Asterios Agkathidis

AI-Assisted Architectural Design

Generative Form-Finding Methods by Using Artificial Intelligence

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Abstract

Artificial Intelligence (AI) tools are currently making a dynamic appearance in the architectural realm. Social media are bombarded by word-to-image/image-to-image generated illustrations of fictive buildings generated by tools such as “Midjourney”, “DALL-E”, “Stable Diffusion” and others. Architects and designers appear to be fascinated by the rapidly generated and inspiring ‘designs’ while others criticise them as superficial and formalistic. In continuation to previous research on Generative Design, this book aims to investigate whether there is a suitable way to integrate these new technologies as a generative tool in the educational architectural design process. To answer this question, we developed a design workflow and tested it for two semesters in an architectural design studio in parallel to other studio units using conventional design methods but working on the same site. The studio outputs were evaluated by guest critics, moderators and external examiners. Furthermore, the design framework was evaluated by the students through an anonymous survey. Our findings highlight the advantages and challenges of the utilisation of AI image synthesis tools in the educational design process of an architectural design approach.

Introduction

Artificial Intelligence (AI) tools have been increasingly influential in the field of architecture and are starting to have an impact on the architectural design process. Word-to-image and image-to-image generated illustrations of imaginary buildings, based on AI technologies such as Computer Vision, Generative Adversarial Networks, Image Synthesis and Neural Style Transfer are bombarding social media platforms, mostly utilising tools such as Midjourney, DALL-E, Stable Diffusion, StyleGAN and DeepDream among others.

Many architects and designers appear to be fascinated by the visually impressive and quickly produced ‘designs’ generated by AI. It is capable of generating unique and imaginary buildings, landscapes and atmospheres, challenging the conventional design process. On the other hand, many sceptics have raised concerns that these AI-generated “designs” prioritize superficial aesthetics over substance, describing them as crude formalism.

Building upon previous research on Generative Design (Agkathidis, 2016) in this area, this book aims to cast insight into the integration of AI technologies as generative tools within the architectural design process. In particular, the main aim is to investigate whether there is a suitable and meaningful way to incorporate these AI tools into a framework of architectural design suitable for architectural education and practice.

The book explores various aspects, including the impact of AI on concept development, the potential for collaborative design processes between humans and AI, the implications for design aesthetics, and the integration of AI-generated designs into the broader architectural discourse. It will also investigate how these AI tools can contribute to enhancing creativity, innovation, and critical thinking skills among architecture students, educators and practitioners. Thus, this book will answer the following questions:

- How can we integrate AI image synthesis tools into the educational design framework of an architectural design studio?
- How successful is such a design process in comparison to conventional design studio module processes?

To answer these questions we develop a design workflow which consists of the following phases:

1) site analysis, data collection and the definition of design principles
2) morphogenesis utilising AI-generated word-to-image / image-to-image illustrations
3) translation of the illustrations into abstract digital and physical 3D models
4) translating the models into architectural solutions.

There are several feedback loops between these phases, thus errors can be corrected. We test this framework for three semesters in an architectural design studio module in parallel to other studios using conventional design methods but working on the same site and topics. The studio outputs were evaluated by guest critics, moderators and external examiners. Furthermore, the design framework was evaluated by the students through an anonymous survey.

Artificial Intelligence, a Brief History

The field of Artificial Intelligence (AI) emerged in the 1950s aiming to develop machines that could imitate human intelligence. In 1935, Alan Mathison Turing was the first to describe a computing machine with a limitless memory, equipped with a scanner capable of reading symbols and writing further symbols as well. During World War II he was a leading cryptanalyst for the British government. In 1950 Turning introduced a practical test to measure computer intelligence, which is known as the "Turing Test" (Turning, 1950).

The Dartmouth Conference (McCarthy et al., 1956) held in 1956 was the playground where AI was defined as a formal discipline defined by a small group of researchers who had specifically gathered for that purpose. They focused on rule-based AI systems capable of manipulating symbols and following logical rules. That same year, Allen Newell and Herbert Simon developed the Logic Theorist program (Newell and Simon, 1956), which became the first AI program to verify mathematical theorems.

In the 1960s, ELIZA (Weizenbaum, 1966) was developed, which was another computer programme capable of simulating human-machine conversation by using pattern-matching techniques. In the 1970s, further programmes were created focusing on solving complex problems in specialised domains.

AI research slowed down during the 1980s and 1990s, due to a decrease in funding and interest, often known as the “AI winter.” However, research continued focusing on areas such as machine learning, neural networks, and natural language processing. The 21st century arose as the century of the AI Renaissance stimulated by technological advantages in computing power, the availability of large datasets, and improved algorithms.

Machine Learning, particularly Deep Learning, was driven by the development of neural networks consisting of multiple layers capable of learning complex patterns. This led to the widespread adoption of AI in various fields, such as computer vision, speech recognition, natural language processing, and robotics.

A significant milestone in AI evolution is the development of the “Watson” AI algorithm (Ferrucci et al., 2010), capable of defining a human champion in the Jeopardy quiz show. Similarly, the ‘AlphaGO’ program by Silver et al (2016) defeated a world-champion Go player.

Terminology and Definitions

Currently, AI technologies continue to advance rapidly, with breakthroughs in areas such as autonomous vehicles, virtual assistants, medical diagnostics as well as the world of architecture. AI is capable of assisting architects as a generative design tool, generating multiple design variants, as an analysis tool for large data sets, energy consumption, structural performance, and acoustics, as an intelligent building management system, capable of operating and managing building operations and monitoring, and never the less as a powerful visualisation tool, capable of facilitating design explorations, spatial qualities, materialities and atmospheres.

AI-based image generation and image manipulation are some of the most upcoming fields in digital image processing. This process involves generating, altering or modifying images using various techniques, tools, or software (e.g. word-to-image generation, image-to-image generation or modification, and image blending among others). As it remains a new field of technology invading the fields of architecture and design, many of the AI-related image-processing definitions and terminologies remain hard to grasp for architects and designers.

Artificial Neural Networks (ANNs) draw inspiration from the structure and functioning of the human brain to process and learn from input data (Haykin, 1999). ANNs consist of interconnected artificial neurons, or nodes, organized into layers, which enable them to learn complex patterns and relationships in data by undergoing a training process. ANNs can “learn” through the training processes and make predictions on new, unseen data, making them applicable in various domains such as image and speech recognition, natural language processing, and recommendation systems, among others.

Deep Learning (Goodfellow et al., 2016) is a subfield of machine learning that focuses on artificial neural networks and algorithms following the principles and structure of the human brain and plays a key role in image modification tools.

Computer Vision (Szeliski, 2022) is a research field focusing on enabling computer power to gain a high-level understanding of digital images or videos. AI image modification tools often use computer vision techniques to analyse and intelligently modify images.

Generative Adversarial Networks (GANs), (Goodfellow et. Al, 2014) are deep learning models that consist of two neural networks, the generator and the discriminator, and can be utilised for image modification tasks such as image synthesis, style transfer, and image super-resolution.

Image Synthesis (Isola et al. 2017) can be described as the process of generating new images that do not exist in reality, while Style Transfer (Johnson et al., 2016) combines the style of an existing image with the content of another.

Image Super-Resolution (Wang et al. 2018) describes the process of increasing the resolution and enhancing the details of an image. AI-powered inpainting (Munteanu et al., 2021) algorithms can intelligently guess the missing information based on the surrounding image context. Image enhancement techniques can improve image quality, resolution, appearance, or visual style. AI-based image enhancement algorithms can automatically adjust image brightness, contrast, sharpness, and colour balance, thus improving the overall image quality. AI-based super-resolution techniques utilize deep learning models, while image inpainting involves filling in missing or corrupted parts of an image with plausible content.

Neural Style Transfer (Gatys et al., 2016) is a technique that combines the content of one image with the style of another, while Deep Dream (Mordvintsev, 2015) uses deep neural networks to generate dream-like and surreal images.

A Critical Review of AI-based Design Methods

Despite the fact that AI-based design tools have only appeared in the past few years, there are many researchers exploring their use in the architectural design process. Campo et al. (2019) present the Church of AI advanced design studio project where they utilize Deep Neural Networks, such as the DeepDreem generator, to create mash-ups of two-dimensional images. They also utilize two different techniques for further 3D exploration: the utilization of poly-mesh rendering software which embosses images into 3D meshes as well as the application of Neural Mesh rendering solutions.

Asmar and Sareen (2020) describe an AI-driven pipeline, based on GANs. Their method includes the initialization of latent space through StyleGAN model training, followed by 512D vector-generated images. They finally generate a voxel 3D structure by using the pixel values of these images, while Basasir and Erol (2021) explore the use of Generative Adversarial Networks (GANs) as part of a representational framework to translate an architectural textual design brief into corresponding images; however, the paper does not demonstrate design outputs.

Furthermore, Hassab et al. (2021) present an AI methodology for generating double-curved surfaces. They use CycleGAN, Pix2Pix, and Grasshopper to produce what they consider as ‘unique surfaces’. Yousif and Vermisso (2022) introduce a generative design method including the wave function collapse (WFC) method, agent-based modelling (ABM), and GANs that are connected to evaluate possible scenarios of those methods; AI is used as a control mechanism for guiding the general framework. They use tools such as C# embedded into a Rhino/Grasshopper algorithmic definition, the Culebra tool, PyTorch, and TensorFlow deep learning packages for training the neural networks. A number of Python algorithms are written specifically for the management of datasets.

Kavakoglu et al. (2022) present a pedagogical experiment on integrating AI in an early-stage design studio process. They use styleGAN2-ADA to train AI using a collected dataset for a façade design. They combine several techniques alongside AI-generated images, including sketches and physical models. Bank et al. (2022) also utilize 2D GANs to explore spatial characteristics with architectural students based on a training dataset of 3D models of material-labelled houses. They use vertical section slices through 3D models as the primary medium between humans and neural networks in the framework of a design studio.

Halici and Gül (2022) explore a combined method utilizing GANs and Augmented Reality (AR) to produce architectural massing studies. Their technique consists of two steps. First, they prepare synthetic data in Rhino/Grasshopper to be trained with an image-to-image translation model and implement the trained model in a Mixed Reality design environment. Liu et al. (2022) display a so-called AI-assisted 3D modelling design method that utilizes Convolutional Neural Networks (CNN) based Style transfer for 2D image generation of building design. Yang et al. (2023) propose a machine learning-based framework to convert hand-drawn 2D sketches into 3D models. The user can sketch a web-based interface, which is then automatically transformed into a 3D mesh model via the Rhinoceros/Grasshopper software. The models are further refined using an optimization step. The researcher use a dataset, consisting of 5,000 houses, to train the neural network, thus it can perform its task. Although it cannot replace traditional 3D modelling software, the framework allows architects to explore different forms quickly. The code and the dataset are available on GitHub. The framework operates more as a 2D to 3D conversion tool than a design method.

Dai et al. (2023) present a framework for AI-human collaboration in the architectural design process. It combines the use of semantic AI models, 2D and 3D modelling, and neural networks. The users can iteratively explore and transform conceptual forms by combining prompts, 2D images and 3D models utilising the Rhinoceros/Grasshopper interface. The framework is validated through a case study involving early concept exploration for a museum, demonstrating its practical application in design scenarios.

Materials and Methods

Having reviewed the above work, this book proposes a novel design framework that utilizes AI-driven image synthesis tools not as means to generate buildings directly but rather as exploratory mechanisms in abstract geometrical, spatial, and typological prototypes that undergo various transformations before becoming buildings, such as physical and digital 3D modelling, contextual adaptation, sketching, functional and environmental adaptation, incorporating a wide range of AI, 3D modelling, and CAD software.

To answer the research question stated above, a design framework is developed, consisting of four distinct phases as described in Figure 01:

1. Site Analysis, Data Collection, and Definition of Design Principles: This initial phase involves analysing the site, collecting relevant data, and defining a set of design principles that inform the subsequent stages. Site analysis considers physical context, environmental factors, social dynamics, and historical background. The data collected during the analysis phase are translated into prompts, to be used in the next phase and include AI tools such as Stable Diffusion, Midjourney and DALL-E.

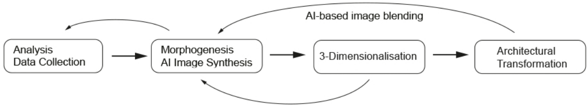


Figure 01: AI-based design framework

2. Morphogenesis Utilizing AI-Generated Images: In this phase, AI-generated illustrations are generated utilizing image synthesis algorithms, using text-to-image, image + text-to-image, and image+image techniques. Hereby, the images do not depict buildings, but rather abstract geometrical compositions, volumetric studies, nature-inspired spatial principles, and typological hybridizations among others.

3. Translation of Illustrations into abstract digital and physical 3D Models: Once the AI-generated illustrations are produced, they are translated into abstract digital and physical 3D models. This translation allows for the exploration and refinement of the design principles and concepts derived from the AI-generated visuals.

4. Translating Models into Architectural Solutions: In this final phase, abstract digital and physical 3D models are further refined to transform into architectural solutions. The translation process considers programmatic as well as performative parameters such as structural integrity, functionality, and aesthetics to create viable designs that address the project's objectives and constraints.

The design workflow incorporates feedback loops between the different phases, enabling iterative refinement and correction of errors or deficiencies identified during the design process. By incorporating feedback loops, the workflow allows for continuous improvement and optimization of the design solutions.

The tools and techniques used include image synthesis algorithms such as Stable Diffusion, Midjourney, DALL-E, 3D modelling and parametrization software like Rhinoceros/Grasshopper and SketchUp, as well as 2D CAD software like AutoCAD and image manipulation software Photoshop with its newly introduced AI components.

To evaluate the design framework's effectiveness and the integration of AI-generated illustrations as generative tools, the workflow is tested in an architectural design studio module environment conducted over two semesters. The projects are conducted in two different contextual environments, one located in a natural context, on an uninhabited island, and the other one in a dense city centre urban environment. The design brief related to the natural context requests a small/middle-scale building focusing on a visitor centre or a small hotel, whereas the design brief related to the urban context requests a medium/large-scale mixed-use building. The project size is related to the group size, as some students work in groups of two while others choose to work as individuals. The same task is conducted in parallel by other studios, which follow a conventional design approach.

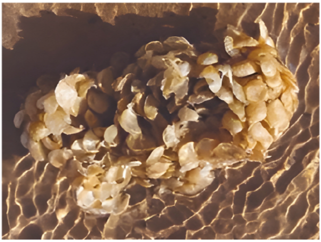
The outputs of the studios, including the designs produced, are evaluated by a panel of experts who provide valuable insights and feedback. Additionally, the students themselves evaluate the design framework through an anonymous survey, providing valuable perspectives on their experiences, challenges faced, and the methodology's efficacy in enhancing their understanding and engagement with the architectural design process. Through a comprehensive evaluation approach, incorporating expert critique and student feedback, the effectiveness of the design methodology and the integration of AI-generated illustrations as generative tools can be assessed, providing insights for further refinement and potential adoption in architectural design for education and practice.

Natural Context

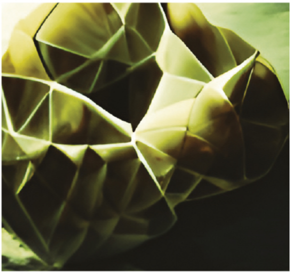
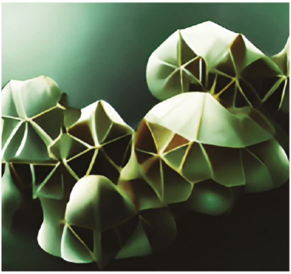
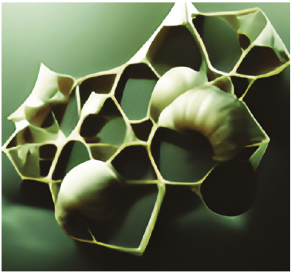
01. Hybrid Clusters

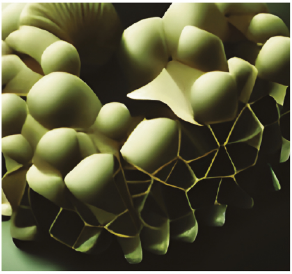
The project's starting point explores natural whelk egg clusters. Initial images of whelk egg cluster formations taken on-site are used as input images in Midjourney, in addition to prompts such as 'cluster, light, translucent, modular, organic, and porous' for image+prompt synthesis. After generating a set of iterations incorporating seed selection, image blending, and zoom-in/out techniques in Midjourney, the project proceeds to phase two by first mapping the most intriguing AI-generated image. It incorporates digital modelling, geometry parametrization, as well as spatial and typological exploration via plan section diagrams of the 3D model prototypes. In continuation, the three-dimensionalized porous structure is transformed into a small spa hotel, which fully integrates itself within the landscape, while accommodating all necessary facilities and environmental strategies for a sustainable operation.

The initial photograph starting point of a whelk egg cluster



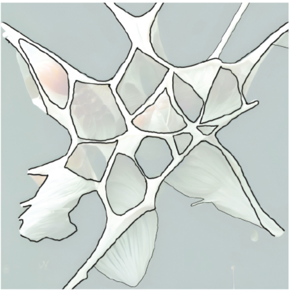
AI image synthesis: Image+text prompts: cluster, light, translucent, modular, organic, porous

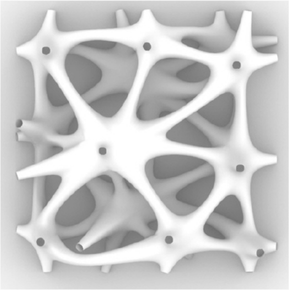





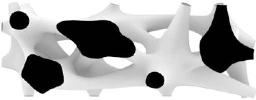


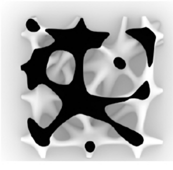
Left page: AI image synthesis iterations

Right page: Three-dimensionalisation of AI generated images, spatial exploration through horizontal and vertical sections

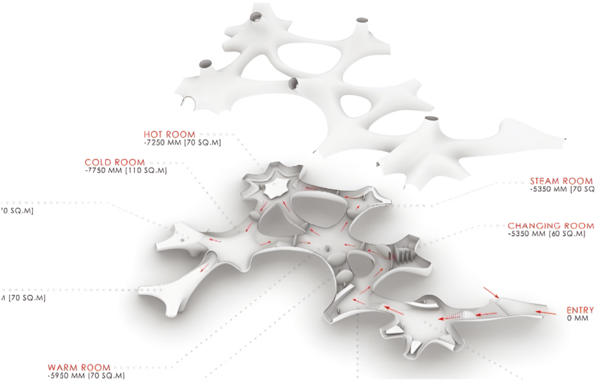




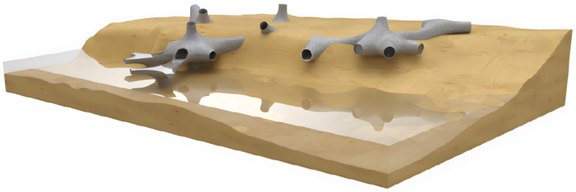




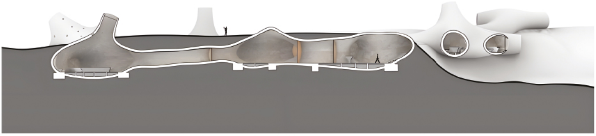
Architectural translation, exploded diagram



3D model of the building in context



Schematic section



Top: Interior image of the hamam space
Bottom: Entrance space, exterior view