UTILIZING BIM AND SIMULATION TO DOCUMENT THE HERITAGE BUILDINGS' SPACE QUALITY, CASE STUDY BLENDUK CHURCH

Michelle Faustine Gunawan[1]*
[1]) Department of Architecture, Universitas Multimedia Nusantara, Tangerang, Indonesia
*e-mail: michelle.faustine@umn.ac.id

ABSTRACT

Indonesia has a lot of heritage buildings that are either damaged or facing design changes. Those damage and design changes transformed the original spatial quality inside the building and erased a part of the history. Simulation methods have the potential to replicate the lost spatial quality and comfort. Therefore, this study aims to test the potential of utilizing BIM and simulation software in digital conservation with Blenduk Church in Semarang as the case study. The data was collected through direct field measurement to obtain the dimension and daylight intensity of Blenduk Church. The data was used to create 3D models of Blenduk Church, the old design and the current design, utilizing Rhino and Autodesk Revit. The 3D models are simulated with DiaLUX to find the daylight intensity and the microclimate surrounding the building. The data validation process includes comparing both data that was obtained through direct measurement and simulation, then calculated the standard deviation. By doing the data validation, it was found out that the standard deviation is 2,8%, which indicates that the simulation software is relevant to be utilized as a tool for digital revitalization as the deviation is still within the acceptable tolerance limits. This research demonstrates that CAD, BIM, and architectural simulation technologies can be used to document the space quality of heritage buildings that have been altered or demolished. This research could contribute as a blueprint to digital conservation that is not limited to recreating 3D model, but also continuous research of the missing space qualities.

Keywords: *Building Information Modelling, Blenduk Church, Digital Conservation, Heritage Building, HBIM*

INTRODUCTION

Many buildings that were built during the colonial era are categorized as cultural heritage buildings because of their historical value in telling the story of Indonesia's politics, economy, social, and cultural development. To preserve the cultural heritage buildings, several efforts can be done by repairing, preserving, and strengthening the building. Although the cultural heritage buildings' restoration tries to maintain the design as close to the original design of the building as possible, it is undeniable that design changes are common. Functional changes from the office building into a cafe can be commonly found in Semarang's Old Town. Sometimes, the changes can be found on the façade of the building, which happened to the Blenduk Church.

Blenduk Church has been built since the Portuguese colonization era in the 17th century. During the Dutch colonization era, the Dutch changed the design of the Blenduk Church from a stilt house with a *tajug* (i.e pyramid) roof into a church with a dome (Wardani & Triyulianti, 2011). Blenduk Church has also experienced facade design change after a restoration in 1894 (Figure 2 and Figure 3). From Figure 2 and Figure 3, it can be seen that a pair of twin towers and a patio have been added to the south façade of Blenduk Church; these changes made Blenduk Church's façade design similar to a drawing in 1820 (Figure 1). With this change, people who are living in the present cannot experience and study the Blenduk Church's space quality before the restoration.

Figure 1. Early Design of Blenduk Church
Source: De Brauw, 1820

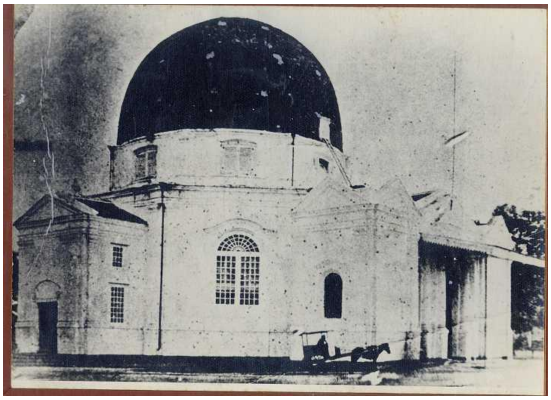

Figure 2. Blenduk Church Before the Conservation
Source: Collection of Tropenmuseum, 1939

Figure 3. The Current Blenduk Church After the Conservation

The importance of studying heritage buildings is to learn about the development of architecture, regional, human behavior, and theories, especially for architecture students. By utilizing both BIM and simulation technology, reconstructing the original traces of cultural heritage buildings – that have undergone changes after revitalization or have been demolished – becomes possible. It is important to integrate technology with heritage building preservation as it could help with future predictions and steps that are necessary to be taken efficiently (Puerto et al., 2024). This research will not only expand the role of BIM and architectural simulation software as tools for designing and remodeling, but also as tools to support spatial narratives.

Another utilization of BIM for heritage is to create a virtual space. During the covid-pandemic era, the concept of Metaverse grew. Metaverse was idealized as a place where people could live normally during the covid-pandemic era that forbade people from going outside as freely as before, allowing people to meet each other virtually while practicing self-quarantine at the same time. Wang, Yu, Peng, and Feng (2024) proposed the feasibility of preserving heritage buildings through Metaverse by storing the building information virtually. However, this technology has not been researched, developed, and utilized a lot despite its potential (Wang et al., 2024). By utilizing BIM in studying heritage building, creating virtual preservation is a feasible idea. It could also be a tool to simulate the integration between the modernity and the traditional aspect of heritage building, similar to what Kardinal (2024) was trying to achieve by integrating Karang Bengang with modern urban planning. This is important because the transformation and the disappearance of heritage buildings due to cultural shifts are real, for example in Bali there is an architectural shift from the traditional *sakaroras* to modern-house-style (Yudantini, 2022). The concept of Metaverse, which is similar to digital conservation that is studied in this article, could be a solution to preserve heritage buildings virtually.

Finding the archives of original designs of buildings that have been demolished or transformed during the revitalization can be difficult. Because of this, extensive studies that are related to space quality inside those heritage buildings were rarely conducted. Digital conservation could be seen as a solution to maintain the completeness of the data, making conducting further studies possible. Collaborating digital conservation by modelling with BIM-based software and simulation may recreate the space qualities and the micro-climate that were missing because of the demolition or the transformation. This research's novelty is the attempt to do digital conservation that is not limited by creating 3D model, but also by simulating the daylight quality and the micro-climate. It is highly hoped that this research could be a blueprint for thorough heritage building digital revitalization, especially for buildings that have been demolished or transformed.

THEORY / RESEARCH METHODS

Conservation of Cultural Heritage Buildings

Cultural Heritage Buildings are buildings that have historical value because they are part of historical and important stories, have aesthetic value, provide an overview of social, economic, cultural, political, and spiritual conditions of a certain era, and have survived collapse for a very long time (Feilden, 2019). The condition of the cultural heritage is not always good; it is very common to find damage caused by vandalism or nature: the gravity that pulls the building down, the plant growth that decomposes the building, or even rodents. Considering that cultural heritage buildings' condition will worsen if they were left without any care, building conservation needs to be done.

Conservation is an effort to extend the culture and nature reflected in the cultural heritage buildings by preventing damage or repairing damaged elements and artefacts (Feilden, 2019). Ideally, conservation should be able to maintain and improve the historical quality of cultural heritage buildings. Cultural heritage building conservation maintains emotional value (related to identity, spirituality, and symbolism), cultural value (because of its function as documentation, historical objects, and the evidence of technology advancement), and functional value (related to economics, functionality, social, education, and politics) (Feilden, 2019). An apparent growth in architecture could be seen on heritage buildings built during the colonization era in Southeast Asia. Before considering the tropical climate, the colonizer's building couldn't stand the constant heat and rain in Southeast Asia (Chang, 2016). The advancement of tropical architecture resulted in colonial buildings that are still standing until today. With digital conservation, studies could be conducted on both buildings during the early and late colonization era, perhaps people could experience the spatial qualities virtually.

The Transformation of Blenduk Church

Blenduk Church is the oldest church in Semarang City that maintains its function as a worship place for Protestant Christians. The Blenduk Church has been categorized as a cultural heritage building in Semarang City based on the Ministerial Decree

243/M/2015 since December 18, 2015. Immanuel West Indonesia Protestant Church in Semarang is nicknamed *blenduk* (i.e. bulging) due to its dome roof. This building is a neoclassical architecture with Gothic elements (Moedjiono & Indriastjario, 2017). The façade's surface is painted white, except for the red roof. The gothic impression is emphasized by the line and curved decorations on the walls, stained glass windows, ornamented chandeliers, and the organ on the pulpit. The neoclassical impression of the building is emphasized by the gable on the front of the building, large Corinthian columns to support the overhang gable roof, and Tuscan columns on the interior (Gaputra, 2019).

The façade uses large and tall colorful stained-glass windows covered with jalousie windows. Stained glass windows can reduce the solar radiation that is entering the room; so that the natural lighting that occurs in it is not excessive, minimizing the heat from entering the room (Megawati et al., 2017). Also, the use of jalousie windows produces air ventilation. The white facade reduces the amount of heat absorbed into the room. The Blenduk Church is surrounded by garden and trees, a Javanese philosophy about uniting the men with nature (Wardani & Triyulianti, 2011); it reduces the rising temperatures due to solar radiation by producing shadow that blocks the sunlight. The combination of colonial architectural styles and the response to the tropical climate, it would be appropriate to categorize Blenduk Church as the Indische Empire style architecture (Wardani & Triyulianti, 2011).

Although best known for its dome roof, when it was first built by the Portuguese in 1753, the Blenduk Church was designed with a *tajug* roof (Husna & et al, 2020; Wardani & Triyulianti, 2011). The transformation of the Blenduk Church into a church with a dome, occurred during the Dutch colonial era. It did not have twin towers for the façade. The addition of the twin towers was done in the late 19th century, designed by H.P.A. De Wilde and W. Westmas (Husna & et al, 2020). Decorative ornaments, gables, Tuscan columns, and decorations at the top were also added. The building has not undergone any changes anymore.

Building Information Modelling in Digital Heritage Architecture Revitalization

Building Information Modelling is the process of managing information that is related to architecture, structure, MEP, and construction. BIM could produce, communicate, analyze, and simulate the building model before it could be built (Sacks et al., 2018). Because every process is being integrated, models, drawings, and simulation results' inconsistencies could be minimized to reduce errors that could be found when working separately.

The maturity level of BIM is divided into Level 0, Level 1, Level 2, and Level 3. Level 0, being the lowest level of maturity indicating the CAD files that have not been managed with the possibility of the drawings being made traditionally (Sacks et al., 2018). Level 1 means the company most likely has been trying to emulate digitalization in their process by creating CAD-assisted 2D drawings and 3D modelling without any integration (Sacks et al., 2018). Level 2 indicates the collaborative works by sharing the same file and editing it on the same file as well; nobody can work on the same project at the same time (Sacks et al., 2018). Lastly, Level 3 indicates full collaboration where every team member could work on the same project at the same time while facing changes in real time, aka Open BIM (Sacks et al., 2018).

During the outbreak COVID-19, BIM had the potential as a medium to restore and revitalize the building, the structure, and other assets virtually (Liberotti & Gusella, 2023). There was even a plugin for CIDOC Conceptual Reference Model (documentation for cultural heritage) called Heritage Digital Twin Ontology to capture the complexity of the real-world artefact and digitalize it (Niccolucci & Felicetti, 2024). Niccolucci and Felicetti (2024) combined it with HBIM (Heritage Building Information Modelling) to see the potential of digitalizing heritage buildings in real-time. HBIM is BIM that's specifically designed for architecture and heritage preservation as opposed to traditional methods in preserving data (Dauda et al., 2025). The digitalization of heritage buildings is seen to be more sustainable than restoration in the traditional manner (Liberotti & Gusella, 2023). The current HBIM is much more developed than HBIM back in 2019 when the utilization of HBIM was relatively limited to concept, while people were still relatively trying to figure out the potential of using HBIM to converse the heritage building (Ewart & Zuecco, 2019).

Other than revitalizing heritage buildings digitally, there was also a concern to make the heritage buildings more sustainable. Despite that heritage buildings were built with different energy efficiency standards, it is still important to calculate the energy consumption and predict how to reduce the heritage buildings' energy consumption (Karatzas et al., 2024). By simulating the previous and current design, an assessment regarding its sustainability could be done, later it could be utilized to make a prediction to increase the sustainability of the heritage building.

Data Collecting

The first data was the dimensions of the Blenduk Church building that were collected by site visit to do direct measurement and referencing from published article, by Husna & et al (2020). The dimension of Blenduk Church was collected to make 3D models of both the old and the new design of Blenduk Church.

The second data was the daylighting comfort as the result of simulating the 3D model of the Blenduk Church using DIALux Evo software. The two designs of Blenduk Church that were simulated. To ensure data validity, data collecting on site was also done on March 21, 2023, at the same time as the simulation. This data will be compared to the simulation result to determine the data accuracy. However, it should be noted that there are limitations on the software, for example there isn't any stained glass which is commonly found at heritage building in Indonesia. Thus, it was impossible to simulate the daylight quality inside the Blenduk Church, meanwhile, compared to the common transparent glass, the stained glass refracts the light differently.

The third data was microclimate study by simulating the 3D models with Autodesk Forma. It was not necessary to remodel buildings in Semarang Old Town other than the Blenduk Church itself as Autodesk Forma was capable of recognizing the buildings and the surrounding area, then made simple masses of those buildings on its own. By simulating the microclimate, data related to sun hours, noise, wind comfort, and daylight potential would be retrieved.

Data Processing

In order to perform the simulation using DIALux Evo and Autodesk Forma, the 3D model of the Blenduk Church is required: the old and the new design. The 3D models were created using the data measurement from previous studies and site visit. The creation of the 3D model used Rhinoceros 7 and Autodesk Revit 2023. Rhinoceros 7 was used to sketch the Blenduk Church building mass based on the measurement. During this step, the 3D model is ready to be studied for simulation in Autodesk Forma. However, to process the data with DIALux Evo, it was required to separate the building based on its elements, then each element was saved as several different ACIS files to store different 3D elements. They were later imported into Autodesk Revit 2023. The building mass sketch that had been entered into Autodesk Revit 2023 was assigned according to its correct elements (deciding which part is acting as the wall, the roof, the floor, et cetera).

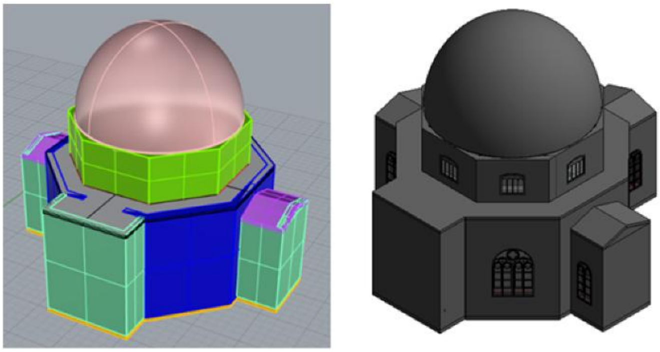

Figure 4. Creating Blenduk Church's Old Design's Mass

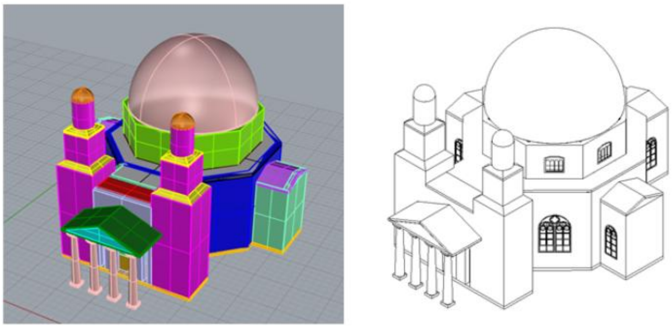

Figure 5. Creating Blenduk Church's New Design's Mass

To obtain accurate data, it is necessary to adjust the location information correctly. After that, set the weather conditions and the simulation date. Because the simulation is seeking to gather the data about natural lighting comfort inside the building, the weather needs to be set as sunny. The chosen days are on June 22nd when the sun is apparent on the north (northern solstice), December 22nd when the sun is apparent on the south (southern solstice), March 21st and September 23rd when the sun is apparent on the equator line. The simulated times are the worship times at the Blenduk Church.

After doing the simulation, there would be an isoline plan and a natural light intensity color plan. The isoline plan can be used to determine the percentage of rooms that receive ideal natural lighting. While the light intensity color plan is used to determine the general condition of natural lighting in the Blenduk Church on a certain date and time.

Doing data processing would result in conclusion to decide the potential of utilizing BIM and simulation software as tools to document the space quality, microclimate around the building in the past, the potential of utilizing BIM and simulation software as tools to document the space quality and microclimate around the Blenduk Church that has undergone changes as a precedent for future similar research, which are heritage buildings that have faced evolution or demolition.

This quantitative research evaluates the feasibility of utilizing software to digitally conserve and complete data that is missing due to the transformation or demolition of said heritage building. This article aims to report on the idea implementation of BIM-and-simulation-based software in digital revitalization. This research is replicable were there any similar research or digital heritage building conservation.

RESULTS AND DISCUSSION

BIM to Document the Heritage Building' Spatial Quality Using Virtual Reality

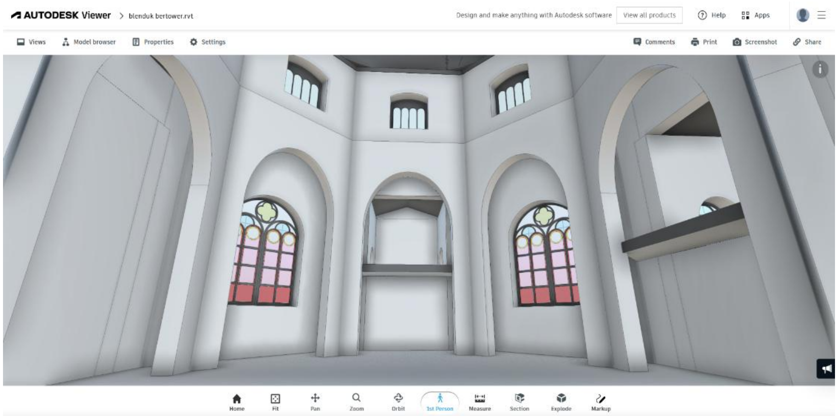

Figure 6. Screenshot of Virtual Reality inside the Blenduk Church

By creating the 3D model using Bim-based software, the model information could be stored in the cloud and processed as Virtual Reality. Because Blenduk Church was recreated on Autodesk Revit, Autodesk Viewer was utilized to create the Virtual Reality. Virtual Reality allows people to experience the space quality as if they were inside the building in first person (Figure 6), this will enhance the immersive experience for people who are studying and trying to understand heritage buildings (Penjor et al., 2024). This helps a lot to visualize the space quality inside the building that is related to the visual after the building has faced changes or been demolished.

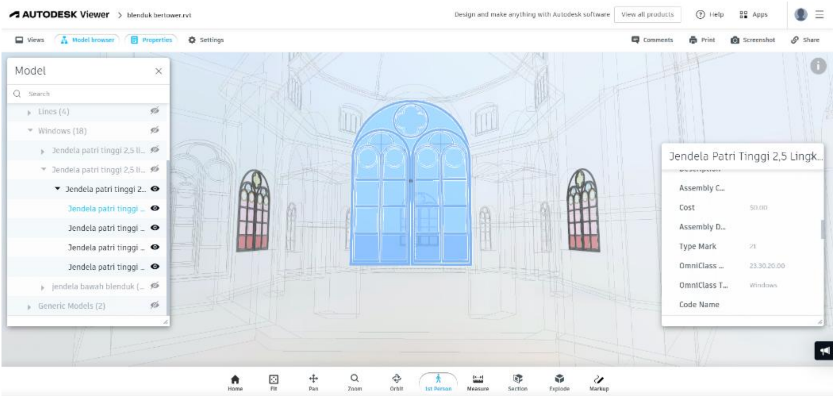

Figure 7. Screenshot of Virtual Reality inside the Blenduk Church

Another feature that's useful for studying any heritage building is its feature to present complete data of each Blenduk Church's architectural element through Model Browser and Properties (Figure 7). This is possible because when the BIM file is being exported to the cloud, it reads every data that has been inputted. If the data is inputted correctly, it could be used to introduce more information about the building in a more fun and effective way. This is also available in first person view, thus people could study the space quality and visual inside the old design of Blenduk Church while also learning about the materiality, price, size, placement, et cetera at the same time.

While utilizing Autodesk Revit and Autodesk Viewer alone can produce Virtual Reality with detailed information about the elements, still a lot of information is missing, for example, the texture and the colorful daylight effect that may come through the stained-glass window. To be immersed into Virtual Reality with a more realistic appearance, rendering software definitely would do a better job in capturing the texture and any special qualities inside the building that are related to the visual experience. The files that are stored in Autodesk can only be kept for 30 days, which means if people wanted to study it, it needed to be reuploaded every time it expired. With enough development, the virtual heritage building could be made into a part of the virtual world, such as Metaverse. This will enable people to visit, study, and even participate actively in the virtual building without actually being there.

The Natural Daylight Inside the Blenduk Church's Old Design

Due to the nature of DIALux simulation software that can simulate any building mass based on the given floor plans, importing both the old design and the new design of Blenduk Church was fine. However, when importing an IFC file, DIALux can only read the whole building as one mass, losing all of its original information: stained glass windows, doors, roof, walls, floors, and columns.

The daylight simulation in Blenduk Church with the initial design was done inside the worship room which is 360m^2. Based on the Indonesian National Standard (SNI), the natural daylight must be able to illuminate a room of at least 50% of the area with the intensity of natural daylight is adjusted according to the activities inside the room, for a worshiping place it's required to have at least 200lux (Badan Standardisasi Nasional, 2011). Therefore, the minimum area that should be exposed to natural daylight in the worship room is 180m^2.

The simulation was conducted when the sun was apparent on the equator line on March 21st from 08.00 am to 12.00 noon, the time when the service was taking place in the Church. It showed that the design of the Blenduk Church without twin towers was unable to meet the established SNI standard. The maximum quality of natural lighting in the building occurred at 09.00 am (Table 1). The total area of the room that received lighting from the sunlight was 53.27m^2, or 14.8% of the area of the worship room. This shows that during the service, the congregation still needed artificial lighting in order to make praying comfortable.

Looking at Figure 8, it is known that the condition of the room is dominated by the darkness which is symbolized by the color gradation of blue and purple. At the same time, there is sunlight entering the room although the intensity is not ideal, it is between 50lux (indicated by blue) and 3lux (indicated by magenta). The area of the room that does not receive any sunlight at all can be considered very small (i.e. black indicates the light intensity with the value of less than 1lux) compared to the rest of the area that receives natural lighting.

Table 1. The Worship Room Area that Was Illuminated, March 21st

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	42.50	11.81
2	09.00	53.27	14.80
3	10.00	50.77	14.10
4	11.00	21.82	6.06
5	12.00	0.55	0.15

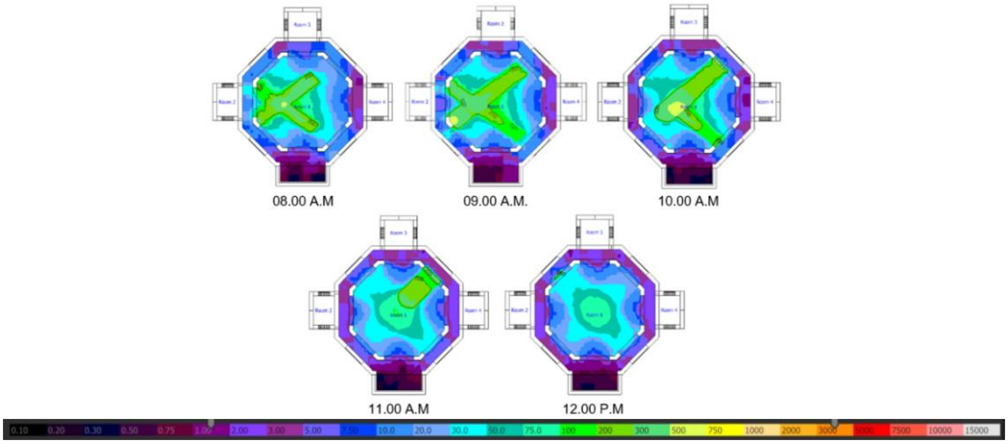

Figure 8. Natural Daylight Distribution Plan Inside the Old Design, March 21st

The simulation results show that when the sun is at the northern solstice, which is on June 22nd, it has poor natural lighting quality. By simulating 5 times a day, every hour is simulated once from 8 am to 12 noon, it is known that the natural lighting exposure in the worship area is not up to standard (see Table 2).

Table 2 also shows that the worship room does not meet the SNI requirements which mentions that 50% of the total room area must be exposed to natural lighting. Despite that the sun is illuminating ideally inside the service room at the Blenduk Church, it still requires additional lighting to achieve the required area exposed to daylight. The highest percentage of room area that is well illuminated by the daylight was achieved by the building during the simulation at 10.00 am (Table 2). The area of the worship room that is well-illuminated by the natural lighting is 55.20m², which is 15.33% of the total worship room area.

The natural lighting quality on June 22nd was better than when the sun was above the equator line. The condition inside the building was still relatively dark. The discomfort caused by the darkness is illustrated by the plan which is mostly colored in the gradation of blue to purple, indicating that the light intensity inside the building is only 3lux to 50lux (Figure 9).

Table 2. The Worship Room Area that Was Illuminated, June 22nd

No	Time	Area with 200lux daylight (m²)	Percentage (%)
1	08.00	35.54	11.81
2	09.00	47.37	14.80
3	10.00	55.20	14.10
4	11.00	53.89	6.06
5	12.00	48.06	0.15

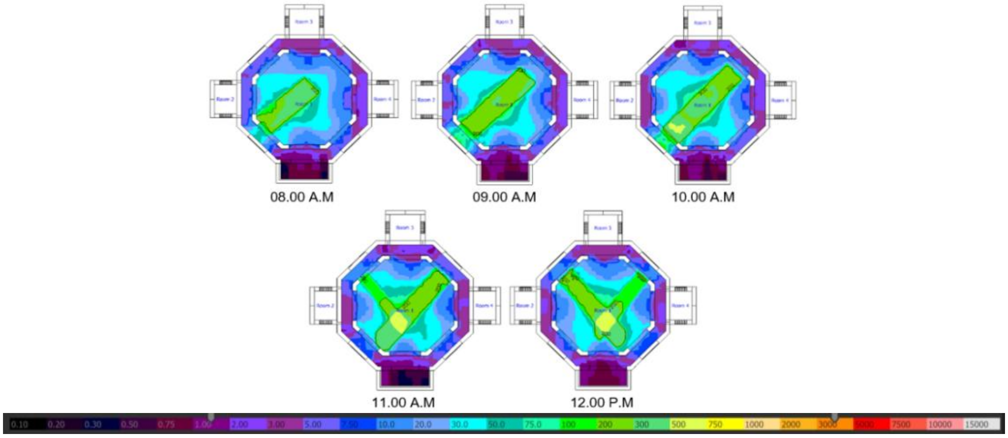

Figure 9. Natural Daylight Distribution Plan Inside the Old Design, June 22nd

When the sun's position is on the equator line for the second time, September 23rd, the natural lighting quality in the worship room is similar to the quality of lighting in the room on March 21st. Based on the simulation results, the maximum area being illuminated by the natural lighting in the worship room is at 09.00 am. At that time, 15.27% of the room area, 54.99m^2, is illuminated with daylight with an intensity of 200lux (Table 3).

The colored plan showing the distribution of natural light in the worship room (Figure 10) on September 23rd, the natural lighting quality was similar to the natural lighting quality on March 21st and June 22nd. The worship room is illuminated by sunlight with low intensity, it causes darkness that may make people uncomfortable during the service (ranging from 3lux-50lux). Artificial lighting is needed to provide visual comfort.

Table 3. The Worship Room Area that Was Illuminated, September 23rd

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	45.07	12.52
2	09.00	54.99	15.27
3	10.00	43.03	11.95
4	11.00	16.06	4.46
5	12.00	15.37	4.27

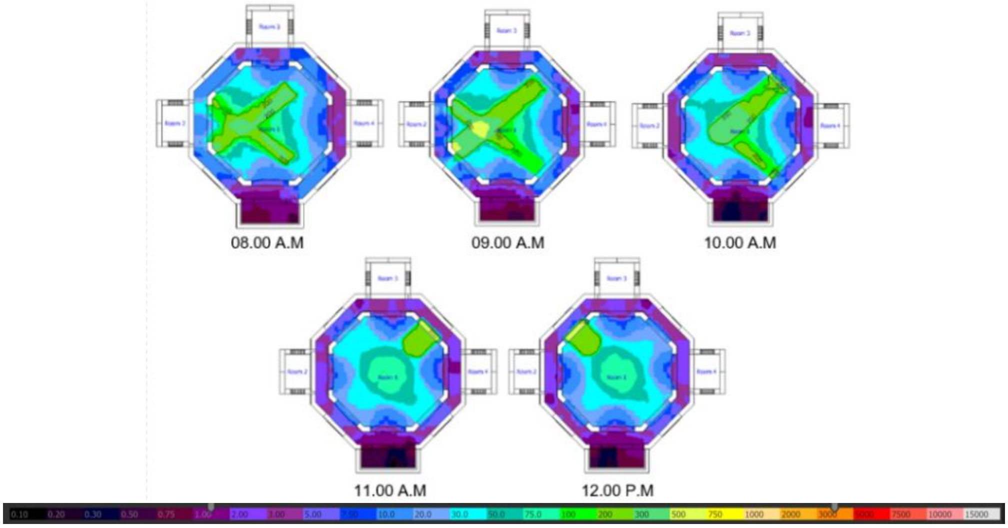

Figure 10. Natural Daylight Distribution Plan Inside the Old Design, September 23rd

Another simulation was conducted when the sun is at the southern solstice, December 22nd. It showed that the natural lighting quality in the worship room was considered poor when compared to the current SNI. The maximum area of space that was illuminated with sunlight is 74.6m^2, which is around 15.59% of the total area. The maximum natural lighting quality in the Blenduk Church worship room at 10.00 am (Table 4).

After simulating the natural lighting quality inside the old design of Blenduk Church for several times, it could be known that on December 22, the natural lighting quality could be considered as the best. This was indicated by the largest percentage of the area that was exposed to natural daylight. However, despite it being the best, the worship room was still relatively dark. The darkness was indicated by the plan which is dominated with color gradation of blue to purple (daylight intensity between 3lux and 50lux) (Figure 11).

The simulation results showed that the old design of Blenduk Church had bad natural lighting quality when compared to the current standards. The best quality of natural lighting was at 09.00 am and 10.00 am. The brightest condition in the worship space was on December 22nd. While the darkest worship room was on September 23rd.

Table 4. The Worship Room Area that Was Illuminated, December 22nd

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	42.43	11.79
2	09.00	54.51	15.14
3	10.00	56.11	15.59
4	11.00	36.67	10.19
5	12.00	11.75	3.26

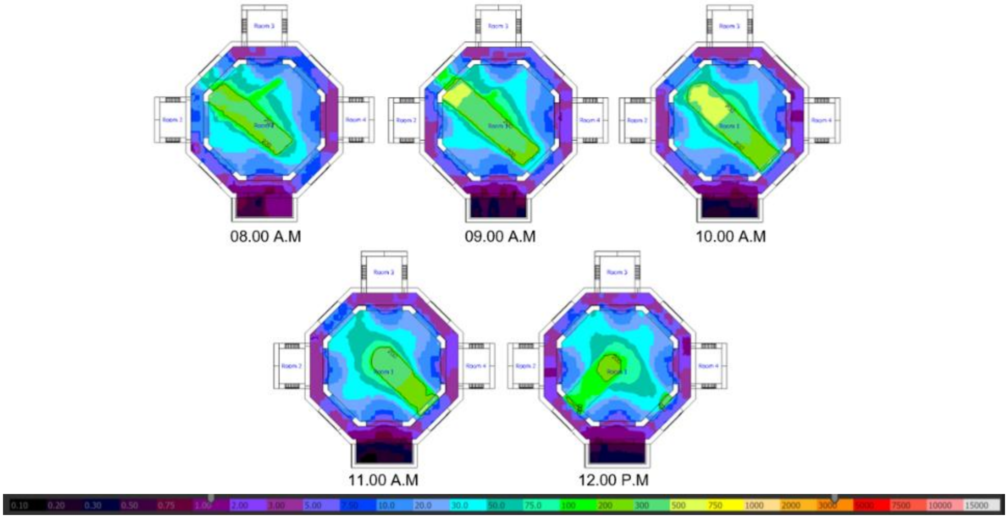

Figure 11. Natural Daylight Distribution Plan Inside the Old Design, December 22nd

The Natural Daylight Inside the Blenduk Church's New Design

The new design of the Blenduk Church is the Blenduk Church with twin towers at the front façade. The standard used as a reference in the simulation of natural lighting for the new design of Blenduk Church, was the same standard that was used when assessing the quality of natural lighting for the old Blenduk Church design: SNI 6197 of 2011. The simulation data collected were the area that was illuminated with natural lighting with an intensity of 200lux, the percentage of the area of space exposed, a colourful plan depicting the distribution of natural light with various intensity in the worship room. The simulation time for the new design of the Blenduk Church was also on the same days and times as the simulation for the old design of the Blenduk Church: when the sun is at the northern solstice (June 22nd), on the equator line (March 21st and September 23rd), and at the southern solstice (December 22nd).

The simulation which was conducted on March 21st showed that the Blenduk Church worship room tends to be dark. The natural lighting distribution plan depicts that the worship room received natural lighting with the intensity ranging from 3lux-50lux (Figure 12). At the same time, some of the worship space was illuminated with sunlight with an intensity of 200lux, it illuminated less than 50% of the room area. The natural lighting quality based on the simulation was at 09.00 am. The area of the worship room that was exposed to the highest natural daylight intensity on March 21st was 16.27%, which was 58.56m^2 (Table 5). Meanwhile, at 12 noon (Table 5) showed that the worship room was illuminated with the least natural daylight intensity amongst the other simulation results, only 0.04% of the worship room area in the Blenduk Church, or 0.16m^2 is illuminated by natural daylight.

Table 5. The Worship Room Area that Was Illuminated, March 21st

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	50.19	13.94
2	09.00	58.56	16.27
3	10.00	43.80	12.17
4	11.00	3.13	0.87
5	12.00	0.16	0.04

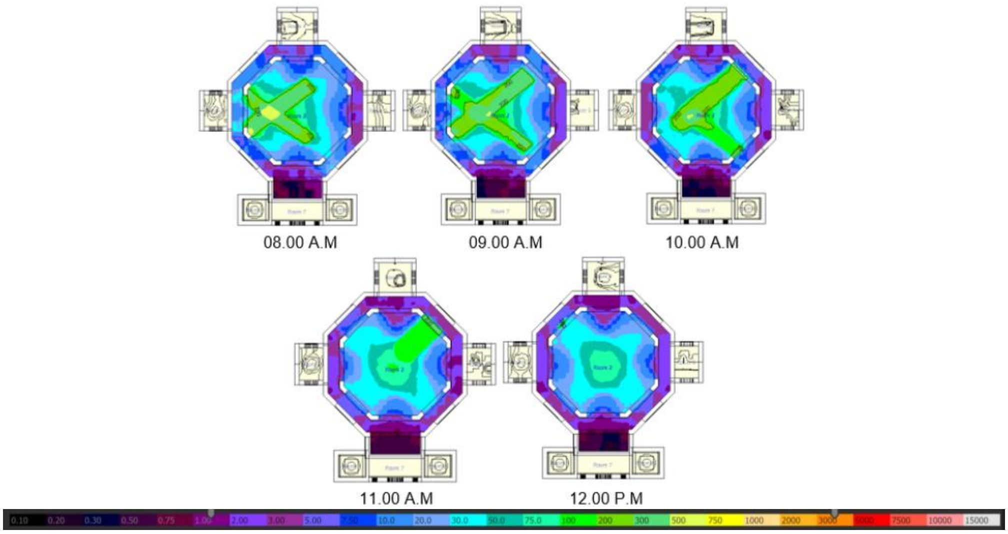

Figure 12. Natural Daylight Distribution Plan Inside the New Design, March 21st

On June 22nd, the sun was at the northern solstice, the quality of natural lighting is slightly better than March 21st. According to the current standard, the natural lighting quality couldn't be considered as comfortable. Looking at the colored plan to see the distribution of natural daylight in the worship room (Figure 13), it could be known that the natural lighting quality of the worship space was still categorized as dark. This was known with the mostly used colors that were light blue to depict areas with a sunlight intensity of 50lux, and purple to depict areas that receive natural daylight with intensity of 3lux.

There was an improvement in the natural daylight quality which was shown by the increasing percentage of the area of the room that was illuminated with the daylighting in comparison to March 21st. The maximum area of the room exposed to sunlight with an intensity of 200lux is 55.44m^2, around 15.40% of the total area of the worship room. The maximum percentage of space being illuminated by the sunlight was at 10:00 am (Table 6). The simulation showed that every hour during the service (the set simulation time), the sunlight was able to illuminate a wider area than March 21st. At 12:00 pm, which was the darkest hour when the sun was on the equator line, 12.35% of the room was illuminated by natural light (Table 6).

Table 6. The Worship Room Area that Was Illuminated, June 22nd

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	50.19	13.94
2	09.00	58.56	16.27
3	10.00	43.80	12.17
4	11.00	3.13	0.87
5	12.00	0.16	0.04

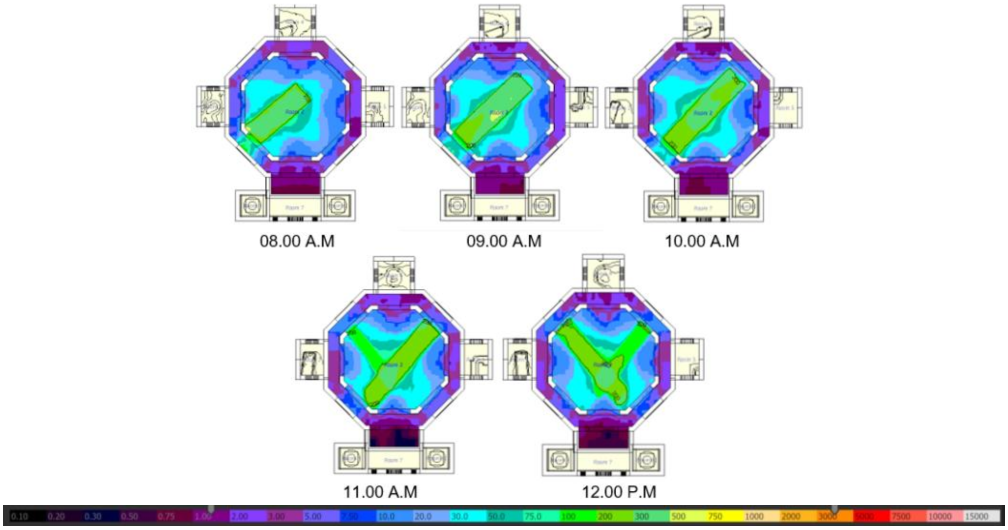

Figure 13. Natural Daylight Distribution Plan Inside the New Design, June 22nd

When the sun was above the equator for the second time on September 23rd, the natural lighting quality of the worship room was similar to the quality back on March 21st. The simulation showed that the worship room was relatively dark. This statement was supported by the colorful plan that illustrated the distribution of natural lighting in the building (the plan with color gradients from blue to purple and a little green) (Figure 14). The blue color illustrates the area that was illuminated by the sunlight with the intensity of 50lux. The purple color illustrates sunlight's intensity was 3lux. While the green color illustrates the area that was illuminated with sunlight that had the intensity of 200lux.

The worship that was illuminated by natural daylight with 200lux intensity did not reach 50% of the total area. It was only around 55.81m^2, or around 15.50% of the total area of the room, at 09.00 am (Table 7) that was illuminated by the natural daylight with ideal intensity. During the day, precisely at 11.00 and 12.00, the Blenduk Church worship room was at its darkest point with 0.85% until 0.86% of the area was illuminated.

Table 7. The Worship Room Area that Was Illuminated, September 23rd

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	54.27	15.08
2	09.00	55.81	15.50
3	10.00	36.44	10.12
4	11.00	3.06	0.85
5	12.00	3.09	0.86

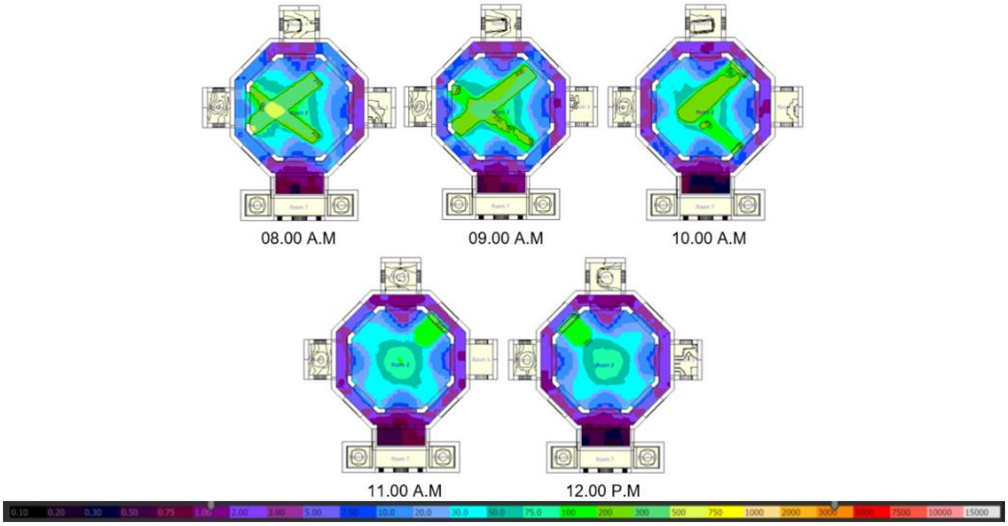

Figure 14. Natural Daylight Distribution Plan Inside the New Design, September 23rd

Compared with the previous simulations, the simulation result on December 22nd, when the sun was at the southern solstice the percentage area of the worship room being illuminated by the sunlight was the largest. However, the worship room was still considered uncomfortable due to the darkness. The natural daylight distribution plan on December 22nd was dominated by color gradation from blue to purple with a little green, indicating that only a few areas were illuminated by natural daylight with the intensity of 200lux (Figure 15).

Other than being shown on the plan that was mostly colored with blue and purple, the darkness inside the worship room was also known by little the area that was illuminated by the sunlight with the intensity of 200lux, which was less than 50% of the total area. The simulation results show that the area exposed to sunlight with an intensity of 200lux is 54.95m^2, which is around 15.26% of total worship room area at 9 am (simulation data number 2, Table 8). Similar to the previous simulation, the smallest area illuminated by natural daylight with the intensity of 200lux happened at 12.00 noon, which was 9.69m^2 or around 2.69% (simulation data number 5, Table 8).

The simulation on the new design of the Blenduk Church worship room showed that the worship room was still too dark to be comfortable. From the data obtained, it was known that natural daylight with the intensity of 200lux was not able to illuminate 50% of the area of Blenduk Church's worship room. The maximum area of the room that was well-lit was 58.56m^2, or 16.27% of the area. This happened on March 21st at 09.00am (simulation data number 2 Table 5).

Table 8. The Worship Room Area that Was Illuminated, December 22nd

No	Time	Area with 200lux daylight (m^2)	Percentage (%)
1	08.00	45.33	12.59
2	09.00	54.95	15.26
3	10.00	48.06	13.35
4	11.00	17.89	4.97
5	12.00	9.69	2.69

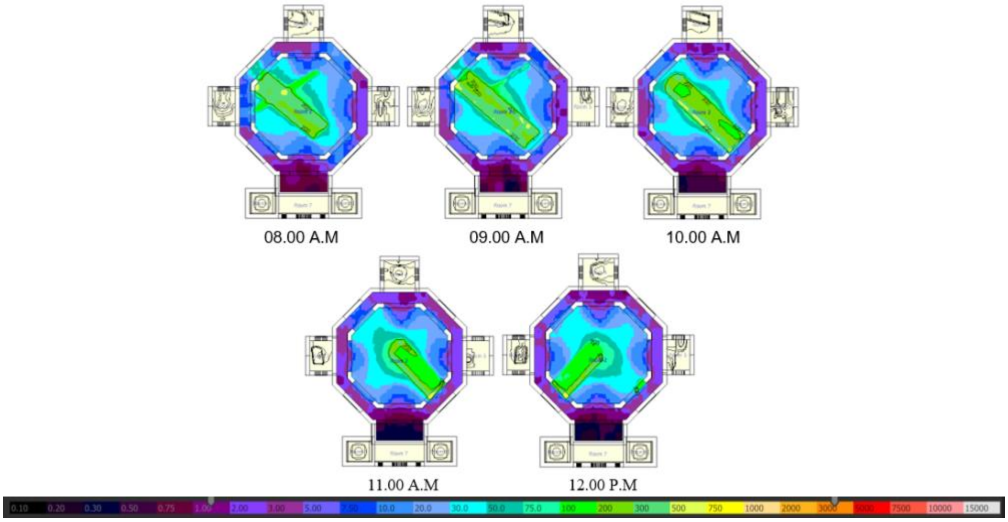

Figure 15. Natural Daylight Distribution Plan Inside the New Design, December 22nd

Data Validation

Data validation is important as previous research done by Lestari (2010), stated that the daylight intensity inside the Blenduk Church is up to standard, however the simulation data stated otherwise. To ensure the validity of data, the data from the simulation are compared with the field measurement data to find the difference. The formula for finding the data difference is:

$$Data\ Difference\ (\%) = \frac{(Simulated\ Light\ Intensity - Actual\ Light\ Intensity)}{Simulated\ Light\ Intensity} x100\%$$

Table 9. The Worship Room Area that Was Illuminated, March 21st

No	Time	Area with 200lux daylight (m^2)	Percentage (%)	Simulated Light Intensity (lux)	Actual Light Intensity (lux)	Data Difference (%)
1	08.00	45.33	12.59	27.90	24.4	12.54
2	09.00	54.95	15.26	32.53	29.7	8.70
3	10.00	48.06	13.35	35.64	30.0	15.82
4	11.00	17.89	4.97	29.00	32.2	11.03
5	12.00	9.69	2.69	31.65	28.6	9.67

The average data difference is 11.55% with a standard deviation of 2.8%. This confirms the software's inaccuracy that is related to the materiality, while falls within the acceptable tolerance. The relatively low difference between the data indicates that DIALux can be used as a reliable instrument to conduct similar research in the future.

Predicting The Micro-Climate of Semarang Old Town Around Blenduk Church in 1939 with Autodesk Forma

The same models were then imported to Autodesk Forma (Figure 16). Autodesk Forma would analyze the building mass to obtain the data of microclimate around the site. It could also make a comparison of two different designs' microclimate data on the same site (Figure 17 to Figure 24). Autodesk Forma could analyze and make predictions of the sun hours, daylight potential, wind comfort, wind direction, thermal comfort, and solar energy analysis. Because the Blenduk Church's design transformation wasn't very drastic, the difference in microclimate analysis between the old design and the new design wasn't very apparent.

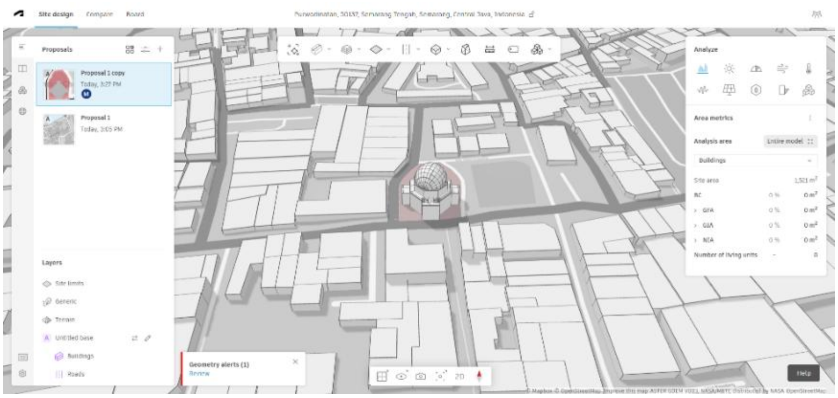

Figure 16. Blenduk Church's Old Design Building Mass on Autodesk Forma

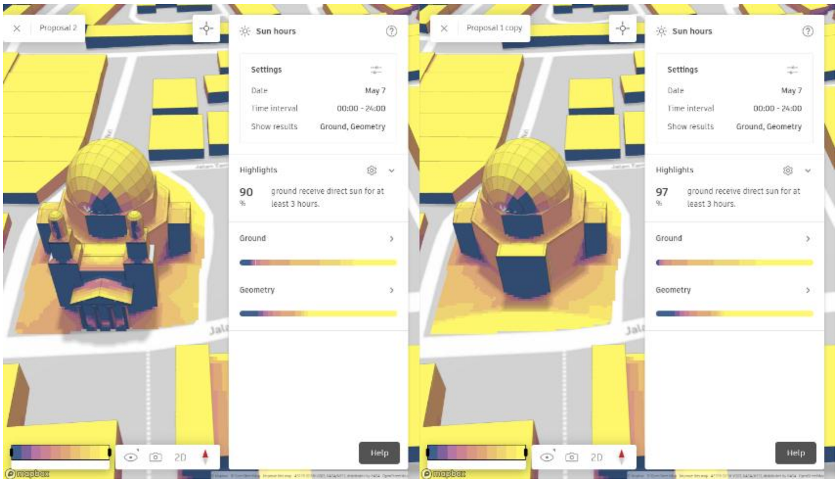

Figure 17. Blenduk Church's Sun Hours

Sun-hours tool is used to indicate how many hours of sunlight the surface of the building would receive. Yellow color indicates that the surface would be enlightened by daylight for a long time, meanwhile blue indicates that the surface would be enlightened by daylight for a short period of time. It could be seen from Figure 17 that the façade of Blenduk Church that's facing south, both in old design and new design, didn't get a lot of sun hours.

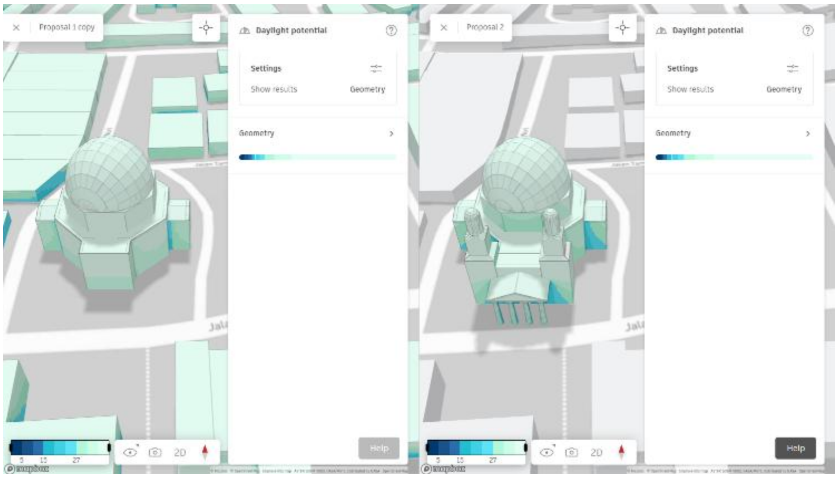

Figure 18. Blenduk Church's Daylight Potential

Unlike sun-hours tool which tells how long the surface will receive illumination from the daylight, daylight potential in Autodesk Forma tells the amount of the natural lighting the building's surface will receive. Navy blue means the surface will receive little to no sunlight, however the mint color means that the surface will receive relatively intense sunlight. Looking at Figure 18, it can be said that by adding the twin towers and the overhang gable cause some part of the new Blenduk Church building stopped getting natural light as intense as the old design.

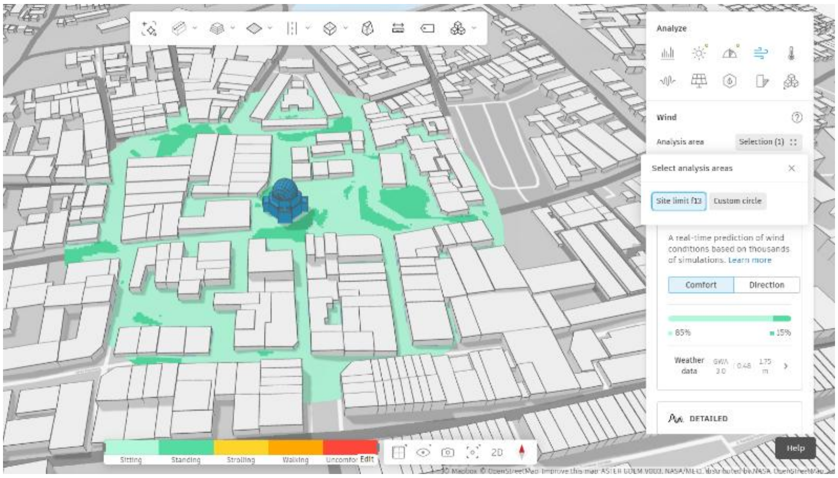

Figure 19. Blenduk Church's Old Design Building Mass' Wind Comfort

There are two types of wind simulation in Autodesk Forma: wind simulation based on comfort (Figure 19 and Figure 21) and wind simulation based on the direction (Figure 20 and Figure 22). The wind simulation based on the direction tells how strong the wind is at the specific area. The wind simulation based on comfort's scale tells what kind of activities that would be comfortable to be done at that specific area depending on how strong the wind is: sitting, standing, strolling, walking, or uncomfortable. The spot with low wind current, which is shown in light blue, apparently is comfortable to sit on. Meanwhile, the spot with strong wind currents apparently is uncomfortable. Both the old design and the new design gave similar results in terms of comfort and wind current: the area around Blenduk Church's old design and new design are relatively comfortable for sitting and standing, with relatively low wind current. This shows that adding the overhang gable at the façade does not affect much to the wind current around the site.

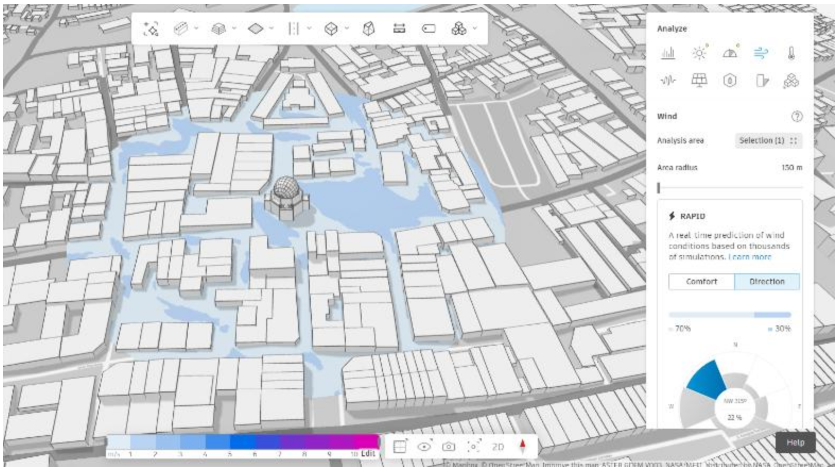

Figure 20. Blenduk Church's Old Design Building Mass' Wind Direction

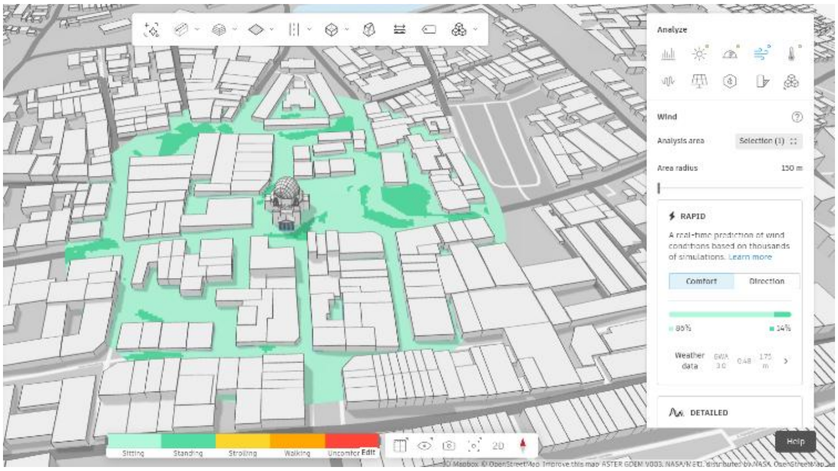

Figure 21. Blenduk Church's New Design Building Mass' Wind Comfort

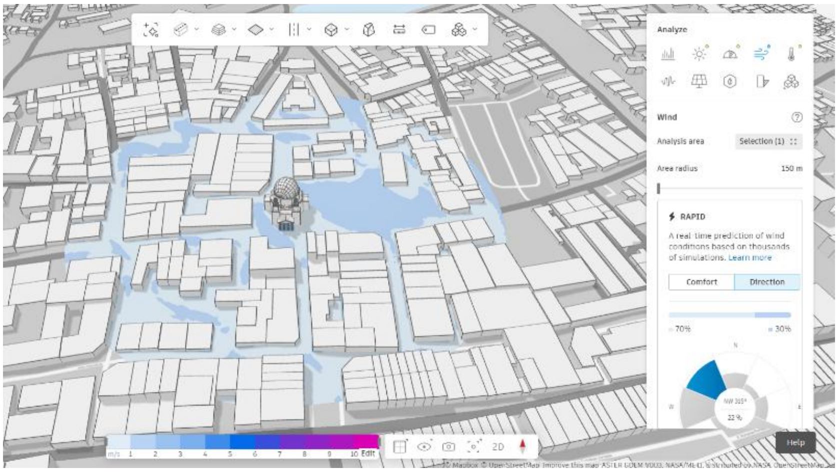

Figure 22. Blenduk Church's New Design Building Mass' Wind Direction

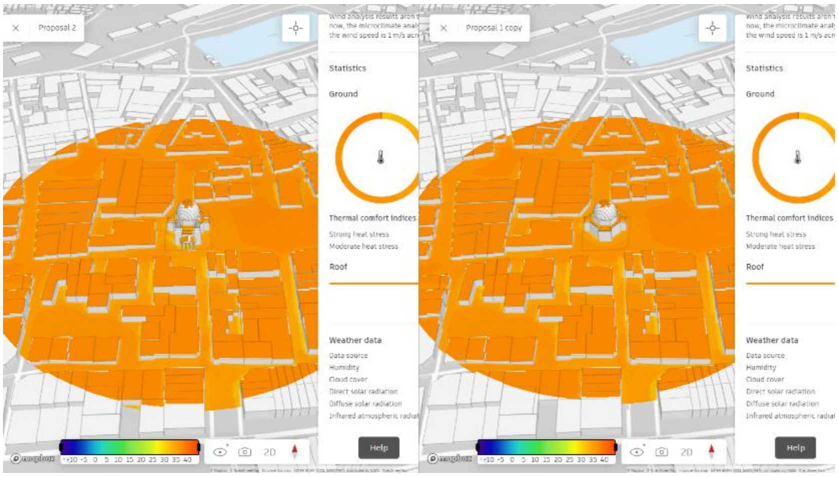

Figure 23. Blenduk Church's Thermal Comfort Comparison

The thermal comfort data can be used to predict how comfortable the area would be. Blue means the temperature is relatively cold, while red means the temperature is relatively hot. Looking at Figure 23, it can be seen that the area around Blenduk Church was categorized as hot and uncomfortable both around the old design and the new design.

By understanding which surface got the longest sun hours and had the best daylight potential on both of the designs, we could get the data to find out which surface had the best potential to generate solar energy. However, as it could be seen on Figure 24, Autodesk Forma has already provided the tool to analyze the solar energy analysis automatically. The result of the solar energy analysis is gradient of color from yellow to brown on the roof of the building masses. Yellow means that placing the solar panel on that specific area would be ideal because it will receive high amount of natural daylight in long hours. The brown color means that the area isn't ideal for placing any solar panel, it is because the area does not get illuminated by the sun long enough nor does it get illuminated with daylight in intensity that is high enough. Comparing the old design and the new design of Blenduk Church, obviously by adding elevated gable on the new design adds more ideal surfaces that can be put on solar panels than the old design.

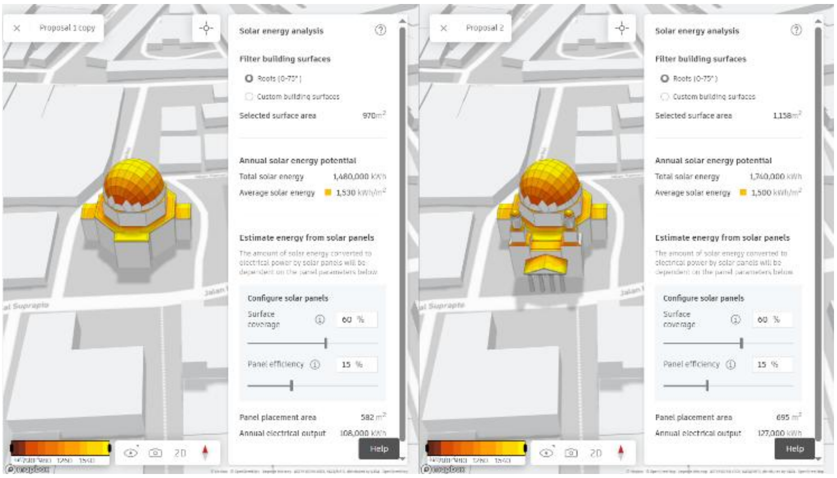

Figure 24. Blenduk Church's Solar Energy Analysis Comparison

Autodesk forma can be used as a tool to simulate the micro-climate around the heritage building that has been demolished and transformed. Because the building mass' changes are not very drastic, the micro-climate around the Blenduk Church did not change a lot. The only noticeable changes are in the sun hours (in the new design of Blenduk Church, some part that was illuminated by the sunlight did not get illuminated anymore due to the façade covering some part of the existing building), daylight potential (some part in the new Blenduk Church wasn't illuminated as well as the older design), and lastly the solar energy analysis (the new design of Blenduk Church has more area that could be covered with solar panel). A feature in Autodesk Forma that isn’t utilized in this research is noise prediction that is caused by vehicles due to the lack of control over the variables. It is suspected that it is unable to be controlled because it relies on the recent data, which would not be relevant to assess the condition back in the day. The result would be ideal if Autodesk Forma allowed variable adjustment based on the year of the simulation to achieve more accurate result.

As the features improved, the accuracy of spatial-quality simulation software would be more accurate. In the future, when more heritage buildings become ruined or transformed, the information about those buildings will not be completely lost and still can be found digitally because of digital conservation with BIM and simulation software.

CONCLUSIONS

BIM can be used to store manufacturing data, construction data, materials, prices, dimensions, and other information, the completeness of the data stored in it is highly dependent on the data that was inputted during the modelling session. 3D models that were created with BIM-based software can be stored into the cloud to create virtual reality. By creating virtual reality, people can directly experience the space quality. However, information that is related to texture and space quality as the result of lighting effect is missing. The DIALux Evo simulation proved that there are changes in daylight quality inside the old Blenduk Church and the new design. The results of this study could be improved if the window material assets that matched the design of Blenduk Church were updated. DIALux Evo did not allow material modification to better suit the stained-glass windows that Blenduk Church had, thus normal plain glasses were used to simulate the daylight comfort. Considering the nature of stained glass which has a lower transparency index, it is more likely that the simulation results with appropriate indicators will result in poorer daylight quality inside the Blenduk Church. Autodesk Forma simulations showed that the Blenduk Church's design transformation, by adding elevated gables and twin towers on the façade), did not have any significant impact on the surrounding microclimate. However, using it as HBIM requires further development. The default indicators in Autodesk Forma are adjusted to the most recent data, so their relevance to do comparison with the past microclimate cannot be fully relied upon. The nature keeps on changing, the simulation result would be more reliable if Autodesk Forma allowed its user to adjust the year based on the year the building was born. Nevertheless, Autodesk Forma can be used for heritage buildings' revitalization in order to adapt to the current microclimate. To conclude, remodeling and simulating a heritage building could be a step to create the missing space quality digitally.

The theoretical purpose of this research is to report on the application of digital conservation utilizing BIM and simulation software. Practically, this research could be used by architects, curators, and conservators to conserve heritage building digitally. There are some suggestions to conduct further research: similar studies on different heritage building to receive more data about digital conservation, study of the reliability of simulation software for heritage building and required efforts to make it more accurate and study of utilizing HBIM-based software and simulation software for heritage building revitalization to improve its sustainability, further research by simulating the acoustic and energy performance, involving the local community to avoid limiting the data only for researchers.

REFERENCES

Badan Standardisasi Nasional. (2011). *Konservasi Energi pada Sistem Pencahayaan*. BSN.

Chang, J. H. (2016). *A Genealogy of Troopical Architecture Colonial Networks, Nature, and Technoscience*. Routledge.

Dauda, J. A., Bower, N., Adebisi, W. A., Saad, A., Saka, A. B., Kazemi, H., & Ajayi, S. O. (2025). Exploring the application of heritage building information modelling (HBIM) for heritage conservation: insights from industry practitioners. *Journal of Architectural Conservation*, 1–14. https://doi.org/10.1080/13556207.2025.2518661

Ewart, I. J., & Zuecco, V. (2019). Heritage Building Information Modelling (HBIM): A Review of Published Case Studies. In *Advances in Informatics and Computing in Civil and Construction Engineering* (pp. 35–41). Springer International Publishing. https://doi.org/10.1007/978-3-030-00220-6_5

Feilden, B. M. (2019). *Conservation Historic Buildings*. Routledge.

Gaputra, D. (2019). Analisis Elemen Fasad pada Bangunan Kolonial Karya F.D. Cuypers & Helswit di Kota Cirebon. *Arcade Jurnal Arsitektur*, *3*(2), 153–160.

Husna, P., & et al. (2020). *Cagar Budaya: Para Saksi Bisu Sejarah Provinsi Jawa Tengah*. KKL Arsitektur Undip 2020.

Karatzas, S., Lazari, V., Fouseki, K., Pracchi, V. N., & Balaskas, E. (2024). Digital twins-enabled heritage buildings management through social dynamics. *Journal of Cultural Heritage Management and Sustainable Development*. https://doi.org/10.1108/JCHMSD-08-2023-0136

Kardinal, N. G. A. D. A., Putra, I. D. G. A. D., Adhika, I. M., & Dwijendra, N. K. A. (2024). Integrating Cultural Heritage and Modern Urban Planning: Transforming Karang Bengang in Tegallalang. *Journal of Architecture & Environment*, *23*(2), 131–142.

Lestari, D. S. (2010). Kualitas Penerangan Alami Bangunan Gereja Blenduk Semarang. *Jurnal Teknik Sipil Dan Arsitektur*, *8*(12A).

Liberotti, R., & Gusella, V. (2023). Parametric Modeling and Heritage: A Design Process Sustainable for Restoration. *Sustainability*, *15*(2), 1371. https://doi.org/10.3390/su15021371

Megawati, B., Antariksa, & Suryasari, N. (2017). Tipologi Fasade Bangunan Kolonial di Koridor Jalan Letnan Jenderal Soeprapto Kota Semarang. *Arsitektur E-Journal*, *4*(3), 143–155.

Moedjiono, & Indriastjario. (2017). Mengenal Gereja Blenduk Sebagai Salah Satu Land Mark Kota Semarang. *Modul*, *11*(2), 55–61.

Niccolucci, F., & Felicetti, A. (2024). Digital Twin Sensors in Cultural Heritage Ontology Applications. *Sensors*, *24*(12), 3978. https://doi.org/10.3390/s24123978

Penjor, T., Banihashemi, S., Hajirasouli, A., & Golzad, H. (2024). Heritage building information modeling (HBIM) for heritage conservation: Framework of challenges, gaps, and existing limitations of HBIM. *Digital Applications in Archaeology and Cultural Heritage*, *35*, e00366. https://doi.org/10.1016/j.daach.2024.e00366

Puerto, A., Castañeda, K., Sánchez, O., Peña, C. A., Gutiérrez, L., & Sáenz, P. (2024). Building information modeling and complementary technologies in heritage buildings: A bibliometric analysis. *Results in Engineering*, *22*, 102192. https://doi.org/10.1016/j.rineng.2024.102192

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers* (3rd ed.). John Wiley & Sons, Inc.

Wang, W., Yu, C. W., Peng, F., & Feng, Z. (2024). Digital development of architectural heritage under the trend of Metaverse: Challenges and opportunities. *Indoor and Built Environment*, *33*(4), 603–607. https://doi.org/10.1177/1420326X231191571

Wardani, L. K., & Triyulianti, L. (2011). Pengaruh Budaya Indis pada Interior Gereja Protestan Indonesia Barat Imanuel Semarang. *Dimensi Interior*, *9*(1), 34–45.

Yudantini, N. M. (2022). BALI AGA VILLAGES DOCUMENTATION IN BANGLI REGENCY AS ARCHITECTURAL CONSERVATION AND CULTURAL HERITAGE. *Journal of Architecture & Environment*, *21*(1), 45–54. https://iptek.its.ac.id/index.php/joae/article/view/12809

This Page is Intentionally Left Blank