The Study of AI integrated Simulation in Building Information Modelling (BIM) Use at Architectural Design Studio

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ABSTRACT

The presence of Artificial Intelligence (AI) has been widely spread and used in many aspects of life, including education, as an image generator, source of data exploration, and means of visualisation. Nevertheless, there is still little research regarding the use of AI in the architectural design studio process, especially in the context of Indonesian architectural education. Therefore, this research aims to picture the use of AI-integrated Building Information Modelling in the design studio. This research was done by combining observation and a questionnaire. The use of AI in wind and thermal simulation of 5th-semester students with medium-rise building projects was studied. The students were exposed to conventional simulation software before being introduced to Autodesk Forma, an AI-based cloud simulation. After the semester ends, students are asked to fill in a questionnaire regarding their simulation process. The result is that most students find the AI-based simulation easy, regardless of the limitation of simulated areas and the maximum file size of the trial-free version. They still find more benefits in using AI than conventional simulation, as they can reflect on their design and develop them according to the simulation results more effectively and holistically. Future studies regarding the use of AI in other design stages could be done as a follow-up to ensure the creativity of architectural design thinking

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1. INTRODUCTION

Artificial Intelligence (AI) and Building Information Modelling (BIM) have evolved significantly since their origins. Since the Dartmouth conference in 1956, AI has evolved through various phases, such as natural language processing, machine learning, and artificial networks [1]. AI refers to the ability of machines to perform tasks that typically require human intelligence, such as learning, reasoning and problem-solving [2]. This enables AI to process large amounts of data, identify patterns, and provide informative recommendations. However, BIM was introduced in the late 1970s and became popular in the 2000s. It was widely adopted in the construction industry by facilitating better collaboration and more efficient management. It serves as a shared database for information about a building, which can be used by various stakeholders in the lifecycle of a construction project, from planning to operation and Maintenance [3]. BIM enables 3D visualisation, simulation, and analysis of building performance, which gives architects better insight into the building's performance [4]. AI and BIM technology advancements are supported by increasingly sophisticated hardware and software, whereas cloud-based BIM software [5], for example, allows easier remote access and collaboration. In contrast, increasingly sophisticated AI algorithms can process large amounts of data at high accuracy speeds. BIM development is moving towards using a Common Data Environment (CDE) that supports coordination between stakeholders in the design and construction world; in other words, BIM helps coordinate between parties, allowing parties to get the correct information at the right time [6]. Integrating AI and BIM in architectural design reflects a significant evolution in modern architectural practice [7].

In Indonesia, the adoption of BIM is increasingly supported by investments in infrastructure and education [8] That can improve the quality of teaching by integrating BIM and the use of AI [9] Due to the growing realisation of the importance of incorporating these technologies to improve efficiency, which can also enhance the standard of architectural education, which also affects the national architecture and construction industry to prepare the future workforce to face the challenges and opportunities in the digital. In recent years, technological developments have brought significant changes in architecture. One of the most critical innovations in the architectural design process is the integration of Artificial Intelligence (AI) with Building Information Modelling (BIM) [10]. AI enables deep data analysis, automation of complex tasks and accurate predictions, while BIM provides a comprehensive digital representation of a building's physical and functional characteristics. Combining the two changes in how architects design, plan, and manage building projects, especially in tall buildings, requires high precision and efficiency.

AI-based BIM has recently become more widespread in higher education and applied to the architecture studio learning process [11]. Students can now utilise this technology to explore various design alternatives more quickly and effectively. AI-integrated BIM learning allows students to simulate and analyse building performance in real-time, therefore understanding the implications of their design decisions and developing innovative solutions that are more efficient and sustainable. For example, AI and BIM are very useful in designing tall buildings to manage complexity. AI can predict tall buildings' energy demand and thermal efficiency based on historical and simulated data, which helps architects make more informed decisions. [12].

This research thus aims to explore and identify how integrating Artificial Intelligence (AI) in Building Information Modelling (BIM) can improve the architectural design process in design studios. This research seeks to understand how AI technology can be integrated into BIM to speed up, simplify, and enhance the quality of design outcomes. This research is expected to make a significant contribution to improving the quality of architectural education and the efficiency of the construction industry in Indonesia through the utilisation of AI and BIM technology.

2. RESEARCH METHOD

This research uses a mixed method that combines observation and a questionnaire. At the beginning of the study, a literature review was done to find specific artificial intelligence for the architectural design process feasible for this research's observation stage. As the students will have to learn to use AI while designing their project, this research targeted an architectural AI that is user-friendly and easy to operate and, at the same time, has a high impact on the students' design. These criteria were used to minimise the error that might occur and to maintain the validity of the observed student's response. The chosen AI is then introduced to the students and used during the studio. The research framework can be found in the Figure 1 below.

A prior survey was held before the observation to determine the target of the observed student, which helped to map the student's initial ability to operate digital architecture software. As a result, the target of the observation is the 5th-semester students in the Undergraduate Program of Architecture, as the usage of digital architecture is found to be not common in the first and second year of a studio in Indonesian Architectural education. The result of this prior survey also maps the types of software used by the respondents in each of the design processes in the studio, as seen in Figure 2.

The observed students were asked to assess their initial software usage in the first observational questionnaire, as they already had digital software skills. After processing their design iteration and progress for 2 months, they are introduced to Autodesk Forma. This AI-based simulation software can be used together with Autodesk Revit as the BIM. After completing the semester, the students were given the second questionnaire regarding their simulation process, preferences, and difficulties. The questionnaire had four sections: (1) Identity and computer specification – 4 questions; (2) Wind flow Simulation – 9 questions; (3) Thermal Simulation – 9 questions; and (4) Difficulties – 1 question.

The question regarding the computer specification was needed to ensure that the student's challenges were not rooted in the lack of computer performance. The wind flow and thermal simulation section also included a self-assessed reflective question regarding their response in design to the simulation result to capture the student's preferences and opinions regarding the AI Simulation. The results are then analysed further to find patterns of AI usability within the architectural studio and are compared to previous research to enrich the analysis of the findings.

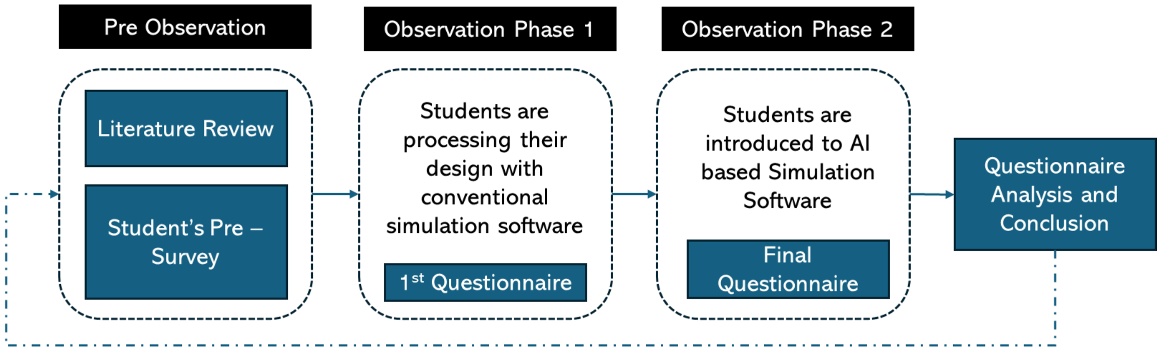


Figure 1. Research Framework

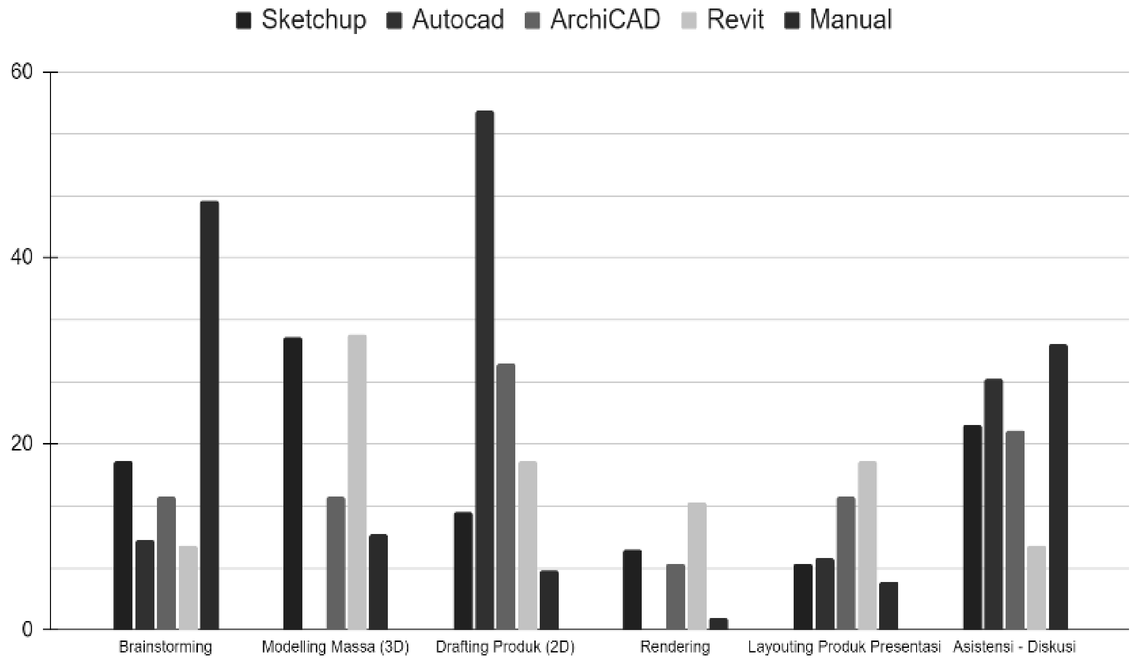


Figure 2. Student's software initial preference
Source: Author, 2023

3. RESULTS AND DISCUSSION

3.1 AI in BIM Simulation: Autodesk Forma

From the literature review, the design process can be divided into a few phases, which are (1) Data Collection and Processing, (2) Creating Design Options, (3) Building Performance Analysis, (4) Energy Performance Analysis, (5) Architectural Representation, and (6) Construction Phase [13]. The process in the design studio does not cover the construction phase. Table 1 below shows the AI alternatives in each design stage:

Table 1. Examples of Possible AI Use within Design Stages

Stage	Use	AI Examples	Task	Easiness	Design Impact	Design Dependency
1	**Programming, Brainstorming**	Chat GPT, Gemini	Searching standards, design considerations and initial ideas	Easy	Low	Low
	Image Generator	Midjourney	Form finding, massing and detailing idea	Easy	Moderate	Moderate
2	**Design Options**	Finch AI	Optimising Plan	Moderate	High	High
	Simulation	Forma	Building massing simulation	Moderate	High	Low
3	**Drafting**	AI in Autocad	Automatically create a plan by inputting constraints	Moderate	High	High
4	**Rendering**	Prime AI	Rendering from sketches	Easy	Moderate	High
5	**Layouting**	Canva AI	Layouting presentation	Easy	Low	Low

Source: Author, 2024

Three characteristics were considered while deciding which AI should be used in this research: ease of use and design impact. As mentioned, AI must be easy to use and significantly impact the design. Students' dependency on the AI is also considered, as we did not want to limit students' creativity by being entirely dependent on the AI, such as letting the AI optimise the plan. The word high from Table 1. in the design dependency column means that the AI directs the design based on the optimisation and efficiency parameters. Therefore, as we made the comparison, we decided to focus on the simulation phase with the Autodesk Forma, as it dramatically impacts students' decision-making to enhance their design in the initial form-finding phase.

Autodesk Forma is an AI-powered tool that can simulate how a building mass affects the environment by providing real-time, real-world contextual data, such as daylight - sun hours, solar energy and microclimate, wind, and noise, in a real-time analysis [14]. The simulated model and result can also be exported and imported from Autodesk Revit, making it more accessible and integrated with the BIM in Revit.

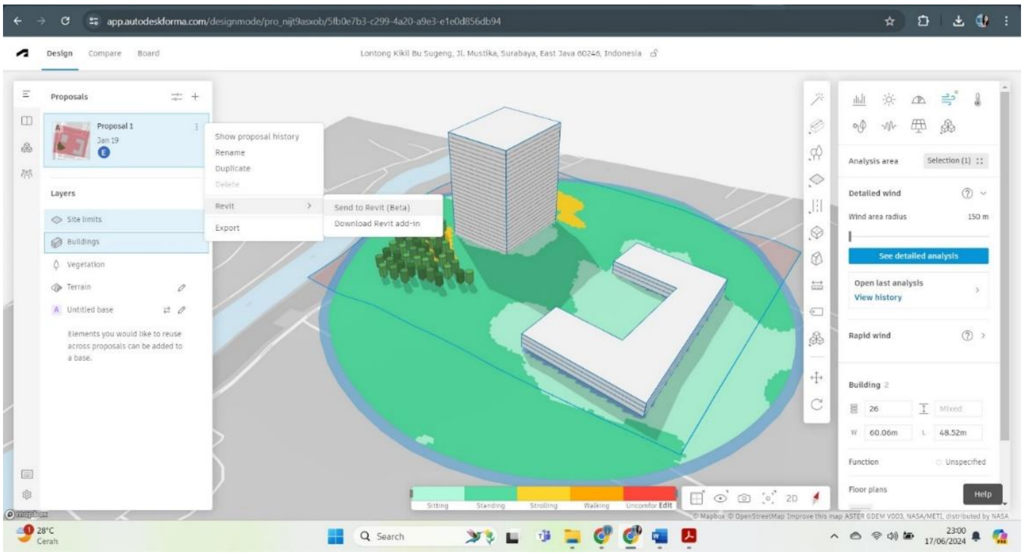


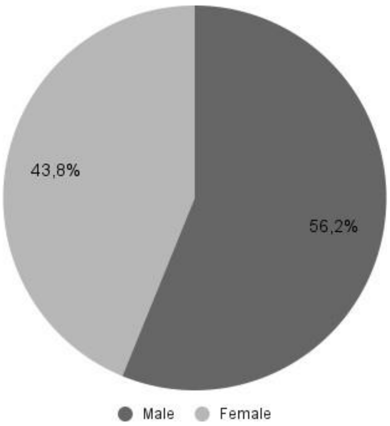
Figure 3. Screen Capture of Autodesk Forma
Source: Author, 2024

In the experimental observation stage, Autodesk Forma was introduced to students in the 5th semester of Architecture Studio. The 5th-semester design studio project, a medium-rise mixed-use building, was suitable for wind and thermal simulation. In medium-rise buildings, the area of the building envelope is larger than the roof. Therefore, the design of massing and building envelope plays a vital role in determining the building's performance [15], [16].From the simulation, we can also understand our impact on the environment by designing certain building forms. The simulation can serve as the basis of performance-driven design [17].

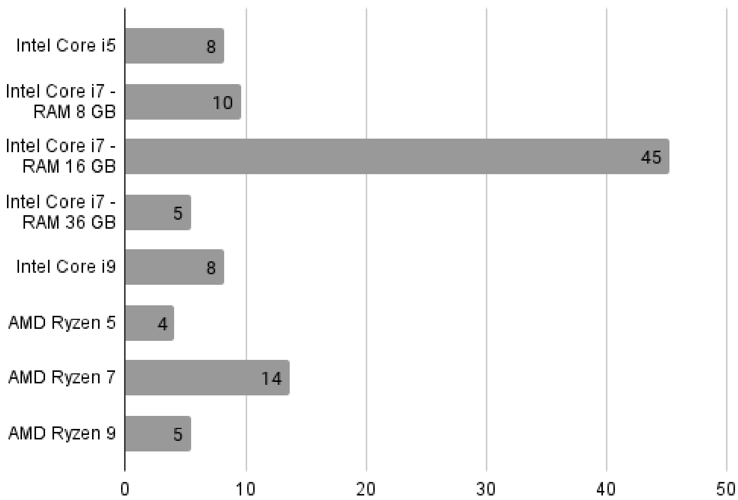
At the beginning of the semester, a classic simulation software, Autodesk Ecotect Analysis 2011, was introduced to the students, and it was wind and thermal simulation software. After one simulation assessment to measure the student's skill and knowledge in using and interpreting the simulation result, the students were introduced to Autodesk Forma. There were two following assessments within two academic active months, where students could choose whether to use Ecotect, Forma, or other preferred simulation software. Students: The student's final submission included wind and thermal simulation results and a description of the design impact based on the simulation result. The students' learning process for operating the AI and the students'student'sstudents' product was documented.

3.2. The usage of AI

The questionnaire was given to 77 students observed during their 5th-semester studio. Seventy-three students responded to the questionnaire with valid answers. Of 73 students, 59 (80.82%) used Autodesk Forma as their wind and thermal simulation tools. Even though they might use Autodesk Forma in one of the simulations, all their responses are included in further data analysis. The rest of the students kept using Ecotect for the simulations and were excluded from further analysis regarding AI use. The profiles of the respondents are shown in Figure 4 below.



(a)



(b)

Figure 4. Respondent's profile (a) Gender Ratio, (b) Laptop Specification

Table 2. AI within the Design Stages

Software Combination	Wind Simulation		Thermal Simulation	
	Number	%	Number	%
Forma	47	79.66	22	37,29
Ecotect	2	3.39	0	0
Insight	0	0	17	28.81
Forma + Insight	0	0	8	13.56
Ecotect + Insight	0	0	3	5.08
Forma + Ecotect	10	16.95	7	11.86
Forma + Solar	0	0	1	1.69
Ecotect + Solar	0	0	1	1.69
	59	100	59	100

Source: Author, 2024

The minimum specification requirement for Autodesk Revit and Forma is a CPU equal to Intel i-series 7 with 16 GB RAM. 45% of the students already have a laptop that meets the standard, while 22%

have laptops that "just fit" to lower specifications. As mentioned in the research method, the students were first introduced to non-AI simulation software and then to Autodesk Forma. Given the freedom to choose, students answer the questionnaire according to their preferences, as showed in Table 2 below.

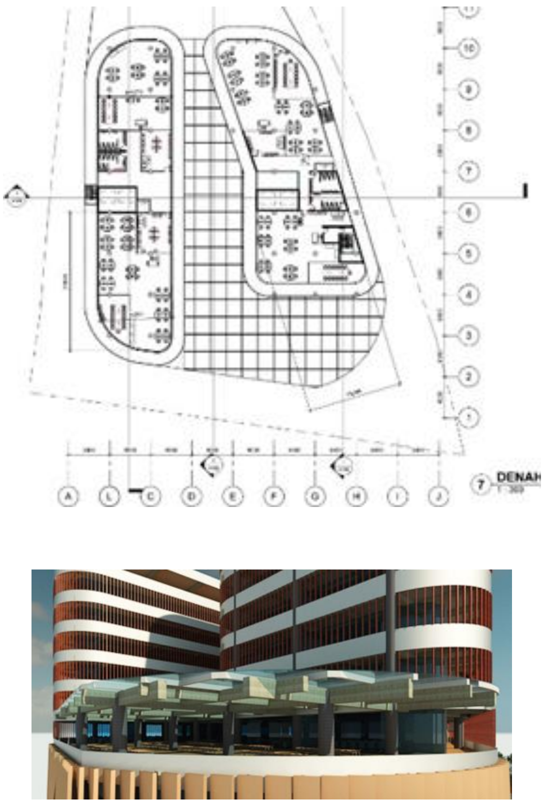
The percentage of students who used Ai (Autodesk Forma) for at least one simulation is more than 80%. For the wind simulation, 96.61% of the students used the AI, and some were still doing the wind simulation in ecotect simultaneously to validate the results. In the thermal simulation, the AI was used by 64,41% of the respondents. The rest of the respondents use various software and plug-in applications, such as Autodesk Insight or simulate thermal performance in Autodesk Revit itself (by using built-in solar analysis tools).

3.3. The implementation of AI simulation result

3.3.1 Wind Simulation

During the observation, students faced two assessments: one design evaluation and one final evaluation. In between the evaluations, students had time to interpret the simulation result and improve their design for the final submission. The studio's target product for both evaluations includes wind flow and thermal simulation. Wind flow simulation aims to picture the wind movement and speed around and inside the building. Students can also use the simulation to see the wind performance on their podium's building rooftop, as the area is usually designed for occupant activity.

The most common design response from the simulation result is to design openings in the building envelope that enable these ventilation strategies (49.2%). The simulation could contribute to further form finding, to direct the wind to the most beneficial areas (22%), and make the air condition comfortable throughout the designed area. From the simulation, we can also detect areas with high wind speed or even stagnant wind so that we can give a response to the result. When the speed of wind movement is too high, the student can design a buffer area, like greeneries, to make the wind movement slower or add operable secondary skin to protect the envelope. Lastly, the simulation could also serve as data to determine the orientation of the mass itself.



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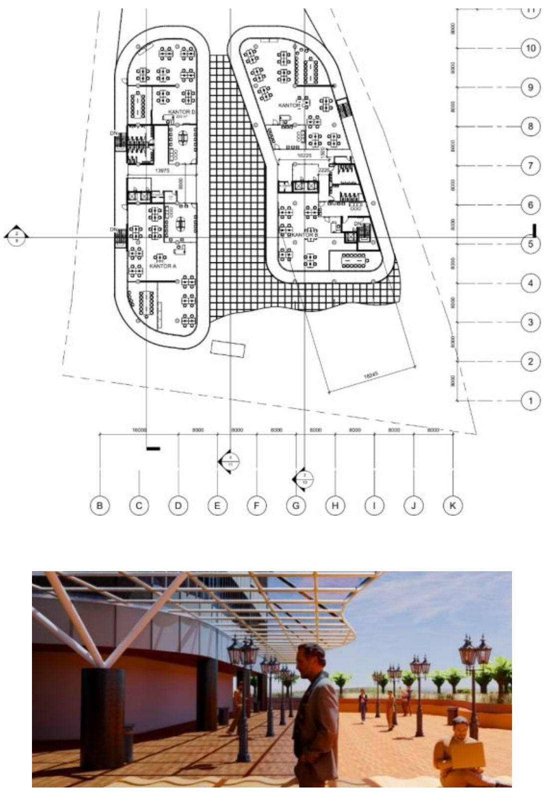

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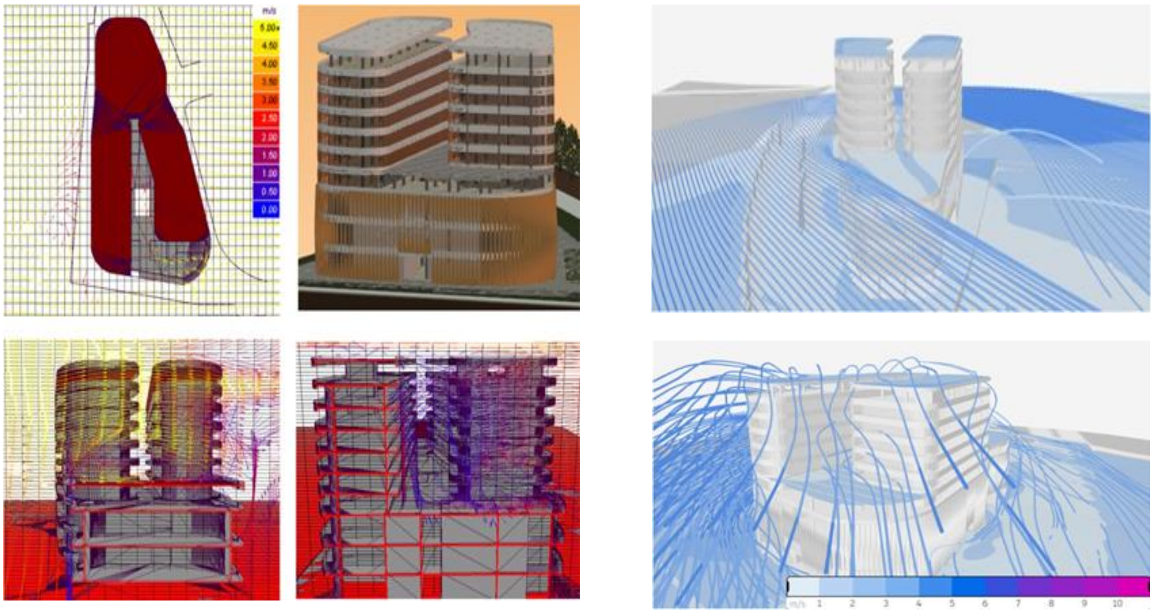


(c) (d)

Figure 5. Example of Design Progress from Simulation Result: (a) Initial design - full canopy, (b) Modified design – half canopy + perimeter vegetation, (c) Simulation using Ecotect, (d) Simulation using Forma

Figure 5 shows one example of the student's work that enhances the design by simulation results. When the prototype of the building massing is being simulated in Forma, it has been found that a full canopy above the podium roof will create a relatively stagnant wind speed unsuitable for the designed outdoor communal area. By modifying the canopy area, the communal area is now open to 4-5 m/s wind that is still comfortable for communal outdoor activities, such as sitting while having a break and leisurely walking.

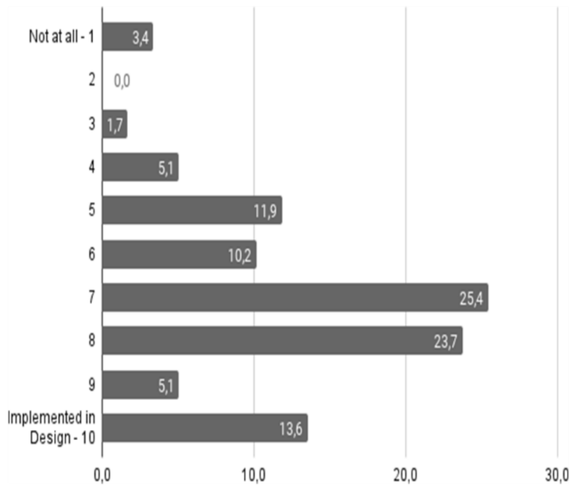


Figure 6. Wind Simulation Impact on Design

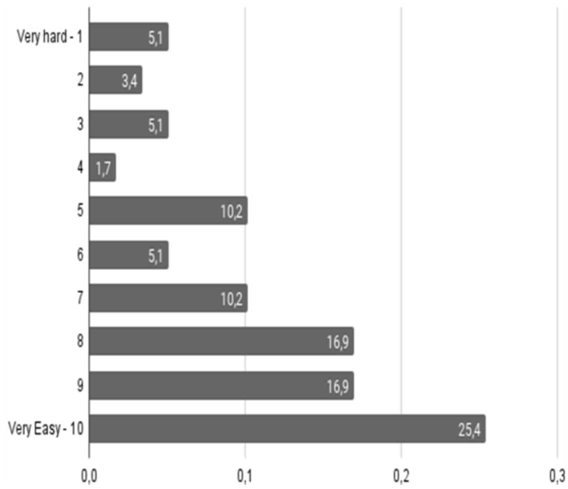


Figure 7. Wind Simulation Ease of Use

The percentage of students who apply the simulation results to the design is relatively high. When asked in the questionnaire to rate between 1 to 10 regarding their response to the simulation result, 13.6% of the respondents gave a score of 10, which means that they are very confident to revise their design in response to the simulation result accordingly. Around 49,1% of the students give "7" and "8" scores, which means they also tend to implement the simulation result. Only 3.4% of them find the simulation useless and do not make any changes to their design. The result of the design development from the simulation result can be seen in Figure 5.

For the wind simulation, 25.4% of the respondents find Forma straightforward, followed by 33.8% who find it easy. Around 8,5% of the students see the simulation as somewhat complicated, and 5.1% think it is difficult. When asked further questions regarding their difficulties, most students (39.6%) answered that the simulation is very time-consuming, as it depends on the speed of the internet. 17% of the students also faced connectivity problems from the complicated BIM modelling in Revit to Forma, as they had to make a more simplified version of their building to import the files smoothly. Around 17% of the students also highlight the limitations of Forma; for example, the inability to precisely define the height of a certain wind speed in an observed area makes room for subjectivity issues in interpreting simulation results. All of the students used the trial-free version of Forma. Therefore, their simulation has limitations such as simulated area and file size. According to the questionnaire, 7.5% of the students had difficulty with the 100 MB maximum file size limitation. 5.7% of the students face gadget problems that make their modelling and simulation not optimally run. Fortunately, around 13.2% of the students faced no difficulties or hardships in the wind simulation.

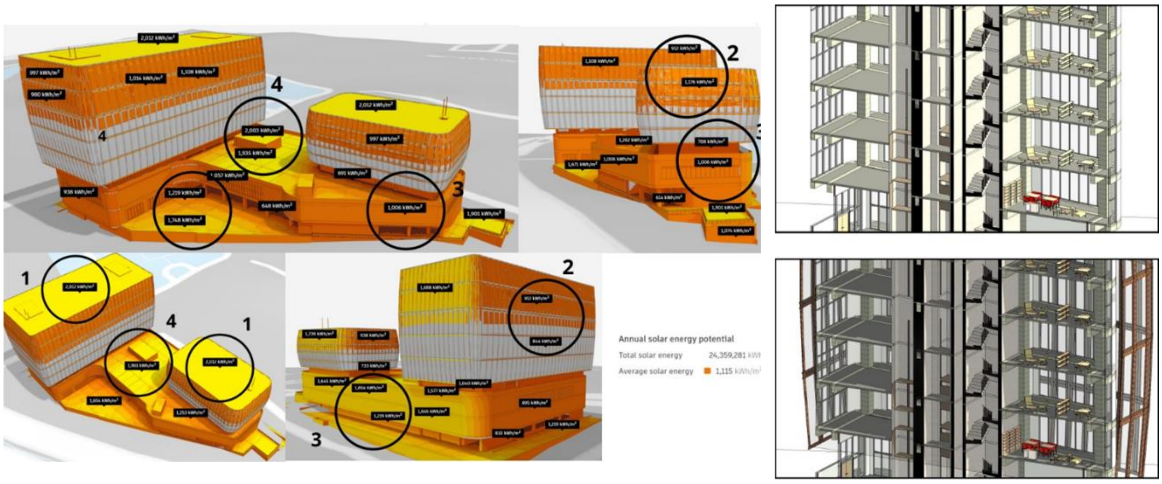
We also asked the students about the benefits they felt from doing wind simulation on Forma compared to the previous simulation tools. The question was an optional open-ended question that made the students choose whether to answer it or not. Most of the answers stated that they prefer Forma to other simulation apps, as it is very easy to use and informative. The students can reflect on their design, whether what they have to do to respond to the prevailing wind, recheck and reconfigure the design of the openings, like the dimension of the opening and the types of windows. The wind simulation in Forma also visualises the wind conditions in the open spaces. One of the answers also highlights the effect of the simulation on the approximation of lateral loads

3.3.2. Thermal Simulation

Thermal simulation aims to picture the solar exposure to the building envelope. From the simulation, most students (30.5%) stated that they could design their shading devices better regarding location, types and shapes. The simulation can also help students identify the presence of a second skin to protect the building envelope. 33.5% of the students felt they could understand where to apply the second skin by doing the thermal simulation using Forma. Figure 8 shows the thermal simulation results and the design development of one of the observed students. The initial simulation shows that the most significant solar exposure is on the roof. Therefore, the students decided to design a green roof at the podium while placing solar panels on the rooftops of the typical floors. The students also decided to give a second skin to the facade, especially on the west and north sides of the building, as the project site is in Surabaya, which is located at 70 south latitudes. By doing the simulation, the designed second skin could also be specified in the depth and distance to the central building mass in every direction. The second skin in the north-facing envelope has a 60 cm distance from the main building, while those in the west-facing envelope have a 200 cm distance from the main building, as it has more depth than the louvres in the North..

Besides, students can better orient their design using thermal simulation (13.6%). Some students change their building orientation to ensure comfort from the thermal exposure in the west-east axis. The simulation also provides the students with the actual visualisation data of thermal exposure, which can be the basis for rearranging their zonings and atria (6.8%), including vegetation (6.8%), which could benefit them

The number of students who developed their design based on the simulation result is almost the same as that of the wind simulation. 11.9% of the students revise their designs accordingly, and more than 58% partly develop their designs for better building thermal performance. Only 1.7% of the students could not see the thermal simulation's benefit and did not change their building design. The accumulated answer from the questionnaire can be seen in the figure 9. Around 15.3% of the students think the thermal simulation in Forma is straightforward, while 54,2% of them could operate the simulation well. On the contrary, 6.8% of the students still feel extreme hardship in doing the simulation, and 10,2% still feel the difficulties of operating thermal simulation in Forma.



(a) (b)

Figure 8. Example of Design Progress from Simulation Result: (a) Initial design - to model the thermal exposure of the envelope, (b) Condition in initial design – above, compared to the condition after the second skin louvre is applied – below

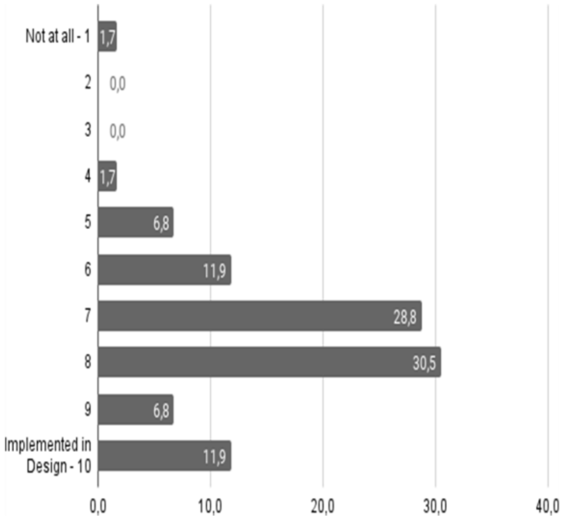


Figure 9. Thermal Simulation Impact on Design

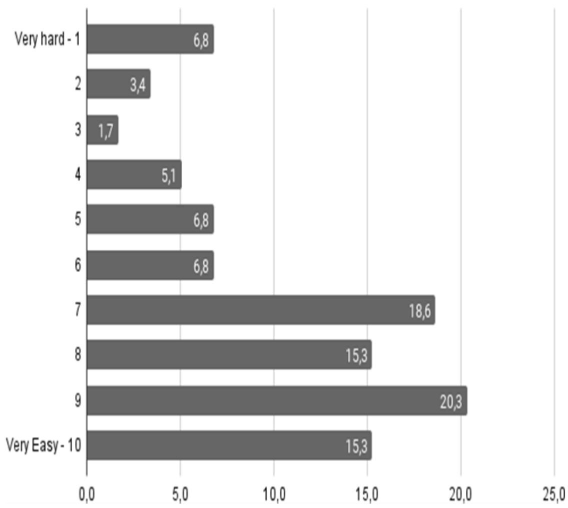


Figure 10. Thermal Simulation Ease of Use

Regarding the hardship, almost the same with wind simulation, 26.5% of the students also feel that the thermal simulation took a long process dependent on the internet speed. This condition can be seen as a real barrier in the simulation, especially for students with low internet connection. Forma tool limitations, which cannot see the value of solar energy at the desired point, can be a weakness for simulation performance. This issue is also reported by 14.7% of the students as the hardship they faced. The problem of importing models to Forma needs more consideration, as it also contributes to the length of the process done in Forma (11.8%). The limitation of the trial version and the problems with gadgets, such as in the wind simulation, also come as a challenge that students must face (14.7). Surprisingly, 2.9% of the students have doubts about the result of the thermal simulation using Forma.

As for the benefit of doing thermal simulation in form, compared to other software, students think that, by doing the simulation, they can ensure that the shading device they designed previously is effective while receiving information regarding different areas that need unique treatments, too, in terms of shading. The simulation also shows the area needing the second skin or active cooling. The simulation also gives information regarding the solar hours that can be considered for installing solar panels.

3.3.3. Comparison

The questionnaire's result regarding the usage of AI in BIM proved that, overall, students prefer to use a newer AI-based simulation. The detailed questionnaire's open-ended answers regarding the comparison of using conventional simulation software and AI-based simulation are shown in Table 3 below.

Table 3. Responder Comments on Simulation

	Pros	Contras
Conventional	• Able to understand the wind flow direction and speed, as well as the thermal zones on the building • The numerical result brings clarity and trust in the reliability of the simulation	• Very impractical to use • Hard to understand and review
AI-Based	• Able to simulate with the cloud-based data for the whole year condition in a single simulation • It is easier to understand and read, as the simulation has better graphic • Able to simulate faster, therefore promote creativity in refining the design	• The easiness of operation brings doubt regarding the result of the simulation • The simulation area is limited due to the free education version

(Source: Author, 2024)

Despite the contra argument, the majority usage of AI was found to be contrary to the conclusion of the previous research, where the students feel that more engineered software is needed and trusted in the architectural education setting. [18]. Regarding using AI Simulation, students answered that the previous simulation software had an advantage in providing more numerical results. Yet, the AI Simulation brings students a more holistic understanding, as the simulation results are easier to understand.

Nevertheless, previous research suggested that architecture students need a more practical software update in their education [19], as they are urged to learn skills that will help them in their professional architectural practice [20]. These two statements aligned with the findings of this research, which resulted in more AI-based simulations used by the students to optimise their design, as they think using AI-based simulation promotes more creativity in doing the design.

4. CONCLUSION

Integrating AI in BIM offers a range of benefits, including automation of complex tasks, in-depth data analysis, and more accurate building performance prediction. It is especially relevant for designing medium-rise buildings requiring high precision and efficient energy. In the educational sphere, using AI-BIM enables architecture students to explore design alternatives, conduct simulations and understand the implications of their design decisions more effectively. AI helps analyse and detect design flaws in real time, improving the quality of learning and preparing students to face the challenges of the modern construction industry.

The students prefer using Autodesk Forma over previous simulation software for wind and thermal simulation. Students think that Autodesk Forma provides real-time data and is easy to operate. The drawback of this AI-based AI-based simulation is that the process is cloud-based and needs high internet connectivity to ensure a smooth simulation process. The limitations of this newly launched AI simulation platform are also barriers that students face, besides the limitations of the free trial version. Nevertheless, students could still greatly benefit from the simulation by developing their design with validated simulation.

This research also suggests the integration of AI-powered BIM learnings in the design studio, as the result from the questionnaire shows that students will still be able to make design decisions themselves, even if the result of the simulation brought by the AI is quite applicable, as BIM is used in the professional work of architecture. In the future, more research regarding the use of AI in other design stages could be done to maintain creativity in the architectural design studio process. More research regarding other design typologies, like high-rise buildings and vernacular and historical buildings, could also be a focus of future research.

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