at step t.

-N denotes Gaussian distribution and βt I is the variance matrix of the noise.

This equation describes the process of noise addition from time step t-1 to time step t. βt is used as a parameter to control the extent of noise added at each step.

Reverse denoising process:

The model uses inverse denoising to generate the image with Equation 2as follows:

$$p_\theta(x_{t-1}|x_t) = \mathcal{N}(x_{t-1}; \mu_\theta(x_t, t), \sum\nolimits_\theta (x_t, t)) \qquad (2)$$

Among them:

-μ_θ (x_t,t) is the mean value learned from the model.

-∑_θ▒〖(x_t,t)〗 is the covariance matrix obtained by learning, often simplified to a fixed diagonal matrix.

This formula describes the inverse generation of the model during diffusion, by predicting the image at time step t-1 from time step t.

3.2.2. Loss Function

In order to train the model so that it can recover the real image from the noise, the goal of the model is to minimize the mean square error between the prediction noise and the real noise, and the commonly used loss function Equation 3 is:

$$L_{simple} = E_t, x_0, \epsilon[\|\epsilon - \epsilon_\theta(x_t, t)\|^2] \qquad (3)$$

Among them:

-ϵ is the real noise added.

-ϵ_θ (x_t,t) is the noise predicted by the model.

This loss function describes the optimization of the model weights by minimizing the mean square error between the noise predicted by the model and the true noise. It is a commonly used training objective function in diffusion models.

3.2.3. ControlNet Conditional Control Extension

ControlNet guides the generation process of the diffusion model by providing external conditions (e.g., edge map, depth map, etc.). Its generation process can be expressed as Equation 4:

$$p_\theta(x_{t-1}|x_t,\ y) = \mathcal{N}(x_{t-1}; \mu_\theta(x_t, y, t), \sum\nolimits_\theta (x_t, y, t)) \qquad (4)$$

Among them:

-y denotes additional conditional information such as depth maps, edge maps, etc.

-μ_θ (x_t,y,t) and∑_θ▒〖(x_t,y,t)〗 are the mean and covariance matrices after conditional control.

This formulation describes the probability distribution of conditional generation by introducing conditions y (e.g., edge maps or depth maps) to control the generation of images. The conditional control part here is an extension of the traditional diffusion model.

3.2.4. Style Mixing Model Equation

In the thesis experiment, a mixture of traditional and modern styles is generated. A linear weighted average can be used to represent the style mixing Equation 5:

$$G_{mix} = \alpha G_{traditional} + (1-\alpha) G_{modern} \qquad (5)$$

Among them:

-G_mix is a hybrid style of the generated image.

-G_traditional is the traditional style of generating images.

-G_modern It is a modern style of generating images.

-α is a parameter that controls the mixing ratio of the two styles, the0≤α≤1.

This is a linear weighted average formula to represent the mixing of different styles. The blend ratio is controlled by adjusting the α parameter.

3.2.5. LoRA model fine-tuning equation

LoRA (Low-Rank Adaptation) is used in the thesis to fine-tune the large model.LoRA controls the updating of the model parameters through a low-rank decomposition, Equation 6 is given below:

$$W' = W + AB^T \qquad (6)$$

Among them:
-W is the weight matrix of the original model.
-A and B are low-rank factorisation matrices, typically A ∈R^(d×r),B∈R^(r×k) , where r is a low-rank parameter.
-W′ are the fine-tuned model weights.

LoRA fine-tuning updates the original weight matrix W by means of a low-rank matrix decomposition.A and B in Eqs. A and B denote the matrices after the low-rank decomposition, which are used to fine-tune the model. This formula fits the description of the LoRA technique.

4. Experimental Procedures

4.1.Data Sources and Processing

The image data of Lingnan buildings (Table 2 and Figure 3) is the primary source of this experiment. The image data is categorized into two groups: traditional Lingnan buildings and modern Lingnan style buildings. The experimental data is processed in accordance with the following criteria:

- Image source: Images of Lingnan architecture were sourced from Flickr, Baidu Map, and Google Street View. There are 200 images of traditional Lingnan architecture and 100 images of modern Lingnan architecture.
- Criteria for image screening:
- The primary structure of the building is transparent, thereby reducing the amount of background interference. The building's storey heights range from two to three stories. The images are captured from a variety of angles, with a predominance of horizontal outdoor views.

In order to guarantee a consistent input data format, the final filtered and processed images were cropped to 512x512 pixels. Airchi Design automatically assigns descriptive titles to each image, including "Traditional Southern Architecture" and "Courtyard," in order to enhance the model's training accuracy.

Table 2.
Data sources and processing statistics.

Data set name	Data sources	Number of images	key feature	Size of processed image
Traditional Lingnan architecture	Flickr, Baidu map, Google	200	Traditional grey brick and green tile buildings	512 x 512 px
Modern Lingnan Architecture	Design portfolios, streetscapes	100	Modern Lingnan Architectural Design	512 x 512 px

Figure 3.
Lingnan Architecture Atlas with Screening Analysis.

4.2. Training process

4.2.1. Analysis of the Training Process

In this experiment, the base model is the pre-trained model from Airchi Design, which is utilized in conjunction with the LoRA (Low-Rank Adaptation) fine-tuning technique to train the model for the image data of the Lingnan architecture (Table 3 and Figure 4). The training process consists of numerous iterations (Epoch), during which the model continuously optimizes its weighting parameters by calculating the loss function (Loss).

- Airchi Design's official pre-trained model—the initial model.
- There are 20 epochs designated for the training process, and the generation results are preserved once after each epoch.

Loss function: the loss function in each Epoch is progressively reduced during training, and the final loss value is maintained within the range of 0.08 to 0.12, indicating that the model has achieved an optimal state for the extraction of Lingnan architectural styles.

- LoRA weight adjustment: the model's performance was optimized when the weight value reached 0.7, and the LoRA weights were progressively increased.

Table 3.
Key parameters of the training process.

Epoch	Loss	LoRA weights	Generated image quality (Subjective rating)
1	0.22	0.2	Lower (One's head)
5	0.16	0.4	Middle
10	0.12	0.6	Middle
15	0.1	0.7	Your (Honorific)
20	0.09	0.8	Stabilize

4.2.2. Analysis of Training Experiments

The Loss value is chosen as the primary index for dynamically modifying the layout of Lingnan architectural pictures in this experiment. This value is determined by examining the correspondence between charts and pictures (Table 3 and Fig. 4).

Initially, the Loss versus Epoch curve indicates that the Loss value decreases progressively as the training progresses. This suggests that the model is perpetually optimized, and the error in image generation is progressively diminished. The model's convergence process is illustrated by the graph, which demonstrates a progressive decrease in the Loss value from 0.22 to 0.09.

Secondly, the layout of the images below is dynamically altered in accordance with the Loss value. A high Loss value indicates that the model is in an early stage and the quality of the generated images is low. Consequently, the images that are associated with high Loss values are enlarged and highlighted to demonstrate the features in the early-generated images. This method enables us to more intuitively observe the output results at various phases of the model training process. For instance, the structural defects in the generated structures are readily apparent in the images with high Loss values that correspond to Epoch 5 and Epoch 10, which are closely associated with the fluctuations in Loss values.

The architectural design is more detailed, and the quality of the images is considerably enhanced in regions with lower Loss values (e.g., images corresponding to Epoch 15 and Epoch 20). The fact that these images are reduced in size and are not highlighted suggests that the Loss value decreases as the model training progresses; the generated results become more accurate, and the shapes, details, and overall structure of the buildings are better preserved and reproduced.

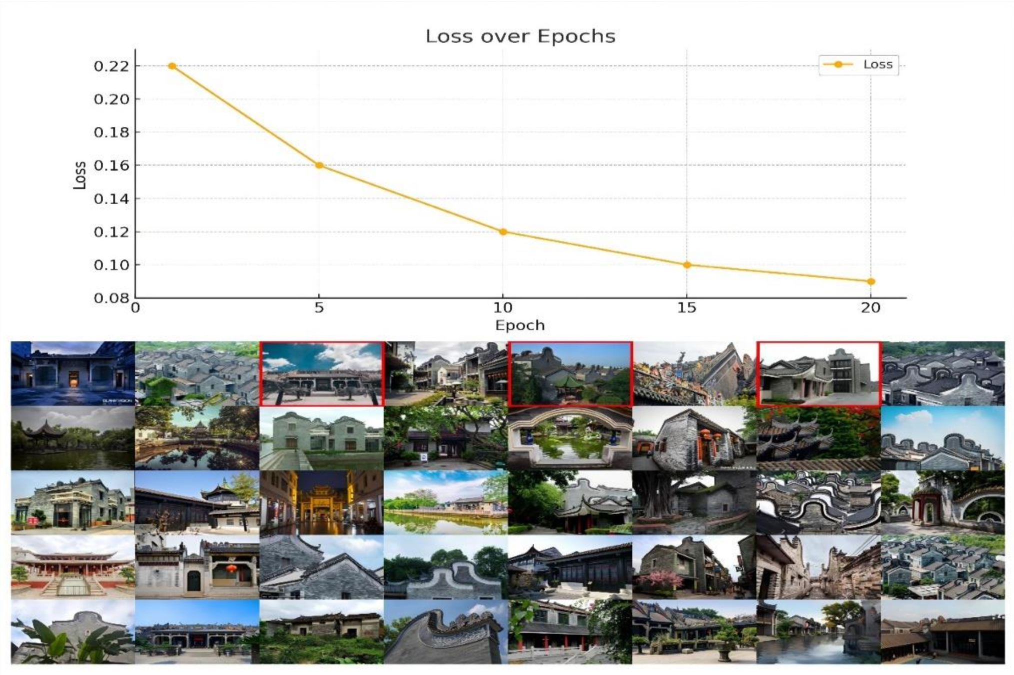

Figure 4.
Dynamic comparative analysis of generated images of Loss and Lingnan buildings.

This dynamic correlation between the Loss value and the image layout enables us to more intuitively comprehend the fluctuations in the quality of image generation that occur during the model training process. This method not only enhances the visualization of model performance analysis but also enables researchers to promptly identify potential issues in the model output. This can further enhance the accuracy and structure preservation of image generation in future optimizations.

In conclusion, this experiment offers a comprehensive understanding of the model's performance and generation quality by dynamically correlating the Loss curves with the generated images, thereby illustrating the model's optimization process and the effect of its generation at various phases.

4.3.Generating Maps

Based on the depth information of ControlNet and the LoRA weights, the subsequent phase of the experiment involves generating a mapping of Lingnan architectural styles (see Table 4 and Figure 5). The LoRA weights are represented by the horizontal coordinates (every 0.1 increment between 0 and 1), while the depth control weights of ControlNet are represented by the vertical coordinates (every 0.2 increment between 0 and 2).

- LoRA weights: the weights are progressively increased from 0.2 to 1. The model primarily generates large model designs at lesser weights, and as the weights increase, the model progressively generates more Lingnan-style architectural features.
- ControlNet depth information: the structure of the generated image is rendered more lucid as the depth control of ControlNet is increased. However, the quality of the image begins to decline when the depth control exceeds a specific value.

The tabular data is used to generate a visualization of the LoRA weights against the similarity of the generated images.

Table 4.
LoRA and ControlNet experimental data.

LoRA weights	ControlNet weights	image similarity	Image structure retention
0.2	0.2	0.78	0.65
0.5	0.8	0.85	0.88
0.7	1	0.92	0.95
0.9	1.2	0.88	0.89
1	1.5	0.83	0.8

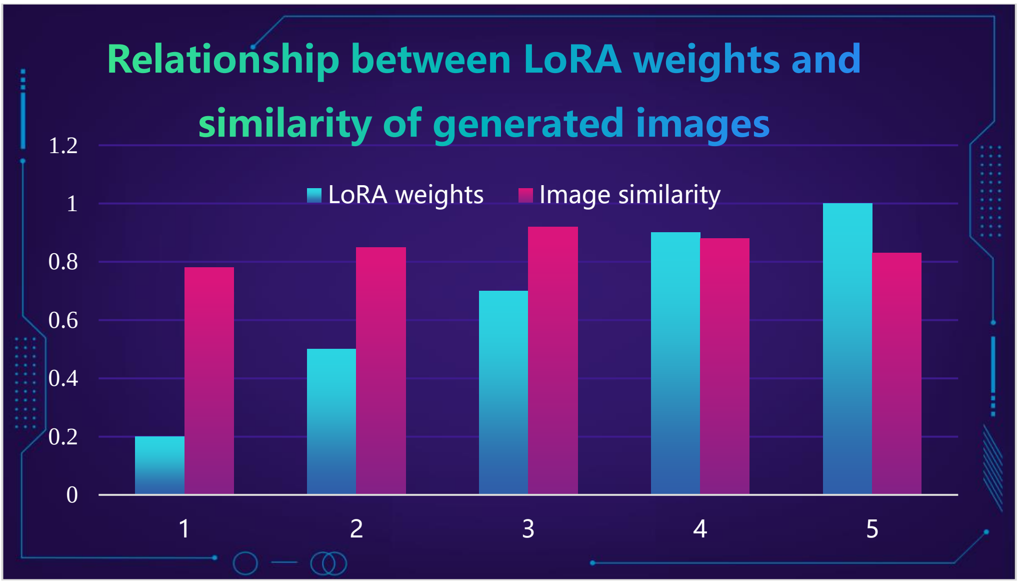

Figure 5.
LoRA weights with respect to similarity of generated images.

4.4.Analysis of Results

4.4.1. Effects of Data Processing on Model Training

Data processing is essential for the entire model training procedure. First and foremost, the model is able to concentrate on the stylistic features of the building by avoiding background interference and ensuring the clarity of the building body through strict filtering criteria. Secondly, the uniform image size (512x512 pixels) assists in enhancing the model's training efficiency and accuracy, in addition to simplifying the pre-processing of the input data. The accuracy of the data labels is further enhanced by the implementation of Airchi Design's autonomous labeling system, which offers precise guidance for the model's feature extraction.

4.4.2. The Impact of Controlnet Depth Information and Lora Fine-Tuning on the Generation Effect

- LoRA fine-tuning: The experimental data indicate that the model progressively produces images with Lingnan architectural designs as the LoRA weights increase. As evidenced by the data in Table 3, the image similarity is at its highest (0.92) when the LoRA weights are approximately 0.7, suggesting that the model accurately represents the Lingnan architectural style at this juncture. The image similarity decreases when the LoRA weights exceed 0.9, which is likely due to the danger of overfitting, resulting in the model generating images that deviate from the target style.

- ControlNet depth information: The optimal state of image structure retention (0.95) is achieved when the ControlNet weight is approximately 1.0, and ControlNet controls the structural information of image generation. In contrast, the image structure retention and similarity decrease as the weights continue to rise to 1.5. This may be attributed to the fact that the model loses a certain degree of flexibility in the generation process, resulting in a mechanized generation result due to the excessively high depth control weights.

4.4.3. Loss Function Reduction and Model Optimization

The loss value decreases progressively as the epoch increases, as evidenced by the loss function change in Table 2. This suggests that the model is always being optimized. The final loss value is maintained at approximately 0.09, indicating that the model has achieved a more perfect state in the extraction of the Lingnan architectural style. In the actual training process, the model's performance at various phases can be more accurately observed by storing the generation results of distinct epochs. This allows for the targeted adjustment of the training parameters.

4.4.4. Subjective Evaluation of Image Generation Quality

While the model is generating images, the image quality is assessed through subjective scoring. This approach effectively integrates the experimenter's experience to provide an intuitive assessment of the generation results. The Lingnan architectural style generated by the model is characterized by evident features and rich details, as evidenced by the subjective scores in Table 2. The image quality of the model reaches a high level at Epoch 15, when the LoRA weight is 0.7.

4.4.5. Future Directions and Experimental Conclusions

The experimental results indicate that Airchi Design, when combined with LoRA and ControlNet techniques, is more effective in generating images of Lingnan architectural styles, particularly when moderate weights are used. The images produced by the model achieve a satisfactory balance between style similarity and structure preservation. In particular, future research can further investigate the potential of combinations of various LoRA weights and ControlNet parameters, particularly in the areas of detail generation and style integration. Increasing the detail extraction of building materials, incorporating more complex building type data, or further fine-tuning the variability between various architectural styles to enhance the diversity and realism of the generated buildings are all examples.

The experimental findings illustrate the current model's potential and also establish a clear path for future enhancements. Continuously optimizing the data processing flow and modifying the model parameters can enhance the quality of image generation, thereby providing robust support for architectural design and style simulation in related fields.

5. Discussion

5.1. Prospects Of AI Generation Technology in the Study of Lingnan Architectural Styles

In the field of Lingnan architectural design research, AI generation technology exhibits significant application potential and a wide range of prospects. Initially, AI generation technology has the capacity to rapidly analyze and process a substantial volume of image data pertaining to Lingnan architecture. Through the use of deep learning models, it is possible to extricate the structural characteristics of Lingnan architecture and produce pertinent architectural designs. The innovative application of Lingnan architecture's key elements, including mounted buildings, patios, and grey carvings, in modern architectural design can be effectively simulated by this technique, which provides strong support for the integration of traditional and modern architectural styles [17]. Additionally, it can assist researchers in efficiently identifying these elements.

The second aspect is that AI generation technology can offer a more profound comprehension of the fundamental characteristics of the Lingnan architectural style on an abstract level. This is not restricted to the building's exterior form; it also encompasses deeper features, such as regional climate adaptability and cultural symbols. Using this method, researchers can conduct a comprehensive examination of the intricacies of the Lingnan architectural style and subsequently uncover its potential for integration into contemporary architectural design [10]. This opens up additional opportunities for future design, which can more effectively integrate the distinctive architectural styles of Lingnan into contemporary urban construction. This preserves the cultural heritage while constructing modern structures that are both functional and aesthetically appealing.

5.2. Technical Limitations and Future Research Directions

Even though AI generation technology has demonstrated significant potential in the study of architectural styles, it has certain constraints when applied to Lingnan architecture. First and foremost, the current AI generation technology is still insufficient in terms of the precision of spatial perception and architectural details. Lingnan architecture's intricate components, 3D spatial layout, and interaction with the environment necessitate more precise expression in the generated model. Nevertheless, AI generation techniques that are currently in use are primarily based on 2D images, which often lead to architectural designs that lack a comprehensive understanding of 3D space and detail portrayal [18]. In the examination of Lingnan architecture, this is particularly apparent, as numerous design elements, including broad eaves, roof hierarchy, and courtyard arrangement, are predicated on the architectural logic of three-dimensional space.

3D modeling techniques can be integrated into future research to address this limitation. 3D modeling can significantly improve the accuracy of the model's comprehension of architectural style and enhance the spatial relationships and structural features of Lingnan architecture in AI-generated architectural images [18-20]. In addition, one of the potential avenues for future technical advancements is to increase the diversity and scope of architectural datasets. In order to encompass a broader spectrum of Lingnan architectural styles, the AI generation model can further improve the accuracy and diversity of the derived results by incorporating additional Lingnan architectural data.

Furthermore, multimodal generation technology is a critical research area for the future. The cultural connotation, spatial perception, and stylistic features of Lingnan architecture can be more comprehensively captured by AI generation technology by integrating multiple input information sources, including images, text, and 3D data. This not only increases the expressive power of the generated architecture but also allows the model to be more inventive in the design process, resulting in architectural solutions that have a greater sense of reality and cultural profundity.

6. Conclusion

The investigation of the Lingnan architectural style as a result of AI generation technology offers a novel approach to the preservation and advancement of traditional architectural styles. This paper effectively replicates the distinctive stylistic characteristics of Lingnan architecture, including mounted buildings, patios, and grey carvings, by employing advanced AI techniques such as Stable Diffusion and LoRA fine-tuning models. This successful simulation underscores the significant potential of AI in the creation of intricate architectural styles. Furthermore, this investigation delves into the potential for the adoption of Lingnan architecture in contemporary architectural design by exploring the integration of traditional Lingnan architectural styles with modern architectural design through AI generation technology. In addition to effectively extracting the fundamental features of Lingnan architecture, AI generation technology is also capable of generating an architectural style that is data-driven and meets the requirements of contemporary design. The technology presents designers with novel tools that can not only streamline the design process but also contribute significantly to the advancement of a variety of architectural styles. Concurrently, AI generation technology enhances the efficiency and precision of the digital preservation and restoration of Lingnan architectural styles, thereby offering reliable technical support for the preservation of cultural heritage. However, the current AI generation technology is still lacking in architectural details and 3D spatial perception, particularly in the expression of the intricate Lingnan architectural structures, and has not yet attained the desired effect. In order to further improve the expressiveness and application scope of AI models, future research should integrate 3D modeling techniques, multimodal generation, and larger data sets. Finally, the protection, inheritance, and contemporary application of the Lingnan architectural style are all significantly enhanced by the advancements in AI generation technology. The integration and innovation of traditional architectural styles and modern design will be facilitated by the increasing significance of AI in the field of architectural design, as a result of the ongoing improvement of technology.

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