Computational Methods and Artificial Intelligence in The Architectural Pre-Design Process (Case Study: House Design)

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ABSTRACT

The current development of information technology infrastructure has positively impacted the ease with which people can carry out work activities physically and creatively. Artificial intelligence, which is currently starting to penetrate the world of visual design and architecture, is starting to develop from integrating design methods to methods of presenting or communicating architecture. In this study, aspects of artificial intelligence are used as a pre-design method, which is considered to help speed up decisions in design communication. The problem raised in this study is how optimal the involvement of computing and artificial intelligence is in providing pre-design considerations in the case of simple residential houses, especially in the analysis, space, and visual aspects. This study aims to obtain the methods and influence of computing and artificial intelligence in formulating pre-designs and generating understanding regarding the methods of their use. Several analysis tools are used for the spatial approach: the space syntax using DepthmapX software, solar analysis using the Shadedat plugin, and the visual shape of the building using Stable Diffusion. This research uses an experimental approach to obtain the desired design results. This study's findings explain that applying appropriate computational and artificial intelligence methods will produce an effective and efficient design process. With the correct sequence, it will have a measurable design process that can be assessed well.

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1. INTRODUCTION

The Industrial Revolution had a tremendous impact on digital development. Nowadays, software and digital hardware cannot be separated in life. According to Abdullah [1], the presence of the Industrial Revolution 4.0 is in the form of the increasing development of very sophisticated technology that has a significant influence on human life, such as artificial intelligence, digital commerce (e-commerce), giant data, financial technology, economics, and the use of robots.

In its journey, traditional methods have consistently faced significant challenges in the design process; one example expressed by M. Hegazy and A. Saleh was during the design process carried out by Frank Gehry in designing the Guggenheim Museum Bilbao with curved surfaces and Gehry's signature lines, which required a shift from traditional methods to digital methods, namely the CATIA program, which was developed for the aerospace industry to design fighter aircraft [2]. According to John, a design process involves problem identification, problem-solving, solution, and implementation [3]. If connected in real terms in the design process, these three things can be divided into several parts, namely:

1. The initial process, namely searching for data and analyzing the data to find problems,
2. The second process is finding solutions to problems, developing concepts, and designing transformations,
3. The third process is translating into a pre-design, and the final process is creating construction documents.

Architectural computing and artificial intelligence (AI) are technologies developed to help humans make decisions. According to Kyratsis, computational design is a method that uses programming to design and change shapes and structures [4] in [5]. In 1950, a mathematician and philosopher, Alan Turing, developed the concept of how machines think and how machines can learn and are intelligent, which became the beginning of the development of machines that could think. Currently, the development of the field of artificial intelligence is very rapid. A lot of machine learning can help humans do jobs such as recognizing sounds, images, and natural language.

According to A. Kaplan and M. Haenlein, AI is the ability of a system to correctly interpret external data used for learning so that it can achieve specific goals and tasks through flexible adaptation [6]. According to Russell, AI is the study of intelligent agents that receive orders and make decisions [7]. Through their functions, agents are implemented and can take action to perform various tasks, such as logical planning and production systems.

Artificial intelligence has evolved from simple things to complex and complicated things. It started with a simple thing that Alan Turing did in 1950: determining whether machines could "think" like humans. Turing proposed that a human assessor would assess natural language conversations between humans and machines designed to produce human-like behavior and currently use diffusion methods to create an image simply by writing down words.

According to C. Bartneck, C. Lütge, A. Wagner, and S. Welsh, AI requires processing sensory data to find the correct meaning, which can be presented in a digital structure [8]. Next, the data is processed by a machine to determine what actions to take. This entire process requires knowledge (data) about the world, logical reasoning, and, thus, having the skills to learn and adapt. This capability can make the machine autonomous without needing a full human operator.

In today's industrial world, computing and AI processes have become virtual assistants that can help humans carry out activities. For example, here are some applications of AI technology in industry today:

1. Natural language processing (NLP) is used to understand and respond to customer requests.
2. Chatbots are used to improve customer service.
3. Predictive analytics techniques are used to predict market trends and consumer behavior.
4. Robots are used to speed up the production process and reduce labor costs.
5. Facial recognition technology is used to improve security.

The development of AI in various fields indirectly changes the methods of searching for data, analyzing it, and taking appropriate action. In architecture, computing developments align with developments in the digital world—the development of artificial intelligence to assist planners in analyzing and creating images of simple to complex things. AI can speed up the design process, from analysis to building optimization and efficiency.

Davis WeWork evaluated two buildings using computing and machine learning to analyze data generated by occupants, explaining that using computers can complete post-occupancy building evaluations [9]. S. Ida Smith and C. Lasch developed an Intelligent Adaptive Control (IAC) framework that uses machine learning to integrate responsive passive conditioning of the building envelope into a comprehensive conventional environmental control system for buildings, concluding that the IAC method that adopts artificial intelligence can increase the adoption of automation and through the development of an experimental framework that includes testing of physical materials linked to computational simulations, can describe a set of tools and procedures that may be better for architects to visualize and experiment with adaptive building envelope design [10].

Visuals are an essential element in managing forms. Visuals will describe the form of an object well and clearly so that it is easy to understand. The visual aspect is one of the pillars of architecture, making it easier to communicate in the design process. Several architectural elements influence other visuals: composition, contrast, scale, proportion, color, and dynamics. These various components will influence visual perception, visual communication, and the meaning of color.

In architectural computing, visuals represent meaning; for example, in temperature and space analysis, the colors red, green, and blue will be defined as robust, medium, and low values. In AI, the method used in deep learning is the convolutional neural network (CNN), which uses artificial neural networks to identify images and language. They can be used to create new things. According to Gua (2017), the Convolutional Neural Network (CNN) is a deep learning architectural model based on living things' visual perception mechanisms. This architecture is designed to process gridded data, such as images, similarly to how humans recognize graphic patterns.

2. RESEARCH METHOD

This research is limited to how machines assist in the design process. So, several specific factors related to the tools used are selected, and other functions are ignored. The methods used in the research are computing and AI processes in the experimental process of analyzing shape and space and finding forms in the planning process for a simple residence. The tools used in the design process are a) shape analysis using the Shadedat plugin, b) analysis of space configuration using a space syntax approach with the DepthmapX application, and 3) finding the shape of the facade and interior using Stable Diffusion. In the design process, the three tools are used linearly: solar analysis using shaded, space analysis using DepthmapX, and in the final stage, looking for the visual shape of the building using Stable Diffusion. This process is carried out repeatedly until the desired results are obtained (Figure 1).

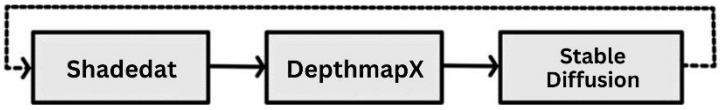

Figure 1. Design Process

Each tool has different procedures for reading results according to algorithms and functions. Shadedat measures how long the area of a building is exposed to the sun and the direction of the shadow. Calculation parameters are used to determine building facade engineering. DephtmapX is a tool used in room analysis with several assessment parameters, namely, integration, room connectivity, and choice; the study results will be obtained from room accessibility values, which are used to create room layouts that are effective according to needs. Stable Diffusion is a tool for visualizing the shape of building facades using text-to-image and image-to-image methods.

3. RESULTS AND DISCUSSION

The case study in the design experiment is a house with limited land. The house is planned to be a small house. Space efficiency is a binding factor in planning. The planning location for the house is in Jogjakarta and has a flat site character. The site is limited land located in a settlement. The site is surrounded by houses with a land area of 100 m^2. The site faces south and has an area of 70 m2 with two floors. The house pre-design experiment process is divided into 3 phases, namely: 1) analysis of geometric shapes of sunlight, 2) analysis of the effectiveness of configurations in space, and 3) finding the shape of the building and space in the house.

a. Phase one: Find the geometry and adopt.

Phase one is the initial "finding"; this phase aims to find adaptive geometric shapes. Phase 1 is limited to how geometric shapes adapt to sunlight. The parameters used are the number of rays falling on the surface and the direction of the shadow. Using Shadedat Tools as a computing tool, a free SketchUp plugin was

created in the Ruby programming language by The Shadow Factory. This plugin considers the geometric surface and is intended to record the amount of time and average intensity of sunshine on a daily and annual basis. Additionally, it visualizes the direction and length of shadows throughout a day or year, consolidating the information. The visual output employs a red-to-blue gradient, symbolizing vitality in weak sunlight. The analysis is executed at specific site coordinates, enabling the calculation of the shadow and sun directions influenced by the geometric plane.

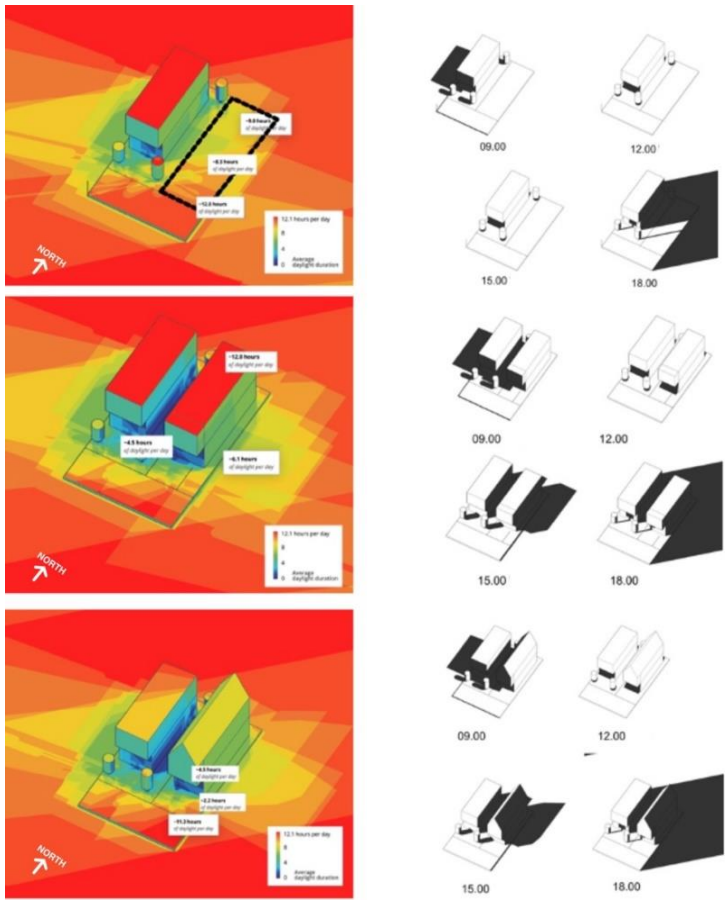

Figure 2. Daylight analysis and shadow direction

Figure 2 is a sequence of output from the Shadedat plugin results from empty site analysis, experiments on simple forms of mass composition, and results of mass composition. This process is a sequence of searching for the shape of the daylight and the direction of the building's shadow to get the maximum amount of sunlight on the building surface for 12 hours (06:00–18:00). The results of daylight analysis and shadow direction can be used to accurately engineer building envelopes that are adaptive to the climatic context in which the building is located. By knowing the daylighting values and the direction of the design shadows, it will be easy to determine the openings in the building and the materials that can be used.

b. Second phase: looking for space effectiveness.

Phase two is a continuation phase of "finding," namely finding an adequate space plan according to efficient space goals regarding space configuration, accessibility, and visibility values. The computing tool used is the DeptmapX application developed at the UCL Bartlet School of Architecture, which was inspired by the space syntax theory developed by Bill Hiller. According to Bill Hillier, space syntax is a collection of theories and techniques for analyzing space in architecture according to its functional characteristics [11]. Space Syntax aims to create a model of space for humans, the structure of space, and its social implications. The method used is a mathematical algorithm. The visual representation is a red-to-blue color gradation to indicate strong, medium, and weak values.

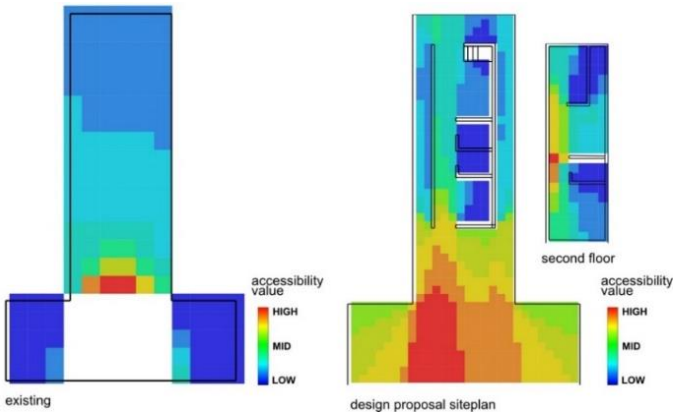

Figure 3. Analysis of accessibility value in the house

Figure 3 shows the space syntax analysis process carried out using DeptmapX software. The analysis measures the level of accessibility of spatial relationships at the existing site using a spatial visibility approach using the Visual Graph Analysis (VGA) method. According to Turner, the VGA method can be used to see and compare the relationship between spaces [12]. From the results of the visibility analysis, space accessibility can be measured, which can be used as a basis for the subsequent spatial relationship process to produce efficient spatial achievement at the existing site. In this picture, the site space is divided into three sections at the level of visual accessibility. The front has high accessibility, the middle has medium, and the back has low accessibility. From these findings, a design proposal for space division was made to suit the characteristics of private, semi-private, and public spaces.

Figure 4 is a design proposal adapted to space requirements and placement rules adapted from Finding 4. Achieving easy access between spaces is very important for houses with limited land; this can be seen in spaces that function as connectors with medium-high accessibility values. In the second phase of the process, searching and placing spatial relationships can be done experimentally with multiple interactions until a spatial pattern that matches the desired parameters is obtained.

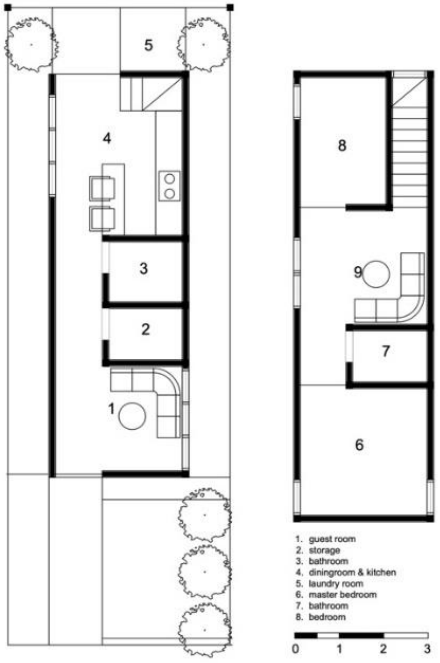

Figure 4. Plan of iteration results and space syntax simulation

c. Third phase: Finding the features of the building and interior spaces.

The third phase is the phase of finding the shape of the wake. In this phase, AI is explored to produce mood board images. The tool used is Stable Diffusion. Stable Diffusion is an Artificial Intelligence (AI) application that uses the Generative Adversarial Networks (GAN) method approach. The GAN method is a method that is strong at producing high-quality images. According to Stöckl, Stable Diffusion current synthetic image generation models can have realistic images and handle many objects [13]. Stable Diffusion can produce high-quality images using text-to-image and image-to-image based on prompts and ControlNet. In the context of artificial intelligence, prompts are a series of texts given to direct a model. In Stable Diffusion, a specific text command related to the keyword modern house is given, and the application interprets the command.

Figure 5a. Results of a generated image with Stable Diffusion

Figure 5b. Results of a generated image with Stable Diffusion

Figure 5a shows a generated image using Stable Diffusion using a shape reference found in the previous process with ControlNet. According to L. Zhang, A. Rao, and M. Agrawala, the function of controlNet is to maintain the quality of the reference model while maintaining its shape or parameters [14]. With

ControlNet, various references with various methods tailored to the resulting image's needs can be controlled, such as Canny edges, Hough lines, user scribbles, human key points, segmentation maps, shape normals, and depths. With ControlNet, it will be easier to maintain the consistency of the shape of the mass composition that has been determined in the previous process sequence.

In the experiment, the shape of the building façade was found using the image-to-image method with the depth method, where the reference image was viewed at the depth level of space so that the shape was visible. The following process is the form-intervention process, which involves adding prompts. From this process, a visual of the house building can be obtained. This process can be done repeatedly by adding or subtracting prompts until a satisfying visual shape is produced. Figure 5b is an experiment to find interior shapes with text and images. Text-to-image is searching for forms based on imagination written into words that will then, through Stable Diffusion, be translated into images. This process can be done iteratively by adding or subtracting prompts until a visual form matching the desired criteria is obtained. Using Stable Diffusion as a tool in finding shapes as a form of design is beneficial in translating imagination into a tangible visual form that can be easily understood, which will then be translated into the design development phase and detailed engineering design.

4. CONCLUSION

From the experimental results in each of the first and second phases of design, a fast and measurable process was obtained for making design decisions adjusted to the predetermined parameters. In the third phase, the AI method produces images using image-to-image and text-to-image, making it easier for architects to create visual shapes and building features that match cognitive imagination. Design in architecture is a complex analytical process that involves intuition and creativity. With the help of computational methods and artificial intelligence (AI) in the design process, complex processes become processes that can be measured and assessed.

Generative Adversarial Networks (GAN) could be better because they sometimes interpret prompting results similarly in shapes or spaces, and this means that the designer has to be able to sort through the results and decide what will be developed further. As a result, a designer or architect's theoretical and practical literacy skills determine the outcome of an architectural product.

The development of computer technology in the analysis and creation of forms has greatly influenced traditional and rational methods. Technology-influenced design methods have developed to complement the glass box and black box methods in architectural design introduced by J. C. Jones, J. Wiley, N. Sons, and C. York [15] to become an inseparable and unified design process.

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