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BIM-Based Simulation on Sustainable Housing Design Using Autodesk Revit

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BIM-Based Simulation on Sustainable Housing Design Using Autodesk Revit

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Abstract. In the master plan of Trisakti University Nagrak Campus, the criteria for sustainable buildings are mandatory in its planning. One of the facilities in the master plan is the Lecturer Housing. In the modern era, sustainable housing design is needed because of the high energy consumption in modern housing design. This study aims to determine optimal strategies for implementing the Sustainable housing concept in lecturer housing design. Simulation methods are applied using Autodesk Revit to create the lecturer housing design. BIM models are more accurately analyzed and support the idea of more sustainable designs. Based on the simulation, the maximum power obtained from Photovoltaics is 26.181 kWh/year, saving Energy by IDR 62,102,167.05 on a payback period of 15 years. This design can also harvest 20.174,062 Liters of rainwater per year. In addition, applying solar chimneys maximized the penetration of natural daylight and cross ventilation process. Based on the modeling findings, it is evident that the average building daylight factor is 6.5%, above the minimum need of 5%, which will decrease reliance on artificial lighting during daylight hours. The fin-shaped shading device mechanism can reduce direct sunlight's glare and radiation, increasing the reflected light that touches the side of the structure. When dealing with big openings, fin shading devices are utilized to get the optimal opening height-to-shade length ratio of 3:2. The rainwater harvesting management system is well-suited for toilet flushing and plant irrigation, and implementing bio pores may significantly enhance excess rainwater soil penetration., and maximize sustainable housing design.

Keywords: BIM, Square Bowl Roof, Sustainable Housing Design

1. Introduction

Sustainable houses have steadily increased in popularity over the years, both in discourse and construction. There is widespread enthusiasm, ranging from the innovative developers constructing these visionary mansions to prospective homeowners actively searching for their ideal residences. However, As purveyors of eco-friendly dwellings including a comprehensive array of residential options, we are delighted to present a compendium aimed at assisting in discerning the intricacies of these abodes, elucidating their construction methodologies, and elucidating the quintessential characteristics that epitomize them as "sustainable." Merely peruse and adhere to this comprehensive manual to become well-versed in contemporary housing. Sustainable houses revolve around minimizing one's carbon footprint by selecting residences equipped with ingeniously designed features, infrastructure, and cutting-edge technology integrated into the dwelling. These property types are meticulously designed to cater to specific requirements, including the preservation of heat and the

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opportunity for homeowners to enjoy the advantages of more environmentally friendly surroundings, among several other perks[1].

As an exciting innovation in research and design, the lecturer's housing at Trisakti University's Nagrak campus was thoughtfully designed, working with up-to-date BIM-based software, specifically Autodesk Revit. This application is exceedingly beneficial in conducting thorough design analysis, encompassing tasks such as calculating the volume of work, producing the materials utilized, estimating energy consumption by the building's design, and doing lighting simulations. Additionally, it enables green building analysis by utilizing the Autodesk Insight building integrated system. The future holds great promise. BIM models will facilitate the identification of design options, enabling a comprehensive assessment of the building's sustainability optimization for each decision made[2]. Given the context mentioned above, when planning the accommodation for Trisakti University Nagrak Campus faculty, it is imperative to thoroughly include environmentally friendly and sustainable architectural practices. Thus, in due course, we shall attain a design that has the potential to make a constructive impact on the environment. This study endeavors to ascertain the most advantageous approaches for integrating the Sustainable housing concept into the design of lecturer housing. The optimization technique is founded upon prior scholarly investigations to acquire all-encompassing design principles for environmentally friendly and sustainable building applications in design products[3]. These techniques will then be simulated in a BIM design model to acquire design options to maximize the implementation of environmentally friendly and sustainable housing projects. The proposed building's design is anticipated to effectively incorporate green construction standards by maximizing its environmental impact.

2. Literature Review And Research Method

2.1. Green and Sustainable Housing Criteria

The escalating expenses of Energy and growing environmental consciousness, particularly in emerging nations, have spurred researchers worldwide, particularly in developing countries, to seek new substitutes for natural ventilation and cooling systems in commercial and residential structures[4]. The Tropics exhibit distinctive climatic conditions, including elevated air temperature, abundant relative humidity, and diminished wind speed, which contribute to an atmosphere that may be perceived as unpleasant. Multiple research about thermal systems in humid tropical regions indicates that the issue remains consistent, precisely the substantial heat burden in structures that impacts the development of interior air temperature[5], [6], [7]. Addressing passive cooling design in residential houses in tropical areas is a formidable challenge. Moreover, an exemplary domestic design entails the preservation of a superior and cozy internal ambiance devoid of the necessity for mechanical apparatus. The most advantageous passive cooling technique for humid tropical climates is the phenomenon of wind circulation, namely the physiological cooling contingent not only upon the velocity of the wind but also on the activities and attire of individuals[7]. This innovative passive cooling technique can potentially significantly enhance the range of comfort experienced by individuals. The stack effect is a remarkable kind of natural ventilation.

The air circulation generated by the stack effect typically falls short of attaining adequate physiological cooling since it is below the necessary air velocity of 0.15 to 1.5 m/s for cooling in tropical climates. For this study, an advanced Computational Fluid Dynamics (CFD) modeling software was employed to analyze the performance of a primary residential structure equipped with a vertical solar chimney[4]. The judicious use of vertical solar chimney ventilation design parameters (height, breadth, length, and material) yields augmented air velocity (0.15m/s), which reduces the ambient temperature within the space[6]. The average inside temperature ranges from 26°C to 29.5°C for around 10 to 15 hours, somewhat lower by about 0.5°C compared to a typical house without vertical solar chimney ventilation[7]. Implementing solar chimneys in buildings offers a promising approach to enhancing natural ventilation and ameliorating indoor air quality.

In addition to providing adequate ventilation, lighting, and Energy, sustainable housing must prioritize water conservation[8]. Water is essential for human beings, and its significance is well recognized. However, while recognizing the significance of this invaluable asset, it is persistently being squandered and contaminated, leading to its gradual depletion. The overarching objective of this endeavor is to explore several methodologies aimed at mitigating water usage and, consequently, replenishing the groundwater reservoir[9], thus ensuring water accessibility for future generations. Furthermore, diligent endeavors are being undertaken to diminish the need for freshwater and replenish the groundwater table to the greatest extent feasible. Here is a comprehensive compilation of many strategies employed to mitigate water consumption: Implementation of Rainwater Harvesting and Groundwater Recharging[10]; Utilization of recycled water for Horticulture, DG cooling, Street washing, and other less demanding purposes; Reusing water supply for Flushing Water Demand; Reusing water supply for Water Demand; the utilize of low flow fixtures.

In addition to addressing water and energy utility concerns, the sustainable housing concept should prioritize enhancing interior comfort through passive design and climate-responsive strategies. It also can decrease the electrical energy consumption of the building[11]. A shading device with a breadth directly proportional to its intended use can shield building walls from solar radiation[12]. This approach is an obligatory passive design in Indonesia's tropical environment. Each story of the building is equipped with a shade mechanism that spans half or third quarter of the entire height of the wall. However, the main criteria that must be met in the standard of lighting quality of the building is the daylight factor analysis. This analysis can determine the percentage of daylight penetration through the building[13]. Implementing curtain walls in the front and back of the building enhances the infiltration of natural light into the structure's interior. This will also enhance the daylight element in the building[14]. Moreover, skylights offer a practical solution for achieving a building's green rating[15]. Optimal lighting and implementing the objectives above can be achieved by applying roof form and solar chimney techniques[6]. A square bowl roof can also maximize rainwater collection[3]. The most incredible renewable energy output of Photovoltaics installed on a roof is significantly influenced by the slope and shape of the roof[16]. The roof design will be the main focal point of the overall design.

2.2. Research Methodology

The research technique applied to this study utilizes a synergistic approach wherein multiple strategies are implemented to conduct the research. This research used simulation to conduct a strategy case study[17]. The research techniques were conducted in a methodical and structured manner. A comprehensive literature review was conducted in the preliminary phase, establishing variables for designing a green and sustainable house. Upon establishing the current design criteria, the case study item was transformed utilizing BIM-based software, namely Autodesk Revit. BIM has gained significant popularity as a widely used design and approach technique tool in architecture and construction research. Many studies include BIM technology and green building analysis simulation[18]. It can potentially use the benefits of the BIM model and is highly effective in assessing sustainable buildings[19]. The weakness of the modeling method using BIM, especially Autodesk Revit, is that it requires mature decisions in modeling, such as decisions regarding materials, systems, and dimensions of building structures and models and shapes that must be finalized before the simulation. However, this weakness can be overcome by creating a complete building database to modify the desired family and type when modeling quickly.

Within the BIM realm, we can enter several factors and make simultaneous modifications until we get a more fitting design, particularly in line with the building idea, particularly in sustainable or environmentally friendly structures. BIM Models enhance the modification and adaptation of architectural designs, resulting in increased effectiveness and efficiency. Within the BIM design process, each stage of development is meticulously documented and may be effectively simulated, particularly concerning assessing the environmental impact during the building design phase. We have the opportunity to positively shape the environmental effect by using innovative building design strategies, ultimately leading to a more sustainable built environment. If the design successfully progresses to the simulation stage, it will undergo a more thorough and all-encompassing evaluation. When dealing with an already constructed structure, we can apply a passive design approach, such as optimizing orientation, shading, glazing, sealing, roofing, and openings, to replicate a changed building design. Next, an extensive building performance simulation is conducted utilizing many simulation tools throughout each stage of the design process [20]. During this phase, a meticulous strategy analysis is conducted to apply the criteria for green and sustainable housing to the case study items. The aim is to achieve an ideal design by carefully analyzing several possibilities. During the concluding phase, a comprehensive qualitative study was conducted to apply every optimization method in the building. This tactic guarantees that the approach can be implemented in structures.

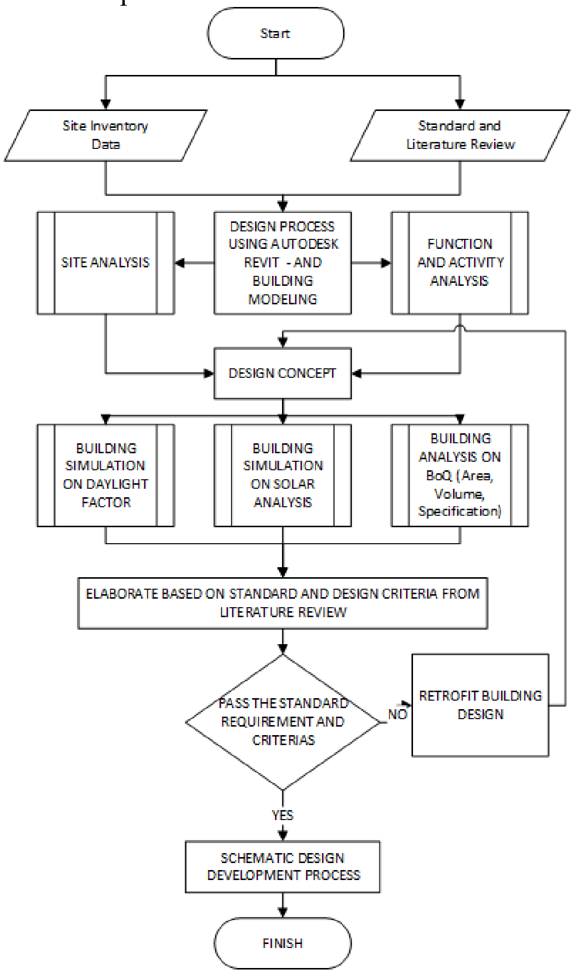

Figure 1 Design Method Scheme

The BIM-based modeling method has several advantages, especially in simulating and retrofitting building designs. The process can be carried out continuously so that the resulting design can better meet the specified standards and criteria. In this research, the design process was outlined, as seen in Figure 1. In this diagram, the design process is carried out using Autodesk Revit software, starting from the design concept and moving to the simulations used. Four main features of Autodesk Revit are used as tools to help analyze the fulfillment of sustainable housing criteria. The Solar Analysis feature simulates the application of renewable energy sources from Photovoltaics placed in the building mass. This feature can measure the level of annual energy production, effectiveness, cost savings, and payback period from installing PV on the building mass. The second feature is the lighting analysis. This feature can simulate daylighting calculations on building models being developed and simulate illumination from daylight penetration through the building in real time. From this feature, several examples of openings can be developed based on literature studies that have been tested using simulation. The third

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feature is the Schedule and Quantities, where this feature can be used to calculate the dimensions of each building element. In this study, this feature can be used to calculate the roof area, which is used to calculate the rain catch area so that it can be calculated how much rainwater harvesting capacity can be carried out. Calculations are carried out based on rainfall data in the design object area. The fourth feature is Autodesk Insight. In this research, this feature is used to assist in analyzing the annual energy calculations required by the building so that later, it can be used to retrofit the design until it meets the predetermined criteria of green and sustainable building design. The study hypothesis posits that by altering the configuration of the roof and enhancing the infrastructure, one may effectively achieve the optimization of diminishing the consumption of energy and water resources[21], [22], [23], [24]. In this research, of course, it is only limited to the selected case studies so that the results produced from the simulations carried out only apply to examples of the case study model, so that the different case studies will produce different data, but the same method can be applied to each similar case study object so that it can replicate the method used.

3. Result And Discussion

3.1. Research object

The research object is one of the facilities of the master plan design that was released in the master plan concept competition for Trisakti University Campus, Nagrak Bogor - West Java. The particular focus of this study is the faculty housing within the envisioned campus master plan. The housing concept has two-story floors. The dwelling can accommodate several rooms, including bedrooms, a living room, a garage, a kitchen, toilets, and a family room (Figure 2). Furthermore, the capacity of the family room may be expanded if effectively utilized. This building design is situated in the thriving northeastern region of the esteemed Trisakti Nagrak campus, showcasing its immense potential and the exciting challenges that come with its meticulous planning.

Figure 2 Floor Plan of Lecturer housing design of Trisakti University Nagrak Campus, Source: Masterplan of Trisakti University Nagrak Campus, Participant Number NG-159

The housing complex bulk has a pleasingly coupled house that is symmetrical, and a modern and tropical design is applied, with the shading device and the solar chimney (Figure 3). The first story has a living room, garage, toilet, and kitchen. In the second story, there is a main bedroom and a secondary bedroom (Figure 2). The housing design began with an environmentally conscious building method, incorporating a passive design strategy to enable the structure to adapt to the local climate naturally. The climate conditions in the area are defined as a delightful humid tropical, characterized by abundant humidity. It indicates that the place's climate is pleasantly moist, with temperatures ranging from 15°C to 26°C. This is partly attributed to the favorable topographical characteristics of the area in the central plains, where precipitation is frequent.

Figure 3 Section Plan of Lecturer housing design of Trisakti University Nagrak Campus, Source: Masterplan of Trisakti University Nagrak Campus, Participant Number NG-159

3.2. BIM Using Autodesk Revit

The focal point of the case study is the lecturer housing design inside the Trisakti Nagrak site, which will be meticulously replicated utilizing the advanced architectural modeling program Autodesk Revit. This endeavor seeks to house a simulation of estimating the amount of green building performance of the item under investigation. In the field of modeling, there is a need to make adjustments to various control variables, including the current position and the orientation of the building concerning the sun. This is significant as diverse outcomes will be achieved at various locations and orientations. The modeling is conducted thoroughly and tailored to the functional requirements of the area, as well as other diverse design factors.

Figure 4 Lecturer housing design of Trisakti University Nagrak Campus, Source: Masterplan of Trisakti University Nagrak Campus, Participant Number NG-159

The Autodesk Revit platform itself is a platform that efficiently transmits data from other modeling applications such as AutoCAD, Sketchup, Blender, 3DSMax, etc. This convenience makes Autodesk Revit a relevant application for working collaboratively.When the building's design has been meticulously designed, an invigorating simulation will be conducted utilizing a myriad of indispensable techniques, notably System Analysis, which can accurately compute the yearly energy consumption of the building. Furthermore, we can conduct a Solar Analysis to model the substantial amount of renewable energy that photovoltaic installations on buildings may generate. A simulation was also conducted using Autodesk Insight to ascertain the commendable environmental performance attained in several alternative design configurations. Within this tool, we have the opportunity to subsequently establish several model variables, including the Wall window ratio, the use of anti-radiation glass, and the implementation of shading devices with a specified Figure 4.

3.3. *Solar Chimney Application*

Applying solar chimneys to buildings is one solution to the design pattern of buildings on rows of plots. This is because there is no open space on the right and left of the building, so there are only two opening directions in the building design, namely towards the front and the back. Therefore, to make the cross ventilation system work, stacked ventilation is needed in the building using a solar chimney, where with this device in the building, the pattern of air movement in the space in the middle will become more dynamic. The solar chimney can improve positive air pressure and force hot air to rise to the top of the building. Hot air moves towards the outside area of the building in this way. This way, the hot air can be replaced with cold air outside the building through the chimney gap (Figure 5 Left). Solar chimneys move air and can be used as a light gap medium by reflecting light from outside areas to enter the building (Figure 5 Right). The narrow and elongated dimensions of the solar chimney make the venturi effect in the building greater so that air movement creates turbulence and moves faster to exit the building.

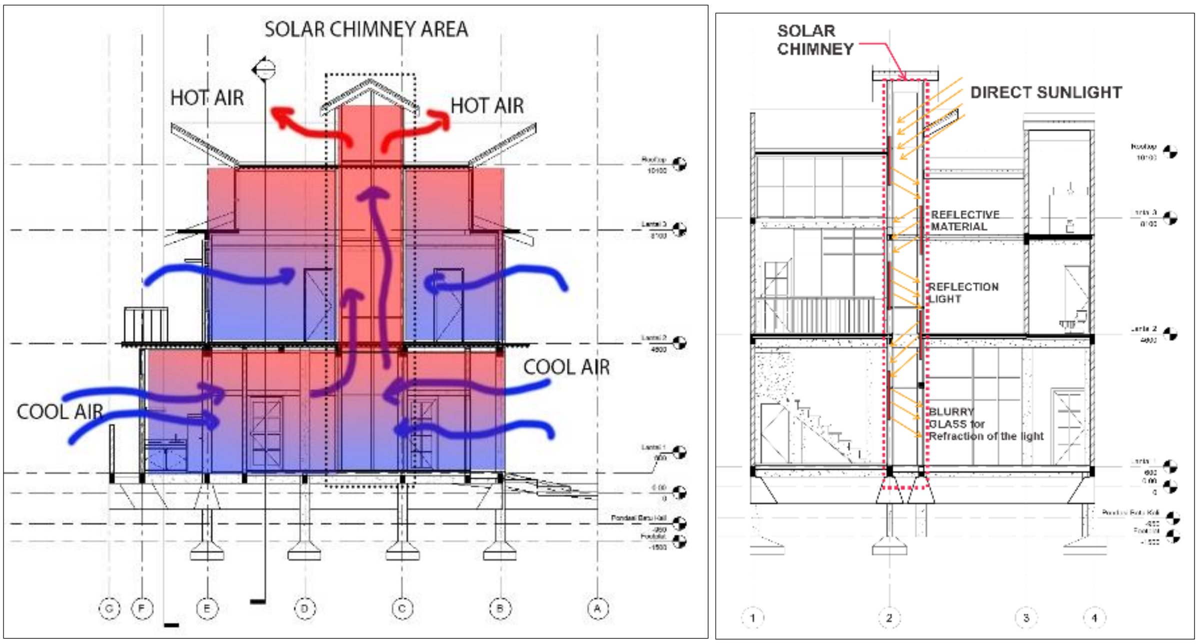

Figure 5 The Application of Solar Chimney in the Building Design Stack Ventilation

The disadvantages of the applied solar chimney system include the need for regular maintenance to maintain the cleanliness and optimization of the solar chimney itself. Positions in the middle of the building and have a continuous height up to the rooftop require special treatment in maintenance. This can be overcome by creating open and closed access that allows users to access the site by installing landings on each floor section for easy maintenance.

3.4. Photovoltaic Application and Energy Analysis

The lecturer housing building design developed has a square bowl roof with several advantages, including the potential for more comprehensive solar radiation. So, there is no shadowed area, or it could be said that every side of the roof will be exposed to sunlight and be able to reflect heat more effectively than other conventional roof forms. Based on simulation results using solar analysis tools on building models, we can calculate alternative Energy produced by Photovoltaics. Photovoltaic systems may generate a maximum power of 26,181 kWh/year, saving Energy by IDR 62,102,167.05 on a payback period of 15 years (Figure 6 Left). Meanwhile, from the annual energy simulation results using Autodesk Insight, it was found that the building requires Energy of 209 kWh/m2/yr or around 27,379 kWh/year for 131 m^2 of the total building area, which means that 95.6% can be accommodated by photovoltaic if it does not use additional electrical devices (Figure 6 Right). Installing PV in buildings is an active response to climatic conditions in locations that are exposed to direct sunlight every year so that PV is placed on all sloping planes of the roof. Using a PV system in the building requires expensive costs in the initial phase, so by using Solar Analysis in the Revit feature, we can determine the estimated payback period for PV installation according to the type of PV installed. The high initial costs are unsuitable if it is developed in low-end housing. However, efforts to use renewable energy sources will reduce the burden of using electricity from PLN, as the majority of the electricity produced is still supplied by coal power plants.

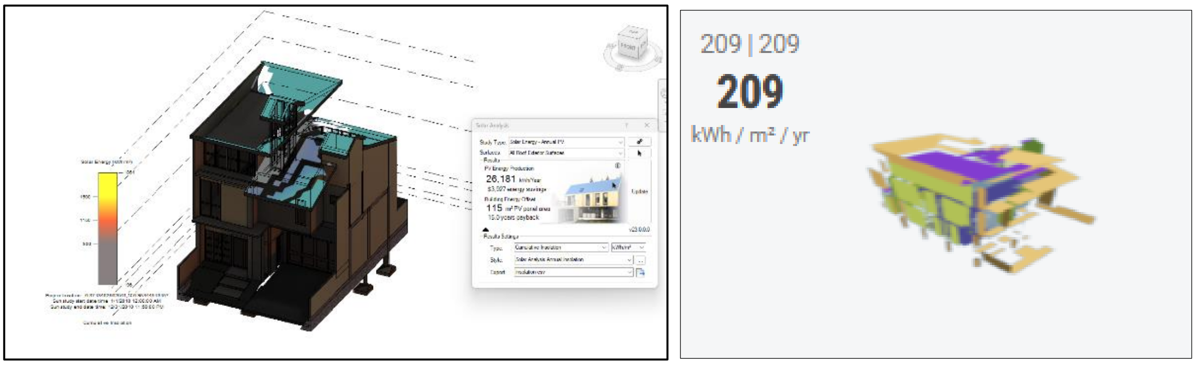

Figure 6 Solar Analysis of PV Annual Energy Production and Energy Consumption / m2 / years of Lecturer Housing Design

One of the weaknesses of solar analysis in Revit is that the system developed in the design analysis uses an off-grid system, which has the disadvantage that if the lighting is insufficient, then not all daily electricity needs can be supplied. In the future, a hybrid system can be developed where the PV system only supplies part of the electrical energy needs, for example, only for lighting. The hybrid system was chosen because until this research was carried out, the on-grid system still had a polemic in the community regarding whether surplus energy transferred to the PLN network could reduce PLN electricity consumption rates. In the future, with strict standards, PLN should be able to create an on-grid system policy that allows energy surpluses to reduce electricity usage rates for PV users with an on-grid system so that the concept of residential sustainability can further develop and reduce the need for electricity sourced from coal power plants.

3.5. Rainwater Harvesting System and Biopores Application

The rainwater collection system is vital in minimizing the utilization of untreated water resources on the premises. This also decreases the utilization of treated water, such as PDAM, which necessitates substantial energy for its processing. The lecturer's residence at Trisakti University Nagrak campus utilizes a rainwater harvesting system based on the concept depicted in Figure 7 Left.

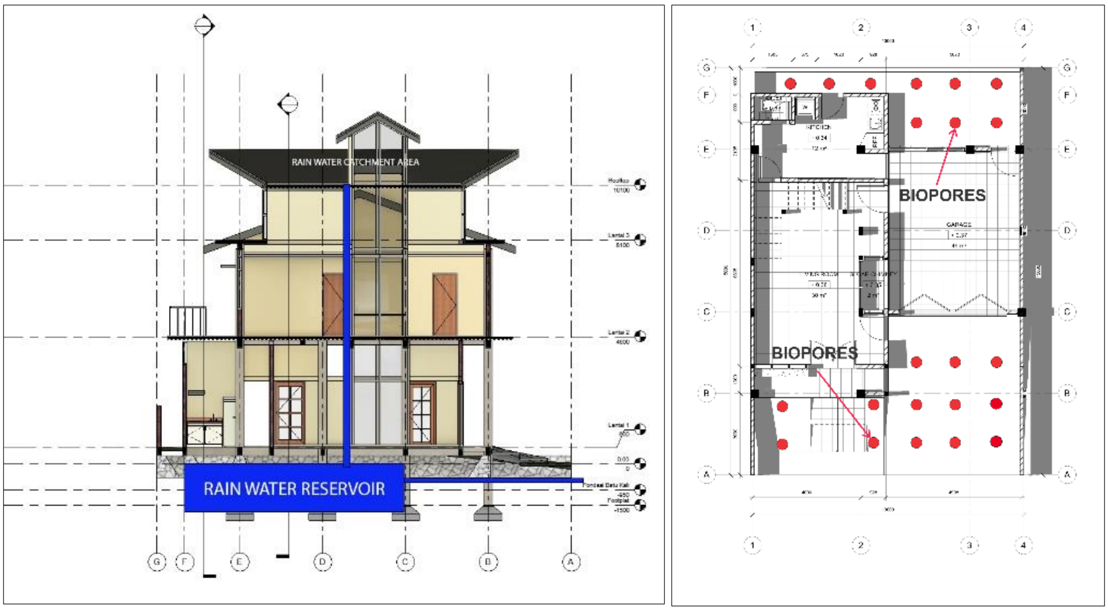

Figure 7 Rainwater Harvesting scheme and bio pores of Trisakti University, Nagrak campus's lecturer housing

The roof's design significantly impacts rainwater harvesting efficiency and the amount of rainwater that can be collected and sent into rainwater harvesting channels. We can maximize rainwater collection using a square bowl roof form because the building reflects or vents less rainwater. Rainwater that comes into contact with the roof area is forced to bounce off it by the roof's curvature. Rainwater will be gathered in the center of the square bowl roof to maximize rain harvesting, as shown in Figure 7. Given that the building is located in Bogor, which receives very high average rainfall, this has great potential. The amount of volume that the building can collect annually is 20.174,062 L, based on the model. Rainwater storage tanks are located beneath garages to facilitate maintenance and lower the possibility of overflowing into the building's interior (Figure 7 Left). The rainwater storage system is one device that must be carefully thought out. Given an annual count of 234 rainy days at the location, with an average rainfall of 86.21 L per rainy day, it is advisable to have a minimum tank size of 100 L for rainwater harvesting. In addition, bio pores are utilized to enhance groundwater absorption capacity and promote groundwater release in open spaces of buildings. This helps prevent flooding and facilitates the rapid absorption of rainwater outside the designated rainwater collection area. Bio pores are positioned in a grid pattern, with each hole having a depth of 3-4 m and a distance of 1 m between bio pores (Figure 7 Right). With the basic concept developed in this research, a fabrication system for rainwater harvesting with capacities, as analyzed, can later be developed. Of course, product differentiation needs to be developed to accommodate different capacities.

3.6. The Passive Design for Maximizing Natural Lighting

Lighting performance simulations were conducted in the lecturer housing building at Trisaktui University, Nagrak Campus, to enhance the implementation of the green and sustainable architecture idea in its design. For a lecturer house building, the minimal need for natural illumination is to achieve a minimum daylight factor of 5%, as specified by SNI 03-2396-2001. The simulation results in Figure 8 demonstrate that the building's natural lighting performance, as measured by the daylight factor, averages at 6.5%. This value exceeds the minimum threshold required for adequate lighting, indicating optimal building design. By employing the lighting simulation capabilities in Autodesk Revit, we may ascertain how light permeates the structure, enabling us to make necessary modifications to enhance the lighting quality of the building.

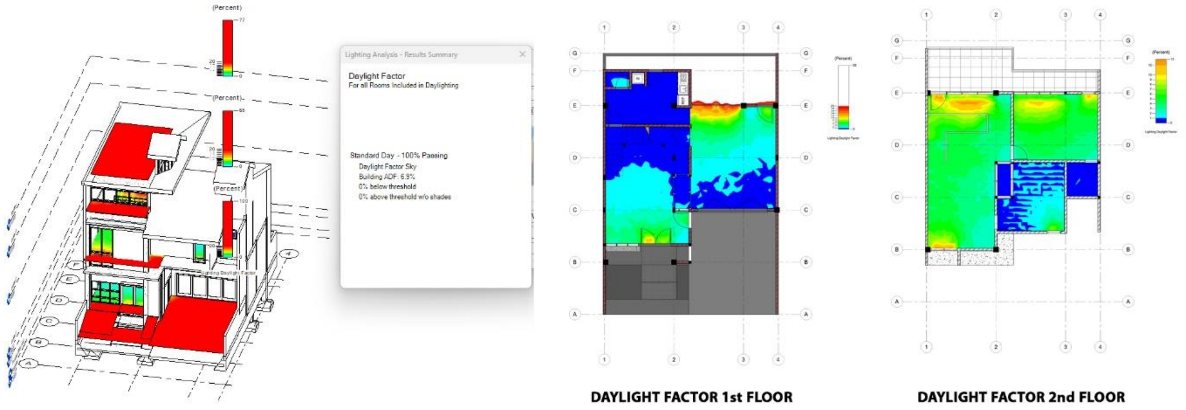

Figure 8 Daylight Factor Simulation of Trisakti University, Nagrak campus's lecturer housing

Adequate opening design is essential for optimum lighting quality in a building design; nevertheless, openings also have a negative effect, namely increasing the penetration of solar heat radiation into the building; hence, proper passive design is required to mitigate this impact. Fins and vertical shading can be used in buildings to reduce direct sunlight entry. This fin-shaped shading device enhances the reflected lighting that hits the building's side, reducing glare. Fin shading devices are used in large openings to achieve the best ratio of opening height to shade length, which is 2:3. Meanwhile, for openings with a vertically elongated shape, a type of shading called vertical shading is used to limit vertical radiation in the building (Figure 9).

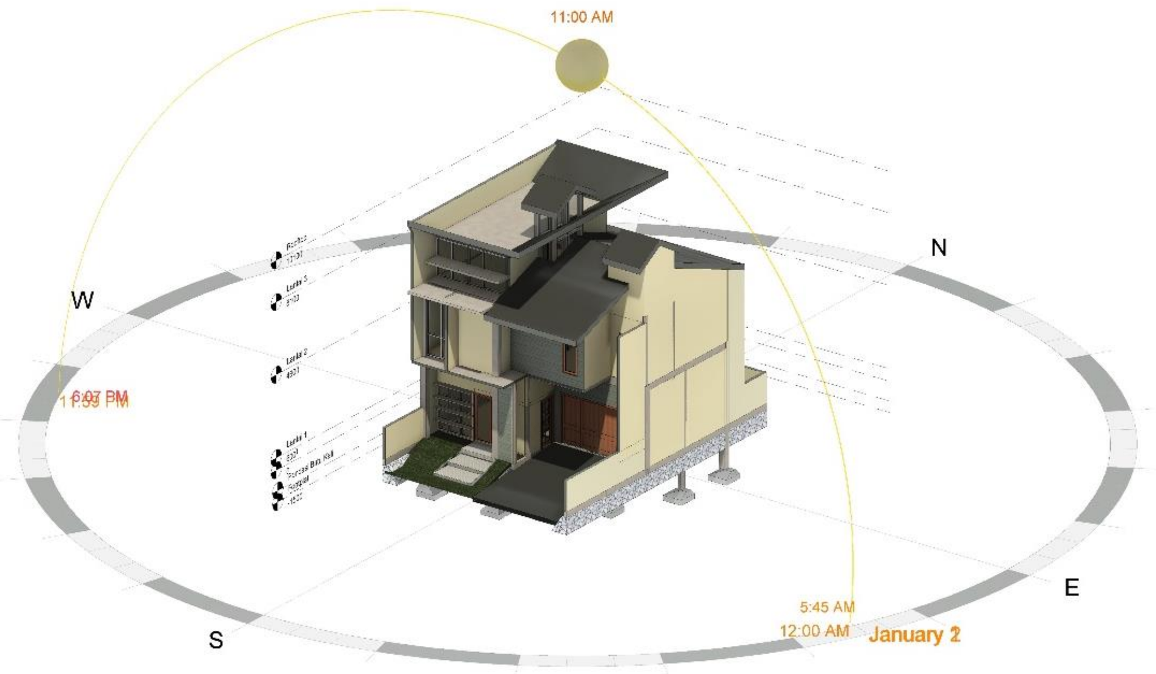

Figure 9 Sun Study Simulation of Trisakti University, Nagrak campus's lecturer housing

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4. Conclusion

The roof shape design and the building code in the Trisakti Nagrak campus master plan planning have emerged as a distinctive and practical symbol. Utilizing this square bowl roof form can enhance the efficacy of rainwater collection and direct the flow of rainfall into designated channels, facilitating rainwater harvesting. In addition, the roof configuration allows for unhindered access to the sun's rays from several directions, and angles of its descent can maximize the PV electrical current production. Utilizing the cutting-edge BIM software Autodesk Revit, the Trisakti University lecturer housing design may be meticulously examined and seamlessly incorporated. According to the modeling findings, it is possible to calculate that the PV system may generate a maximum power of 26.181 kWh/year, saving Energy by IDR 62,102,167.05 on a payback period of 20 years. This design can also harvest 20.174,062 Liters of rainwater per year. Utilizing a solar chimney in the architectural blueprint also enhances the penetration of natural daylighting and maximizes cross ventilation. Based on the modeling findings, it is evident that the average building daylight factor is 6.5%, above the minimum need of 5%. This can potentially decrease reliance on artificial lighting during daylight hours. The rainwater harvesting management system is well-suited for toilet flushing and plant irrigation, and implementing bio pores may significantly enhance excess rainwater soil penetration. Through this system, precipitation replenishes groundwater reserves in the ecosystem. This fin-shaped shading device mechanism reduces direct sunlight's glare and radiation, increasing the reflected light that touches the side of the structure. When dealing with big openings, fin shading devices are utilized to get the optimal opening height-to-shade length ratio of 3:2. Simultaneously, vertical shading is employed to control the amount of radiation that enters a structure through vertically extended apertures. This research can be replicated using similar methods but with different case studies. Of course, based on the simulations' results to obtain a design that meets the sustainability criteria, many adjustments are needed, including thinking about the carbon footprint and emissions arising from construction. This research has yet to discuss the influence of materials on building sustainability criteria comprehensively, so this research can be developed towards developing materials that better support the sustainability of residential buildings.

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