AI-Enabled Conceptual Design: Augmenting conceptual physical models for interior architecture design ideation.

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I. Introduction

Architecture has always progressed alongside technological advances (Oki 2024). The evolution of building sciences and materials technology has significantly influenced design and construction throughout history. For example, flying buttresses revolutionized cathedral design in Europe. The Industrial Revolution introduced new materials and techniques, expanding architectural possibilities.

Technological advances have also transformed architectural processes themselves, from sketching to construction. Computer-Aided Design (CAD) has surpassed traditional hand drawing due to its ease of use and accuracy (Kumar 2023). Building Information Modelling (BIM) has enabled real-time collaboration between offices and contractors, enhancing project management and streamlining the design process.

A survey by the Royal Institute of British Architects (RIBA) indicates that this trend of technological impact on architecture is likely to continue, in that AI will be widely adopted and integrated into professional practice with anticipated benefits in the near future (RIBA 2024). Recently, AI has gained traction in architecture for automating tasks like early-stage planning and site proposal generation, exemplified by Autodesk Forma. AI can enhance building performance by interpreting extensive datasets to generate resource-conserving and energy-efficient solutions.

However, a significant development since 2022 has been the emergence of Generative Artificial Intelligence (GAI), capable of autonomously generating text, images, and videos. User-friendly interfaces like ChatGPT and DALL-E have popularized GAI, prompting questions about its role in creative aspects of architecture, such as concept generation and design rendering.

This recent upstart of AI popularity raises a pertinent question: Can AI, known for its efficiency in handling routine tasks, also contribute to creative aspects such as concept generation or rendering designs in architecture? This research project will investigate how GAI can support and expedite the design process through creative experiments. Despite being a newly emerged and continually advancing technology, examining its current capabilities may provide insights into its future utility for design practices.

Research Objectives

The overall goal of this research is to explore how future AI technologies may impact architecture and design practices by integrating existing AI programs into the architectural design process and examining their effects. Specifically, this research aims to investigate and develop a workflow using multimodal inputs (model making and engineering text prompts) combined with image generative AI in interior architectural conceptual design. This research project's objectives were as follows:

i) To review emerging trends and methodologies adopted by other architectural and design practices in integrating AI systems into their design processes.
ii) To investigate possible utilization of text-to-image AI systems (Stable Diffusion) in conceptualising & design ideation using conceptual physical modelling for interior architectural design.
iii) To develop a personal guide of best practice when utilizing these systems, determining their strengths and weaknesses.
iv) To outline ethical and moral concerns of the use of these technologies in conceptualising and sketching for architectural design.

Research Questions

This research set to answer the following research questions:

- What techniques can be utilized to render images of interior designs using Stable Diffusion[1] accurate to the designer's intentions?
- What are the benefits and drawbacks to using this program for concept ideation, Incl. ethically/moral issues?
- What familiarity or background is necessary to effectively render images using Stable Diffusion?
- Can Stable Diffusion expedite the conceptual design process?

I. Literature Review

Firstly, it is important to define that in the context of this research project, Artificial Intelligence or AI is a "computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages." (Danith & Wright, 2008) or in layman's terms "AI seeks to make computers do the sorts of things that minds can do" (Boden, 2018). Similarly, 'Architecture' is a term used in computer science to refer to the internal organisation of a computer and its components, and thus it should be noted that throughout this dissertation 'architecture' will be exclusively referring its term use in the context of buildings.

In architectural practice, AI refers to the use of computational methodologies, algorithms, and technologies to assist architects and designers throughout various phases of the architectural workflow. Its integration is already evident in multiple digital applications, often operating without being explicitly identified as AI. Examples include algorithms that optimize building efficiency and forecast energy consumption by focusing on solar gain, systems for analysing daylighting and thermal characteristics, and AI which can assess material longevity while balancing environmental sustainability and cost-effectiveness goals.

Used in this way, AI guesses optimal design solutions aligning with specific conditions and user requirements for a project. These systems are able to process high-vector data in a matter of seconds where it might be highly impractical or impossible for an Architect to calculate themselves. Artificial Intelligence tools are already being implemented in industry staples such as AutoCAD and SketchUP.

However, the input and output of these AI tools is quantified data which can be readily analysed, compared, and interpreted using numerical or categorical methods. The current AI boom brought forward by the release and popularization of generative tools such as Large Language Models ChatGPT and text-to-image Midjourney. Though still reliant on data, these GAIs introduce novel, broad-scale techniques for rendering and visualizing concepts.

Through scouring the web for fast banks of creative projects, they are able to delve into and produce aspects that were once deemed immeasurable. These GAI generate outputs which may not fit neatly into predefined categories and may exhibit subjective or abstract qualities that defy simple quantification; data which may require more nuanced evaluation and interpretation.

[1] Stable Diffusion is a latent, text-to-image diffusion model that was released in 2022. Latent diffusion models (LDMs) operate by repeatedly reducing noise in a latent representation space and then converting that representation into a complete image.

There is considerable debate and numerous predictions concerning the future development, use, and impact of these prediction machines, particularly within one's own profession. This disparity has been particularly noticeable over the past year, as many in the arts and humanities have encountered ChatGPT for the first time, prompting profound philosophical questions about automatic writing and integrity. '*Not everyone will be so positive about the introduction of AI into architecture*.' Neil Leach speculates. '*Some will dismiss it, just as some dismissed computers when first introduced into mainstream architectural culture some thirty years ago. Why use computers, they would ask, when human beings can draw so much better? Why use artificial intelligence, some will no doubt ask, when we have human intelligence*?' (Leach 2022).

Some are concerned that, just as technological advancements have rendered many blue-collar workers like supermarket cashiers and auto-manufacturing employees redundant, leaps in artificial intelligence may threaten the job security of those in the creative industry. (Malleson, 2024). However, as of yet there is no advancement in AI that would suggest its ability to automate all aspects of an Architect/Designer's roles and responsibilities, at least for the next few decades. Being a designer is so much more than just rendering designs, it is cultivating relationships, site visits, meeting with manufacturers and networking. A huge knowledge base is required.

As opposed to considering the possibility of AI replacing the architect, we may be better prepared considering AI as an extension rather than a replacement of an architect/designer, in the same manner that AutoCAD did not replace drafting skills but improved the output quality. *"Our current traditional methodology will radically change, but not be substituted… I do think that architects still will need to stay at the centre of being the driver within that process"* (Guida 2023). In the same move that brought drafting boards out of the architectural office and desktop computers in, in our lifetime we may witness AI considered as invaluable as CAD. *"Architects who decide not to go beyond their normal practice will definitely be at risk … If you don't evolve you get replaced, it's nature"* (Mosleh 2023).

Moreover, current AI technology lacks the general awareness necessary to safely and responsibly complete diverse tasks. AI currently operates within pre-programmed parameters and lacks the nuanced judgment seen in human decision-making. For instance, while an intern can efficiently fetch coffee, an AI might achieve the task with high volume but could inadvertently harm the environment if not explicitly directed otherwise (Russel, 2020). Artificial General Intelligence (AGI), which would rival human intelligence, is often likened to computers achieving consciousness. However, experts differ on when this might occur, with some projecting it within the next few decades (Kurzweil, 2018), while others anticipate it not until 2300 (Brooks, 2019).

Insufficient human oversight may result in unchecked biases or errors in AI-generated designs, or even designs inadvertently replicating copyrighted material (Holborten, 2024). To address this concern, architects and designers must maintain a critical stance towards all outputs generated by AI. It is the recommendation of RIBA that AI should be a tool leveraged and to enhance work already being done, and should not be sought to totally replace human expertise and creativity.

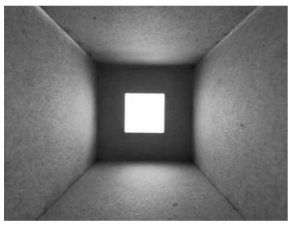
Despite advancements in AI technology and its integration with design processes, architects and designers remain the entities holding professional indemnity (PI) insurance and assuming liability for their work whereas AI cannot be held accountable. Furthermore, datasets used to train AI can potentially compromise the quality of the produced work. Biased, inaccurate, or insufficient training data may result in designs that perpetuate societal biases or yield inaccurate predictions. To mitigate these risks, it is crucial to adopt a transparent and diverse approach to data selection and implement rigorous validation procedures.

II. Methodology

The primary research method for this study involved qualitative research through creative experiments, utilizing photographs of conceptual physical models input into an Image Generation AI, Stable Diffusion. These experiments aimed to assess the effectiveness of employing AI image generators in Interior Architecture design and address the research questions.

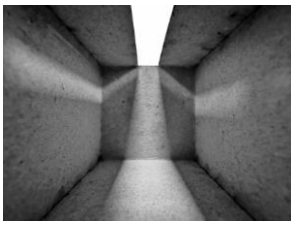
Before conducting the experiments, a thorough investigation was carried out on Stable Diffusion's functionality, offering insights into various approaches and techniques used in image generation. The experiments spanned a 40-day period and involved designing a set of 8 cardboard models (Figure 1) to photograph (Figure 2) for input into Stable Diffusion. Each model represented the general shape of a room with a single window in the back wall, with variations in window cutouts to suggest different positions and shapes. The photos of the models were digitally edited to grayscale so that coloured pixels would not cause bias.

Figure 1: *Camera setup for photographing conceptual lighting models for AI image input.*

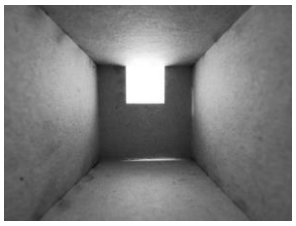


Input1

Input2

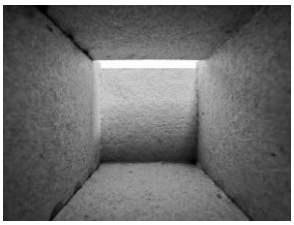


Input3

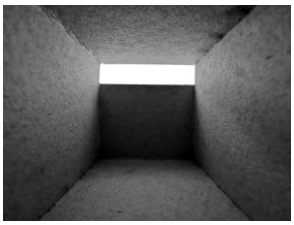


Input4

Input5



Input6



Input7

Input8

Figure 2: *Collection of images made for AI image input, photographs of conceptual lighting models. The photographs were made grayscale so that the color of the material would have no effect on the ai process.*

Stable Diffusion XDSL 1.0 was chosen for the experiments due to its open-source nature, accessibility, and ease of use compared to other AI programs like Midjourney and DALL·E 3, which are fee-based and have limited functionality. The program was also favoured as its system design and datasets were published and publicly available, eliminating unknown variables present in other GAI programs. Experiments with Stable Diffusion were conducted using an online platform and UI Nightcafe due to the unavailability of a machine meeting the required hardware specifications.

Data on best practices with Stable Diffusion in articulating the design of an interior space was collected via Trial-and-error analysis; repeated varied attempts with different textual input (prompt), image input and varying generation settings such as seed, runtime, prompt weight. These attempts were made with the goal in mind of developing a code of practice in where my design intent was consistently articulated through AI, i.e., position of furniture, materials, and lighting.

As the research was running concurrently with a final year studio project, conceptualising design ideas for a single study bedroom was chosen as an objective. All generated outputs (183) were digitally saved and stored alongside record of their corresponding inputs, including image input, prompt input, seed, generation time and prompt weight.

Insights from a pilot study conducted in the previous semester informed the methodology, including the speed of image generation, accessibility of data outputs, and challenges in maintaining objectivity. Limitations identified included the need for more diverse model inputs and the impact of textual prompt vocabulary on output richness. Suggestions for future studies include incorporating metrics for comparing AI-generated results with alternative rendering methods and exploring the use of more nuanced language in prompts.

III. Analysis and communication of findings

Stable Diffusion is capable of producing images from natural language textual prompts. These textual prompts serve as a channel for interaction between a human user and a sophisticated language model, facilitating the generation of the desired output by the model. Stable Diffusion works with prompts up to 75 tokens (words) long. If a longer prompt is inputted, any tokens following 75 are silently ignored. “Prompt engineering” is the process of structuring text that can be interpreted and understood by a generative AI model to effectively generate desired results. (Diab 2022)

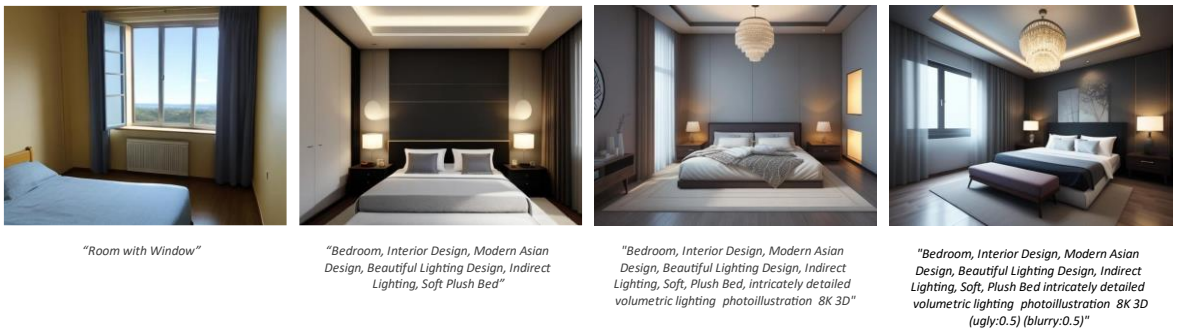


Figure 3: *Image outputs and their correspoding text prompts with Stable Diffusion Text 2 Image function.*

Figure 3 is a diagram which shows the varying affects the complexity of a textual prompt has in the corresponding image output. The results of this creative experiment demonstrate that:

- Short, undescriptive prompts tend to produce plain, unattractive images.

- Adding interior design or architectural terms to the prompt increased the likelihood of the AI pulling relevant information to interior or architectural design from its datasets, producing a more aesthetically pleasing image.

- Vague terms such as “Asian” in “Modern Asian Design” may not generate easily identifiable Asian elements or aesthetics. This may in part be due to the program not being able to differentiate the subtle visual differences between images of a “mid-century modern American bedroom” versus a “modern Asian bedroom,” in where the discrepancy between images of an “apple” and an “elephant” are more obvious. Instead, desired elements such as “natural materials” or “sliding screens” should be explicitly articulated in the textual input if desired, token count permitting.

- Moreso, adding terms referring to 3D photo rendering or specifying high resolution images improves the quality of the image output. (Perhaps because these are terms embedded in high quality images in the AI’s dataset).

- Finally, individual words can be assigned “prompt weights” in syntax. Prompt weighting allows for the emphasis or de-emphasis of specific parts of a prompt, providing greater control over the generated image. This can be done by wrapping a particular word or phrase in parenthesis and add: {weight} inside the closing bracket. E.g. A (beautiful princess:1.3) walking through a (cyberpunk:1.2) city street. Setting a number above 1.0 is a positive prompt weight, whereas assigning a number below 1.0 is a negative prompt. Vague words or terms can be used as negative prompts, e.g., using “ugly” as a negative prompt in turn produces a more pleasing image.

When textual prompts alone are given to this program, images are generated or “diffused” from random gaussian noise. However, base/starting images can be inputted into Stable Diffusion alongside a textual prompt, so that the resulting image can be an evolution of the starting one. This can enable another degree of control over the appearance of the final image, communicating colour, dimensional shape, and scale.

Figure 4: *Image Input and image outputs above their correspoding text prompts with Stable Diffusion Text 2 Image function.*

Figure 4 is a diagram which shows the varying affects the complexity of a textual prompt has in the corresponding image output when a starting image (Input8) is inputted alongside it. The results of this creative experiment find that:

- Img2img functionality still requires a text prompt for the AI to interpet what to do with the inputted image, and benefits from the same prompt engineering as inputting text alone does.

- Inputted images can articulate room and window dimensions. In all image generations, the dimensions of the cardboard model were interpreted as the dimensions and shape of the room. Additionally, the cut-out slit was consistently interpreted as a window. This functionality is valuable in situations where Stable Diffusion cannot process 3D spatial geometry or understand directions or positioning of elements in an image through textual prompts alone, likely due to the tokenization process. For example, phrases like "left foreground" or "back wall" may not be effectively interpreted.

- Materiality, colour, blemishes, and other unintentional items can be interpretated by the program, producing unwanted artefacts, e.g., cardboard colour influence wall colour.

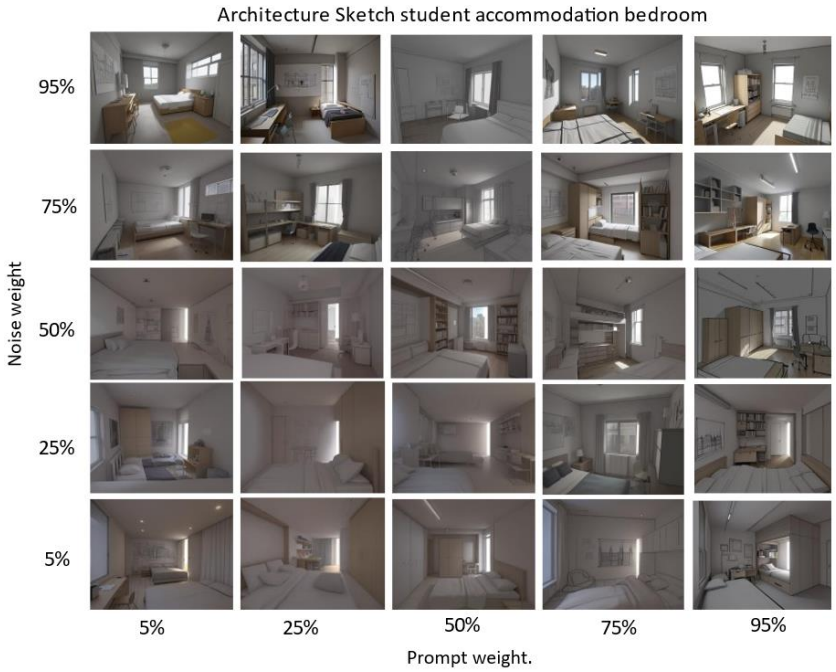


Figure 5: *Diagram of experiment from pilot study, demonstrating the results of various noise and prompt weight values alongside the same image and textual prompt input.*

Figure 5 is a diagram form an earlier pilot study showcasing the effects of various “noise” and “overall prompt” weight settings with the same image and text prompt inputs. In this example, a higher text prompt weight caused the outline of objects to appear sketched or hand drawn. Users are also able to adjust the starting image’s noise, which determines how much of the original image obfuscated and replaced with random pixel noise. A low noise value generates an image closer to the rough outline of the original image but may hamper the AI’s “creativity”. A higher noise value produces an image further away from the original, but allows the AI more freedom.

Images inputted into Stable Diffusion can also be partially masked or isolated. This allows the AI only to edit that region of the image, while considering considering all elements of the image as whole. Images outputted by the program can also be reinserted to form a new prompt. A process was developed (figure 4) wherein portions of an image were masked step by step between generations, to eventually build up a final desired composition.

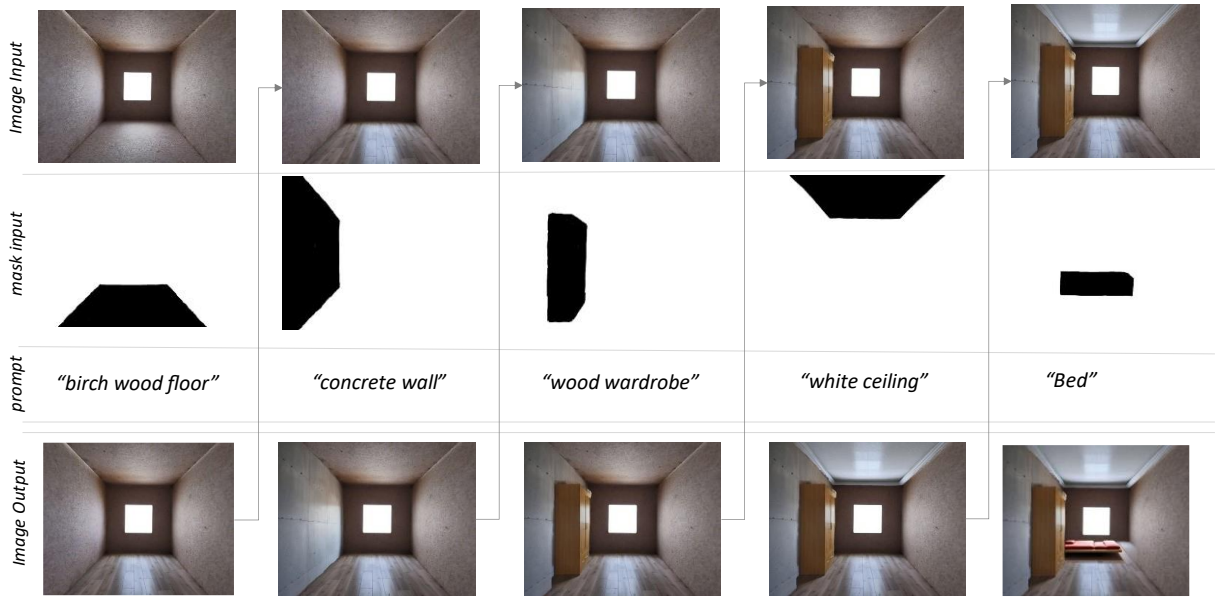


Figure 6: *Diagram of the process of masking an image.*

Figure 6 is a diagram which shows an example of both the function of masking an image, as well as the repeated process described above. The results of this creative experiment find that:

- Image masking enable the precise communication of the positioning of elements for the resulting composition. In where Stable Diffusion may not consistently interpret natural language directions of positions of 3D space, the "floor" was able to be isolated and rendered with a birch wood finish.

- The reflection of light from the birch floor, wood wardrobe and white ceiling demonstrates the AI's interpretation of the window cutout as a source of light in an interior space, and it rendered these light reflections accordingly.

- The process of masking and describing separate elements step by step allows for the generation of images accurate to desired positioning of design elements. However, the process of manually masking portions of each image input for an eventual final composition is considerably more time consuming than attempting to create it in a single generation.

Figure 7: *Diagram of inputting image created from masking process, alongside engineered prompt to generate a asethically pleasing image accurate to design intent.*

Figure 7 is a diagram showing an example of inputting an image created through this masking process along with an engineered text prompt, and one of the resulting outputs, thus rendering an overall more aesthetically pleasing image while retaining positioning of key elements of furniture. Some of the findings extrapolated from this find that:

- Some elements such as the positioning of a wooden wardrobe, red bed and white wall were preserved though the AI processing.

- Other elements such as the left concrete wall and the second bed along the right wall demonstrate that the AI is still prone to unintentional artefacts of the image.

In summary, through the experiments conducted within this research, Stable Diffusion is able to render interior spaces describe through textual prompts. Photographs of conceptual models made can inputted alongside the textual prompt to articulate room shape, positioning of windows, and desired scale. A process of repeatedly masking and generating regions of an image separately at a time facilitates a higher reliability of desired image outputs to be generated.

Despite the methods developed, described above, Stable Diffusion is not foolproof in producing images which are precise to the user's desired output. Images are also prone artefacts of non-sensical geometry, materiality, or non-practical items. This in due in part to the program not understanding or having a basis for 3D geometry or understanding of practical functionality for items in these spaces.

Many of these issues can be addressed by utilizing a checkpoint of Stable Diffusion trained with a better dataset, or by utilizing other tools such as various "ControlNets" which are neural network structures used in diffusion models to control final image generation through various techniques such as pose, edge detection, and depth maps (Cleaveland 2023). In addition, the AI's rapid speed of image generation allows for large batch generation of images, which may vary widely in quality (Figure 8). This allows a user to select outputs preferential or closer in line to their final desired output and further evolve them onwards.

(a) Output 7, Seed 2404036068 *(b) Output 20, Seed 230059159*

***Figure 8**: Two different images both produced by inputting an image created through the repeated process and natural language prompt, both differing only by starting seed. IP PEVOL5_"Study Bedroom, Bed beside window, Wardrobe against left wall, Interior Design, Modern Design, Birch Floor, Smooth Concrete Walls, Beautiful Lighting Design, Indirect Lighting, Soft, Plush Bed, Wardrobe, photoillustration 8K 3D (ugly:0.5) (blurry:0.5)"_5070, Outputs 7 and 20 respectively.*

IV. Discussion of findings considering theory in the literature

The research found that Stable Diffusion can produce detailed interior space images in seconds, but without careful prompt engineering, outputs can be unattractive, warped and/or impossible images. The directions or positioning of elements cannot be reliably articulated through the textual prompt alone, likely due to the tokenization process. These issues may be offset by operating batch image generations to produce a variety of images to choose from, or by utilizing various other systems such as a ControlNet to alter the AI's treatment of a starting image.

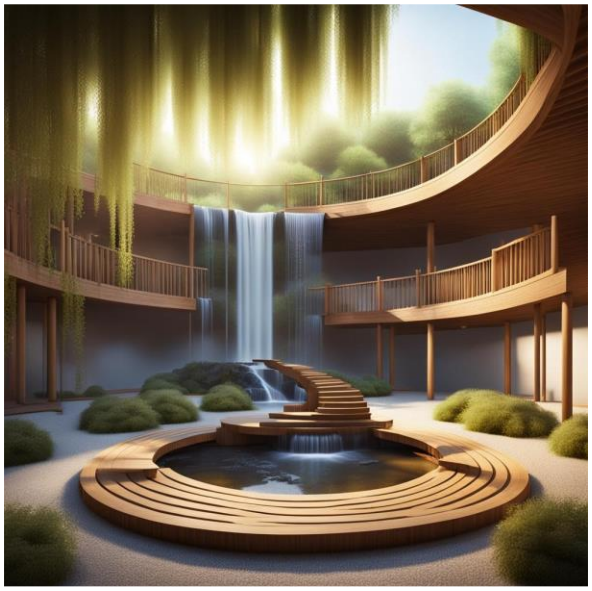
The AI's ability in rendering a specific, desired composition is tied to a myriad of factors and parameters, such as the dataset the AI was trained with, seed, generation time and text/image prompts. As such, best practice of use would be trial-and-error until a satisfying result was achieved, rather than relying on the program to produce a perfect result first time. Whether Stable Diffusion can be leveraged for design ideation is up to discussion, and will likely differ between persons as to their preference. Nonetheless, these findings support the hypothesis that Stable Diffusion can be used to render designs of interior spaces accurately, albeit with knowledge of how to best utilize the program and trial-and-error.

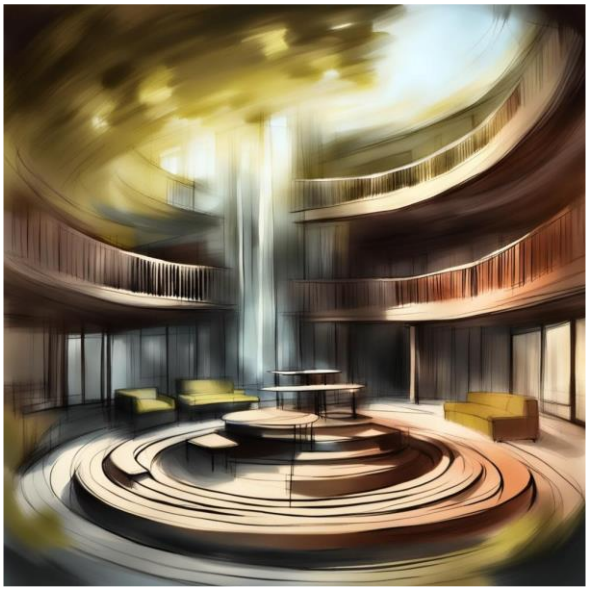
In line with the hypothesis, Stable Diffusion can be used relatively easily to render material and colour pallets for a space. This may be utilized by designers to quickly workshop various material pallets or combinations by rapidly varying compositions with varying combinations. Illustrating these pallets through Stable Diffusion may be significantly faster than composing either a physical or digital materials board.

An unforeseen utility of stable diffusion may be in communicating design ideas quickly to others, particularly those who may lack in design vocabulary. There may be moments where it is easier and more effective to render an image with AI, in where hand sketching would either fail to or not satisfyingly convey key elements.

For either use, users may find benefit in engineering a prompt to produce design renderings in the style of conceptual hand sketching (Figure 7, b) if only simple colour pallets, forms, and the relationships between are the important notions that are conveyed. Otherwise, rendering ideas in

the style of photorealistic renderings (Figure 9, a) are more likely to produce artefacts which either distract or are incorrectly interpreted as design elements to viewers.





(a) *"Courtyard zen garden with large willow tree, (waterfall:1.5) in front of spiral staircase, simple wooden chairs and desks in center,* ***volumetric lighting, photoillustration*** *(blurry:0.5) (ugly:0.5)"*

(b) *"Courtyard zen garden with large willow tree, (waterfall:1.5) in front of spiral staircase, simple wooden chairs and desks in center,* ***Conceptual Sketch, hand drawing*** *(blurry:0.5) (ugly:0.5)*

Figure 9: *Comparison of two different ouputted images with differing inputed stylistic renderings; realsitic rendering versus conceptual/hand drawn rendering.*

Designers may also be able to use Stable Diffusion to produce finished renders of designs for clients and exhibition. Doing so may require considerable amount of time depending on the subject, however the AI may be able to illustrate finished designs in a fraction of the time conventional means such as hand drawing or photo-rendering requires.

This study's literature review and preliminary studies have so far indicated ethical concern amongst architects, architectural designers, developers, and the broader community concerning the creation and use of AI. These include but are not limited to; AI perpetuating biases contained within their training data, determining accountability and ownership for AI decisions and actions, and the automation and augmentation of jobs by AI which may lead to job displacement in certain industries.

Many GAI programs recently released to the public are available exclusively online through cloud-based services, with both the AI's functionality and dataset not documented or available for public viewing. A benefit of Stable Diffusion being open source is that it promotes transparency, allowing users to inspect and understand how data is fed and processed. Users can either download independent datasets to train Stable Diffusion with or create their own. This allows users to have complete control over what information is trained/harvested and being used by the program.

Furthermore, a user can record the current settings of a generation, and note all factors/inputs in the process, such as model version (checkpoint), dataset, prompt, seed & settings. Not only does this allow transparency in what was used to conceive the image for if the designer wishes to recreate said image, it also underscores a designer's input, involvement, and intent in an otherwise seemingly opaque process.

Architects and designers utilizing AI to augment their own creativity or workflow would still be responsible for what it outputs, and would need to remain diligent for mistakes or errors, as they

alone would be responsible for any unforeseen repercussions. They would also need to exercise caution in responsibly utilizing AI to augment one's own creative processes, for example in concept ideation and skillset in articulating design intention, while not letting it hinder, thwart, or replace one's own abilities.

Due to constraints in resources and time for this research project, there was a lack of available metrics for comparative analysis of results. Consequently, it was not possible to objectively measure: a) the positive and negative effects of utilizing Stable Diffusion for design ideation, and b) whether using images produced by Stable Diffusion enables clearer communication of design intent to others.

To address this limitation, future studies could incorporate metrics for comparing AI-generated results with alternative rendering methods, such as hand sketching or photo-rendering. For instance, a survey could be designed to assess participants' perceptions of different image samples generated through AI versus conventional rendering methods.

V. Summarising Conclusion

The current research sought to draw conclusive insights into how Generative Artificial Intelligence can be augmented into various design processes within the field of architecture and interior architecture.

The central aims for this research were as follows:

i) To investigate possible utilization of text-to-image AI systems (Stable Diffusion) in conceptualising & design ideation for interior architectural design.
ii) To establish a framework of best practices in utilizing these systems effectively and efficiently, identifying their strengths and weaknesses.
iii) To outline their inherent strengths, weaknesses, and any ethical and moral concerns of the use of these technologies in architectural design.

A pilot study was conducted to ascertain the chosen methods were effective in answering the research questions within practical and contextual limits available. Research was done into both Stable diffusion's internal mechanisms in order to understand how it functioned, as well as best use guides published by proficient users of the program.

Creative experiments conducted utilising Stable Diffusion demonstrated its capabilities of rendering highly detailed and attractive images of interior spaces within seconds. The AI is susceptible to producing warped/impossible artefacts in their images, and to perpetuating biases contained within their training data. Through a process of prompt engineering, photographing conceptual modelling, image masking and continually evolving outputted images, Stable Diffusion is capable of producing results which are accurate to the desired output.

This research has shown the potential for AI image generators to be leveraged and developed into innovative design methodologies, and may provide valuable guidance for students, educators, and practitioners for what may be an inevitable technology integration into our practice. While AI has its strengths, human oversight is still crucial to ensure accuracy, reliability, and ethical integrity.

Balancing this dual responsibility involves recognizing AI as a valuable tool while maintaining a vigilant stance, cross-referencing, and validating its outputs to minimize potential errors or biases. This approach promotes responsible AI integration while driving innovation in the fields of architecture and design.

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VII. Appendices

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Video Exhibition Link

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