Zairin Zain*
orcid.org/0000-0001-5365-3820

Norita Norita**
orcid.org/0000-0001-9745-8306

Andi Andi***
orcid.org/0000-0002-9869-1246

Photogrammetric Analysis of Wooden Historical Architecture: Case Study of Alwatzikhoebillah Palace

Analiza fotogrametryczna zabytkowej architektury drewnianej. Przypadek Pałacu Alwatzikhoebillah

Keyword: physical elements, building envelope, modelling reviews, photogrammetry, HBIM

Słowa kluczowe: elementy fizyczne, powłoka budynku, przeglądy modelowe, fotogrametria, HBIM

Introduction

Historical buildings play an important role in strengthening an area that continues to grow over time. The architectural features of historical buildings have an identity that acts as placemaking for their homeland and reveals the thoughts of its people [Salleh, Mohtar 2020, pp. 37–46]. This distinct identity serves as a monumentalization of bygone eras and warrants safeguarding akin to a precious cultural artefact. Essentially, historical buildings require focused attention given their intrinsic value, association with urban identity, and significance in cultural memory [Hanachi, Moghimi 2017, pp. 308–316]. The presence of historical buildings in an area provides historical evidence that ensures the sustainability of human life in the development process. Historical buildings should continue to be used to meet current human needs [Ariffin et al. 2022]. The preservation of historical heritage buildings plays an important role in becoming an asset of a nation's cultural treasures. Its sustainability can be enjoyed by future generations and can contribute to education and science as an object of research.

Historic buildings certainly experienced severe conditions for decades in their respective environments. The physical condition of a building changes due to natural conditions. It will certainly experience degradation due to use. Historical buildings in Southeast Asia generally use wood as the main material for its structural system. Wet and dry environmental conditions make construction materials also highly vulnerable to degradation and shorten their service life (Ałykow et al. 2024, pp. 29–45). In addition, the degradation can change the original shape of the building. Historical buildings must maintain their authenticity in accordance with historical records.

The physical elements of historical architecture are diverse and can vary significantly depending on the specific style and time period in question. The common features of historical architecture, including

* *PhD. Eng. Associate Professor, Faculty of Engineering, Pontianak, Universitas Tanjungpura*
** *Student, Center of Southeast Asian Ethnicities Cultures and Societies, Joint Collaboration between Universitas Tanjungpura and National Taitung University*
*** *Arch., Center of Southeast Asian Ethnicities Cultures and Societies, Joint Collaboration between Universitas Tanjungpura and National Taitung University*

* dr inż., prof. UT, Wydział Inżynierii, Uniwersytet Tanjungpura
** student, Centrum Narodowości, Kultur i Społeczeństw Azji Południowo-Wschodniej, Współpraca między Uniwersytetem Tanjungpura i Narodowym Uniwersytetem Taitung
*** arch., Centrum Narodowości, Kultur i Społeczeństw Azji Południowo-Wschodniej, Współpraca między Uniwersytetem Tanjungpura i Narodowym Uniwersytetem Taitung

Cytowanie / Citation: Zairin Z., Norita N., Andi A. Photogrammetric Analysis of Wooden Historical Architecture: Case Study of Alwatzikhoebillah Palace. Wiadomości Konserwatorskie – Journal of Heritage Conservation 2024, 80:

Otrzymano / Received: 5.02.2024 • **Zaakceptowano / Accepted:** 31.07.2024 **doi: 10.48234/WK80PALACE**

Praca dopuszczona do druku po recenzjach *Article accepted for publishing after reviews*

building materials, structural elements, ornamentation, roof styles, windows and doors, and site design, serve to define and distinguish the various styles that have emerged over time. It is, however, of the utmost importance to emphasize the significance of historical texture and to strive to mitigate any discrepancies in its perception and potential degradation [Hanachi, Moghimi 2017, pp. 308–316]. The physical and non-physical elements were employed to construct a cognitive map of the historic core of the city. A comprehensive survey, inclusive building assessment and inspection represent a crucial and instructive phase for the successful execution of interventions within both singular and collective regeneration projects [Vicente et al. 2018, pp. 25–57].

The most common method for detecting building degradation is the life-cycle assessment. This physical assessment principally utilizes data derived from a visual inspection or local non-destructive testing programs, thereby facilitating the implementation of more precise and systematic techniques that are inherently susceptible to assessment uncertainties [Nguyen et al. 2019, pp. 5–19; Zain et al. 2022, pp. 89–100]. A further assessment is that of modelling reviews. A modelling review is an essential process for gaining insight into the design, construction, and cultural significance of historical buildings. The combination of physical and digital modelling techniques can facilitate a more comprehensive examination of the distinctive characteristics and design elements of historical architecture, enabling a more accurate assessment of its degradation. Tafahomi [2021, pp. 75–86] posited that this combination can facilitate multiple criteria decision-making and proposed priorities for conservation. For example, in West Kalimantan, a historical item has been reconstructed with the aid of an appropriate remodeling process and digital documentation [Zain et al. 2023, pp. 34–43].

In light of the aforementioned issues and findings, this study employs a combination of life-cycle assessment and modelling reviews to assess the extent of the building's degradation. The condition of the physical elements should be evaluated in order to ascertain the compatibility, reversibility, and necessity of interventions in reconstructing the wooden structure. This study aims to calculate the deterioration area on the building envelope of a historical building using digital modeling through photogrammetry, integrated into Historic Building Information Modeling (HBIM), to reassess the condition of its physical elements. The Alwatzikhoebillah Palace in Sambas is used as the object of study, with a focus on improving the accuracy of detecting and quantifying the impacted area of deterioration.

Current research and technology in heritage building assessment

A comprehensive and interdisciplinary approach is essential for the assessment of a building's current state. This approach should draw upon historical records, technological surveys, non-destructive testing techniques, and the analysis of crack and decay patterns (Vicente et al. 2018, pp. 25–57). Historical structures frequently display a degree of fragility, which can present challenges in terms of accessibility. Virtual tours have been available for several years, created using open-source or professional software to produce comprehensive animations without causing any harm to the building. It can be seen, therefore, that the utilisation of virtual tour technologies is beneficial in the documentation of historical edifices.

In the context of cultural heritage restoration, digital virtual technology has emerged as a crucial supplementary tool. Techniques such as digital photogrammetry, laser scanning, 3D modeling, and artificial intelligence have been employed in heritage restoration studies [Chen et al., 2023, pp. 12–20]. In the case of ancient buildings, photogrammetry, three-dimensional (3D) laser scanning, or a combination of both methodologies are frequently utilized for surveying and mapping purposes, thereby facilitating post-display analysis and evaluation [Chen et al. 2018]. The application of photogrammetry is advancing architectural methods for documenting the built environment, offering a flexible digital approach to managing images and essential measurements that are critical for architectural analysis and documentation methodologies [Firzal 2021, pp. 100–105].

The objective of utilizing Building Information Modeling (BIM) in cultural heritage buildings is to evaluate the efficacy of the method in documenting, managing and restoring data on historical heritage for specific purposes [Bruno and Roncella, 2018, pp. 171–178]. BIM is capable of providing data for a model pertaining to the dimensions of intricate building components. Heritage Building Information Modeling (HBIM) is a technology designed for the management and preservation of heritage buildings, offering convenient and intelligent data for subsequent analysis [Nagy & Ashraf, 2021, pp. 1–15]. HBIM is a dynamic database for historic buildings that facilitates more suitable integration of documentation data with construction needs. The documentation data are displayed in a more structured manner, with spatial relationships, geometry, geographic information, and quantities of documented building components clearly delineated.

The application of photogrammetry in the quantification of building deterioration has gained considerable recognition in recent research. Nevertheless, there is still a need for integration with Historic Building Information Modeling (HBIM) technology. For example, Dörtbudak et al. (2023, pp. 62–68) employed unmanned aerial vehicle (UAV) photogrammetry to document and model structural deterioration. Although the deformations, such as cracks and collapses, are effectively visualized, the study lacks detailed quantification of these deformations through formulated methods or calculations. Instead, it relies on visual data and 3D modeling to assess structural damage. Similarly, Russo et al. [2019, pp. 1–20] quantified deterioration on historical building facades using ultra-lightweight UAVs but did not integrate their approach with HBIM technology. Similarly, Zollini et al. [2020, pp. 1–16] employed UAV photogrammetry in conjunction with Object-Based Image Analysis (OBIA) to detect and quantify surface deterioration and cracks in concrete bridges. Although their method is effective in identifying and quantifying concrete deterioration, it also lacks integration with BIM systems. This paper aims to enhance current photogrammetry-based building deterioration quantification methods by further integrating them with HBIM systems, thus addressing this critical gap in existing research.

Historical and architectural significance of Alwatzikhoebillah Palace

The subject of this study is the historic edifice that constitutes the primary structure of Alwatzikhoebillah Palace in Sambas, West Kalimantan. This edifice holds historical significance as a component of the Sambas Sultanate, which attained prominence in the seventeenth century [Kusnoto, Firmansyah 2016, pp. 19–28; Zain et al. 2024, pp. 11–21]. The Sultanate was established in 1631 by Raden Sulaiman, who became its inaugural Sultan [Kusnoto, Firmansyah 2016, pp. 19–28; Posha 2024, pp. 18–37]. The palace itself was constructed between 1933 and 1935 under the direction of Sultan Muhammad Mulia Ibrahim Syafiuddin. It is situated at the confluence of the Sambas Kecil, Subah, and Teberau rivers.

The architectural style of the palace is representative of traditional Malay design, with wood utilized as the primary building material [Norita et al. 2022, pp. 482–491]. The design exhibits the influence of the Dutch East Indies colonial era, particularly in its symmetry and geometric patterns, which are imbued with Islamic symbolism [Posha 2024, pp. 18–37]. For example, the octagonal design on the second floor represents the eight cardinal directions, while the rectangular roof symbolizes the four attributes of the Prophet Muhammad [Posha 2024, pp. 18–37]. The palace's ornamentation includes squares, triangles, circles, and trapezoids, with roof structures combining triangular and trapezoidal shapes, as well as repeated circular patterns [Zain et al. 2024, pp. 11–21]. These elements serve to reinforce the Islamic identity of the palace, reflecting the religious foundation of the Sambas Sultanate.

The palace was rebuilt during the reign of Sultan Muhammad Mulia Ibrahim Syafiuddin, with the original design from Sultan Muhammad Syafiuddin II's era being maintained [Posha 2024, pp. 18–37]. Notable renovations were conducted by the West Kalimantan government between 1984 and 1985 [Posha 2024, pp. 18–37]. Subsequently, efforts to maintain the palace have been ongoing, with the objective of preserving its structure and intricate ornamental features [Zain et al. 2024, pp. 11–21]. As observed by Norita et al. [2022, pp. 482–491], the deterioration of the palace's wooden elements can be attributed to a combination of biological and non-biological factors. The former encompasses the presence of fungi, while the latter includes weather-related mechanical erosion.

Preserved as a cultural heritage site, the Alwatzikhoebillah Palace serves as a tourist destination. The historical and architectural significance of the Sambas region is a key factor in the region's identity [Posha 2024, pp. 18–37]. The objective of the conservation efforts is to maintain the traditional Malay woodcarving motifs and symbolic decorations that reflect the region's rich cultural heritage.

Methods

This study employs digital documentation methods to assess and detect deterioration in the building's exterior envelope, which was mapped in 3D Building Information Modeling (BIM). By integrating these digital assessments, the HBIM processes deterioration data on the building in order to calculate patterns of impact. The data can then be used to inform further action with regard to the physical elements of the building, with the aim of preserving and conserving the cultural heritage structure through the use of BIM modeling. This approach allows for the monitoring of the current condition of the building. The data collected on the physical elements, which are influenced by biological factors (mold and mildew), non-biological factors (weather, chemicals), and mechanical factors, are processed to determine the extent of deterioration of the wood surface.

The study by Norita et al. [2022, pp. 482–491] represents a foundational stage for the present research, constituting a pioneering effort in the use of photogrammetry and Building Information Modeling (BIM) for the documentation and assessment of deterioration in heritage buildings. The study focused on the Alwatzikhoebillah Palace and employed a combination of manual measurements, close-range photogrammetry, and UAV imagery to create 3D models and map surface damage. Although this approach yielded valuable insights, it primarily concentrated on 2D surface mapping and basic quantification, without a more comprehensive integration into HBIM. Building on this foundational work, this study extends the methodology by improving the quantification of deterioration and enhancing accuracy. The objective of this study is to develop a more robust system for calculating and tracking structural and surface deterioration on the building envelope, including the exterior walls, openings, and roof, by integrating UAV photogrammetry with HBIM. This will facilitate a more comprehensive and precise analysis, thereby enabling the implementation of more effective preservation and maintenance strategies for heritage structures.

The process of creating the BIM model commences with the recording of the object in question using

Deterioration factor	Color	Source	
White rot		White	[Shang et al. 2013] [Riggio et al. 2015]
Brown rot		Wistful	[Reinprecht 2016]
		Brown	
Soft rot		Brown	[Reinprecht 2016]
Stain		Black	[Zabel, Morrell 2020]
		Green	
		Blue	
		Brown	
		Wistful	
		Grey	
		Red	
		Purple	
Moss		Green	[Sáiz-Jiménez 1999, pp. 27–37]
Mechanical erosion and weather		Brown	[Zabel, Morrell 2020]
		Grey	
Strong acid		Brown	[Zabel, Morrell 2020]
Strong base		White	[Zabel, Morrell 2020]

Table 1. *Color codification of the deterioration factor.*

Code	Deterioration factor
A	– white rot – Strong Base
B	– brown rot – stain
C	– brown rot – soft rot – stain – Weather Influences – Strong acid
D	– stain – Moss
E	– stain – Weather Influences
F – I	– stain

Table 2. *Codification for the impacts type of the deterioration factor.*

the BIM system, thereby establishing it as a parametric component. The parametric object prototype library is then mapped to the point cloud. Point cloud data for HBIM can be obtained from image-based or photogrammetric or structure-from-motion (SfM) techniques (Chiabrando et al., 2017, pp. 605–612). The final product is a three-dimensional model that includes detailed information regarding the construction method and material composition. The implementation of HBIM 3D modelling facilitates the identification of deterioration without causing damage to the fragile historical structure. Moreover, this methodology generates comprehensive and detailed technical drawings, which are instrumental in the conservation and management of historic buildings.

The data obtained from the building survey is processed using the Agisoft Metashape software as a reference for three-dimensional modeling, which is then imported into Blender using the digital asset exchange (DAE) file format. Subsequently, the process is continued using SketchUp for the delineation of each component of the edifice. Subsequently, the SketchUp file is imported into Autodesk Revit, which is used to construct a new building model for the purpose of storing information in a Building Information Model (BIM).

The unmanned aerial vehicle has been indispensable to this project. Given the condition of the building, it was not feasible to reach the top of the building to carry heavier equipment or directly measure its height. It should be noted that unmanned aerial vehicles do have certain limitations. For example, the flight will be adversely affected if there are additional trees in close proximity to the watchtower. Data collection and production for the tree leaves presents a significant challenge. Two methods were employed for the collection of field data, in order to accommodate the specific circumstances of the case study of heritage buildings. Two-dimensional images of the data were collected with great care from the air using the drone technique and from the ground using the DSLR camera. This was done in order to obtain a map of the distribution pattern of the deterioration on the building envelope surface.

The mapping of deterioration patterns in physical elements is conducted on the building envelope in two phases. The initial phase entails the mapping of the subject matter using Joint Photographic Experts Group (JPEG) photo data, which is then rendered into three-dimensional modelling material by means of Autodesk Revit software. The photographic data will provide information about the unobstructed portions of the building elements. The material from the photograph serves as a reference for mapping. Phase two entails mapping on Autodesk Revit using the filled region feature for the photograph of the building elements that are situated in obstructed portions of the surrounding environment. The regions are assigned a color based on the color code, as illustrated in Table 1. This feature also stores information pertaining to deterioration factors that occur in the building envelope, which are marked with letters, as shown in Table 2 and number codes.

Results

Based on the field observation data above, building visualization uses photo data as modeling material (Figure 1 a) while the visualization in Figure 1b shows the original color of the material from the front facade of the building. The building elements were observed to undergo a color change, manifesting as gray at the roof covering elements. Additionally, the roof covering exhibited a transition from gray to brown. The floor material and the foundation cover element at the base exhibited a black stain, which had also taken on a brown hue.

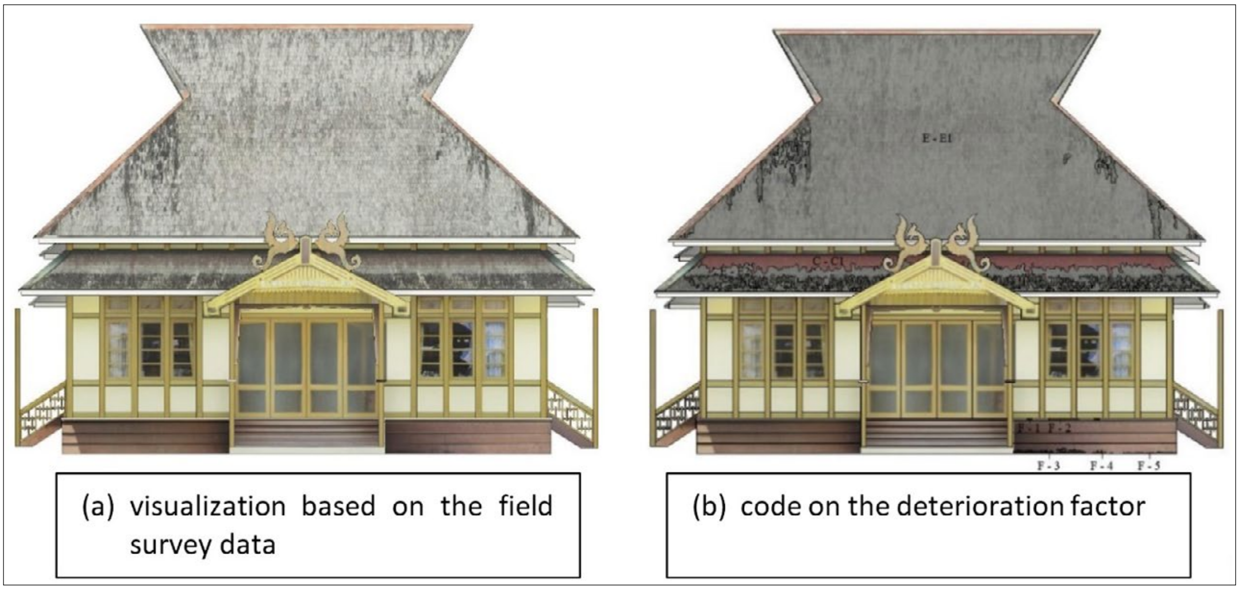

Fig. 1. The front facade of the main building of the Alwatzikhoebillah Palace; by N. Norita.
Ryc. 1. Frontowa elewacja głównego budynku pałacu Alwatzikhoebillah; autor: N. Norita.

The occurrence of color changes within the building is indicated by the pattern of deterioration visible on the facade. The color change from black to gray is indicated by code E (Figure 1b), which corresponds to the deterioration factor indicator. The observed discoloration of the wood material can be attributed to the action of fungi or mechanical erosion and the effects of weathering. The deterioration of roof coverings may be caused by a number of factors, including the presence of brown rot fungi, soft rot fungi, wood-colouring fungi, mechanical erosion, weather changes, and strong acids. A blackish discoloration on the floor and beneath the foundation is indicated by code F, signifying deterioration due to stain.

The deterioration observed on the rear facade of the building was limited to the roof covering and the sheet covering under the foundation. The roof covering exhibited a change in color from its original black hue to light and dark gray tones (code E) (see Figure 2). The covering sheet located beneath the foundation exhibits a black coloration, indicative of stain-related deterioration (code F).

A visual inspection of the rear facade revealed a notable contrast in coloration between the roof covering and the surrounding area. The roofing material, which was originally black, has almost completely lost its pigmentation. The black coloration on the facade has been replaced with light and dark grey hues. It was not possible to visualize the color stains under the foundation due to the presence of vegetation around the building, which obstructed parts of the covering sheet. The vis-

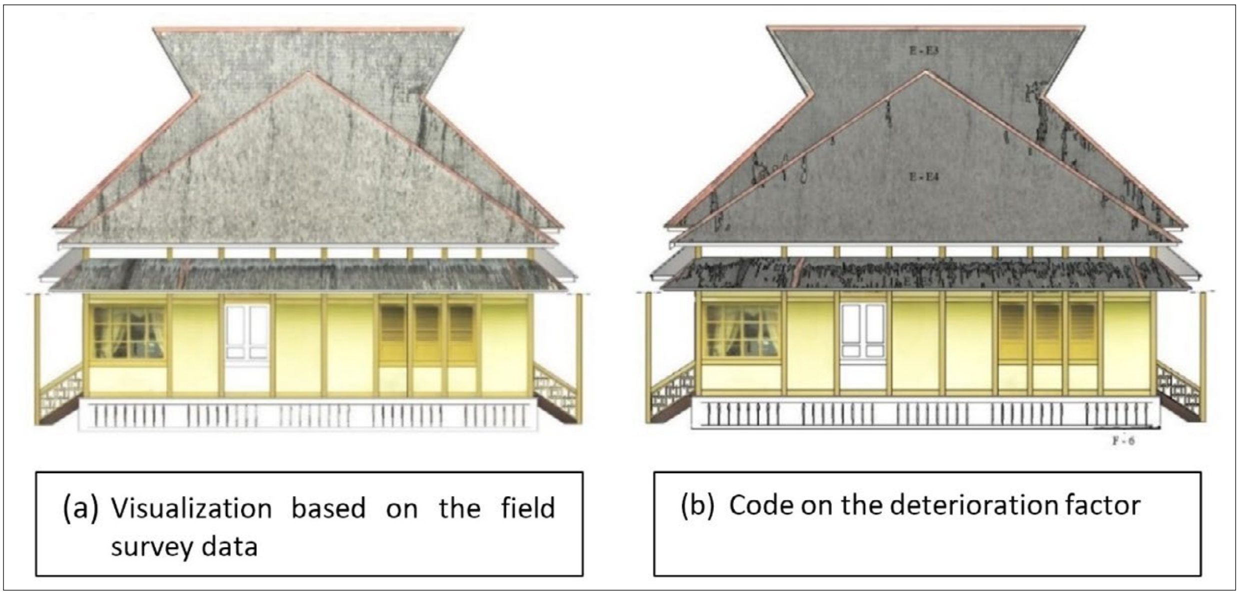

Fig. 2. The rear facade of the main building of the Alwatzikhoebillah Palace; by N. Norita.
Ryc. 2. Tylna elewacja głównego budynku pałacu Alwatzikhoebillah; autor: N. Norita.

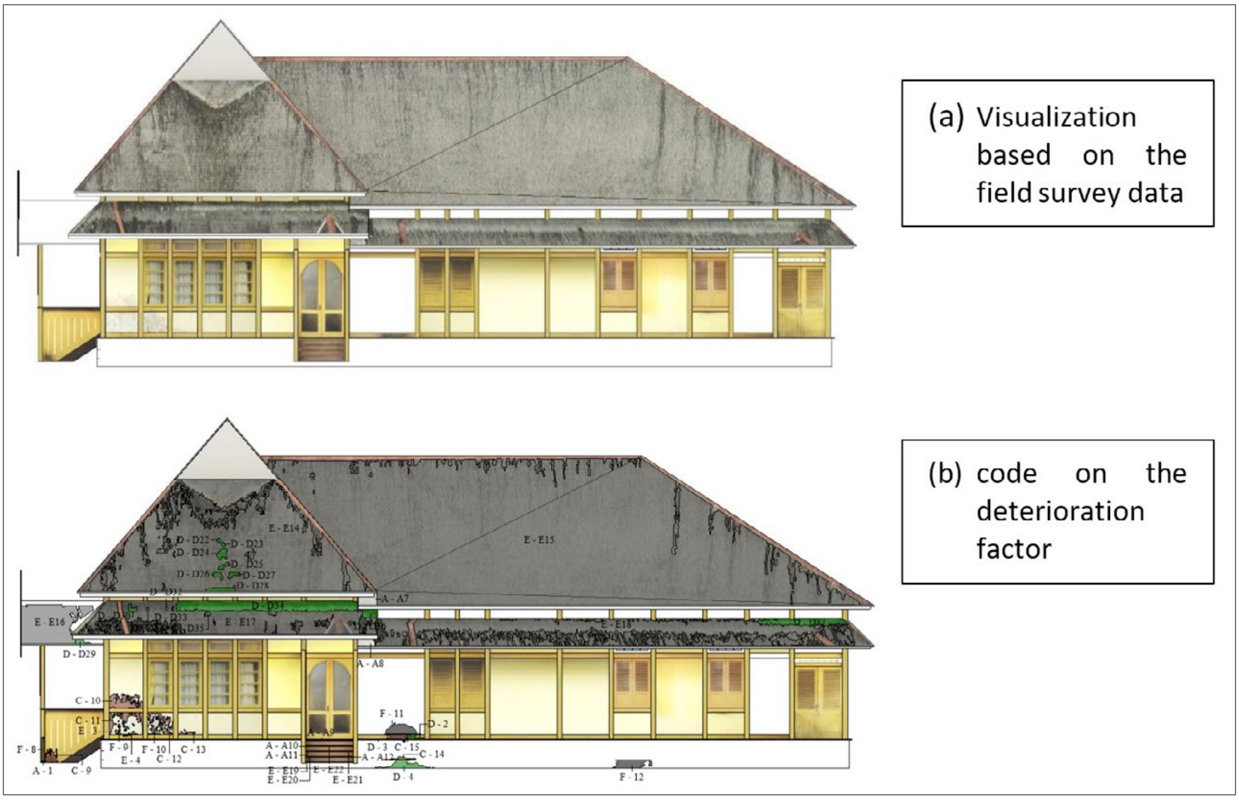

Fig. 3. The left facade of the main building of the Alwatzikhoebillah Palace; by N. Norita.
Ryc. 3. Lewa elewacja głównego budynku pałacu Alwatzikhoebillah; autor: N. Norita.

ualization (see Figure 2b) demonstrates deterioration to the roof covering, stirrups, and stairs. The covering sheet under the foundation and floor was found to be in a state of deterioration. However, it was not possible to visualize this deterioration directly, so it was sketched directly as the original building documentation for visualization purposes.

The deterioration of the roof covering elements visible on the left facade (Fig. 3) of the building is identical to that observed on the right facade. The deterioration is caused by the presence of stains or moss, which impart a green coloration to the affected area. However, the roof covering on this facade is also subject to attack by white rot fungal factors or a strong base, resulting in the formation of white stains. The non-structural elements of the wall on the left facade display a brownish discoloration, which may be attributed to brown rot fungi, soft rot fungi, stains, mechanical erosion, weather changes, or the action of strong acids (code C). Furthermore, the presence of black stains was observed on the wall, which can be attributed to the combined effects of staining agents (code F) and wood-colouring fungi (code E).

The stairs are exhibiting signs of deterioration due to a combination of factors, including stains, mechanical erosion, and weathering. Additionally, the steps and risers of the stairs have been subjected to attack by white rot or strong alkaline fungi (see Figure 3). The stair baluster exhibits the effects of deterioration as defined by code factor C. The covering sheet of the foundation on the left facade has also undergone a change in color, appearing green due to the presence of wood-coloring fungi or moss. Additionally, brown spots have been observed, classified as an effect of code factor C. The stirrups on this side have also demonstrated deterioration, attributed to the same factors that have caused deterioration under the foundation. The structural elements of the column exhibit the effects of wood-coloring fungi and white rot fungi, as well as a robust foundation.

A deterioration effect was observed on the right facade (see Figure 4), specifically in the section of the bracing material that constructs the wall element. This section appears to be no longer intact. This section displays grayish spots, which indicate deterioration classified as category E according to the code. The deterioration is caused by wood-coloring fungi, mechanical erosion, and weather changes. Additionally, deterioration effects were observed on non-structural wall elements coated with yellow paint, resulting in the formation of brown stains. This condition is classified under code factor C, which encompasses brown rot fungi, soft rot fungi, wood-coloring fungi, mechanical erosion, and weather changes, as well as strong acids.

The non-structural elements of the stairs, including both the steps and the riser, have suffered deterioration due to the combined effects of wood-colouring fungi, mechanical erosion, and weather changes, classified under code E. Additionally, the deterioration observed on the right side of the staircase's main structure can be

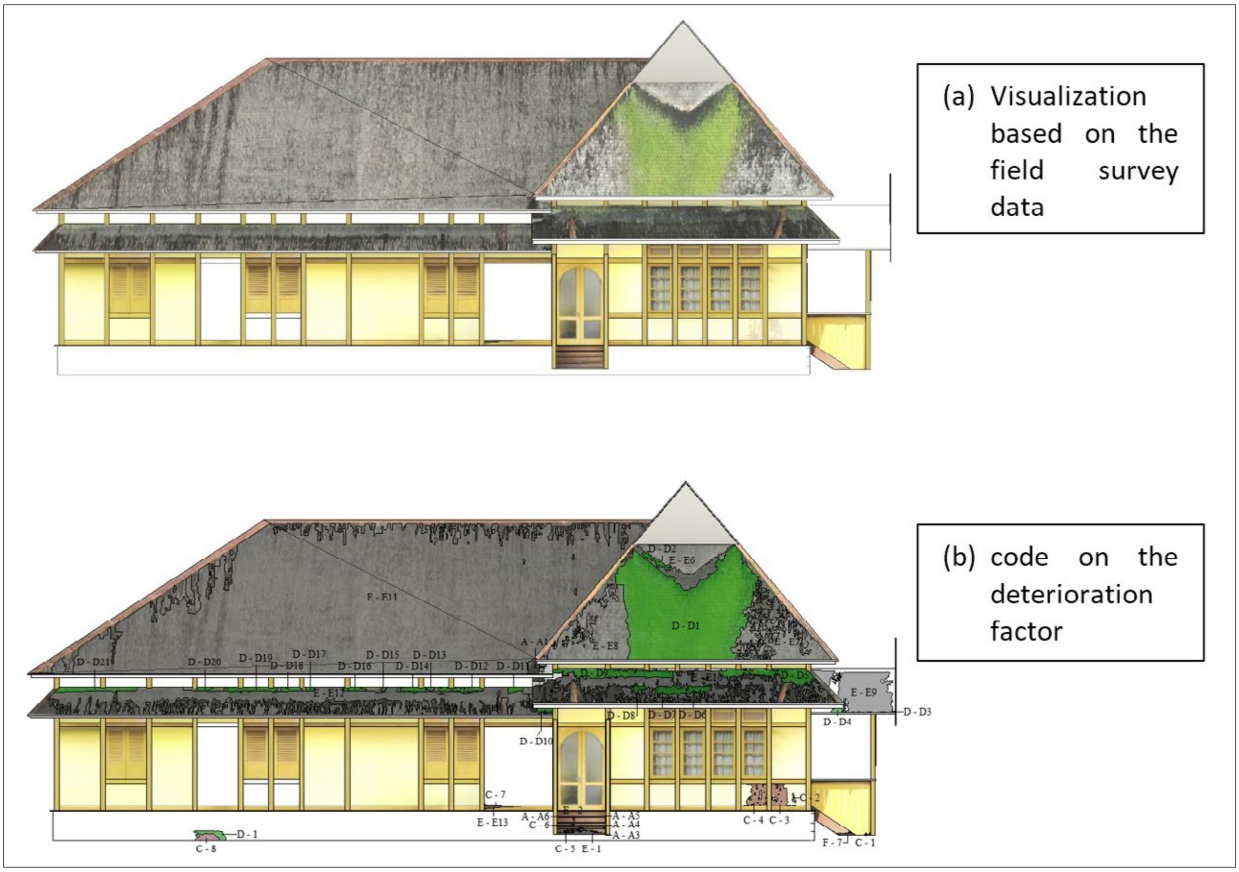

Fig. 4. The right facade of the main building of the Alwatzikhoebillah Palace; by N. Norita.
Ryc. 4. Prawa elewacja głównego budynku pałacu Alwatzikhoebillah; autor: N. Norita.

attributed to the presence of white rot fungus or strong base (code A). Another deterioration effect factor that affects the staircase elements is code factor C. The lower part of the building, situated beneath the foundation on the right side, also exhibits a change in coloration to green, which is attributed to the presence of wood-coloring fungi or moss. The brown spots observed in this area are categorized as a result of code factor C.

Identification of deterioration effect on the physical element

This study builds upon the work of Norita et al. [2022, pp. 482–491] by advancing the integration of unmanned aerial vehicle (UAV) photogrammetry with historic building information modeling (HBIM) to reassess the structural and surface conditions of historical building envelopes. While Norita et al. [2022, pp. 482–491] concentrated on the utilisation of UAVs for fundamental structural evaluations, this study takes a more comprehensive approach by emphasising 3D digital modelling using Structure from Motion (SfM), thereby creating more precise and comprehensive models of facades and roofs. The improvement lies in the enhanced accuracy in quantifying deterioration areas, which allows for a more detailed and systematic analysis of the impact of such deterioration on various building components.

In light of these assessments, two distinct deterioration mechanisms were identified as the underlying causes of the observed condition of the elements. The first category comprises elements coated with paint, while the second category comprises elements that are uncoated. The roof covering elements are not coated with paint, whereas the floor covering, foundation sheet, and exterior floor have been coated with paint. In contrast with the stairs, all the components of the stair railing have been painted, with the exception of the steps. The application of a coating has been demonstrated to enhance the durability of the material. In a study conducted by Santos-Bobadilha (2020), the performance of coated and uncoated wood samples was compared. The uncoated wood samples exhibited a greater proclivity towards deterioration as a consequence of environmental factors, including moisture and ultraviolet (UV) radiation, in comparison to the coated samples, which demonstrated superior water repellency and reduced swelling [Santos-Bobadilha, 2020].

The deterioration of the roof covering elements that are not coated with paint on the building with the most significant area is caused by wood-colouring fungi or mechanical erosion and weather changes (code E), which collectively account for 48.88% of the total roof covering surface area. The proportion of deterioration caused by white rot fungi or strong bases is minimal, representing only 0.08% of the total area. The presence of brown rot fungi, soft rot fungi, wood-colouring fungi, mechanical erosion, and weather changes or strong acids with a brown staining effect was observed in up to 0.60% of the samples.

This underscores a significant challenge in the evaluation of biological deterioration, particularly in the context of heritage buildings constructed from organic materials. The study's emphasis on fungal and moss-related deterioration represents a significant advancement in the field of preservation techniques. In comparison to the pioneering work of Sánchez and Quirós [2017, pp. 21–30], which introduced the use of low-cost material detection through spectral classification, this study builds upon their work by integrating photogrammetry with HBIM, with the specific aim of addressing the preservation of wooden historical structures. The combination of high-accuracy deterioration quantification with a cultural heritage focus renders this study more comprehensive and applicable to real-world conservation efforts.

Meanwhile, deterioration due to wood-colouring fungi or moss with a green stain effect was 2.86%. The deterioration factor for the elements of the stairs with a white effect was 0.83% on the painted section and 0.09% on the unpainted section. Additionally, the presence of brown stains is frequently observed on painted staircases, with an estimated prevalence of 1.14%. Additionally, the stairs exhibit a gray color effect, resulting in deterioration of 0.69% on the painted surface and 0.89% on the unpainted surface. Another noteworthy phenomenon is the presence of a black stain on painted elements, which was observed to have a severity of 0.85%.

On the floor, minor deterioration caused by wood-coloring fungi (code F) was observed, affecting a mere 1.39% of the total floor surface area. Another form of floor deterioration is caused by wood-coloring mold with a green stain effect. The observed deterioration was found to be as much as 1.07%. The architectural elements situated beneath the foundation exhibited indications of deterioration attributable to the wood-colouring fungus factor (Code F), which constituted 0.78% of the total surface area beneath the foundation of the building. These findings align with the methodology proposed by Zollini et al. [2020, pp. 1–16] for condition assessments that lacked the capacity to monitor changes over time. The incorporation of HBIM into this study affords the opportunity for long-term monitoring, thereby enabling stakeholders to continuously track deterioration and make informed decisions regarding proactive maintenance. Similarly, while Russo et al. [2019, pp. 1–20] concentrated primarily on surface-level mapping and visualization, their methodology lacked a mechanism for storing, managing, or tracking deterioration data over time. Furthermore, a green stain effect was observed at a rate of 0.58%, while a brown stain effect was noted at a rate of 0.23%. The deterioration of wall architectural elements was attributed to the code C factor, which may be caused by brown rot fungi, soft rot fungi, wood-coloring fungi, mechanical erosion, and weather changes, as well as the presence of strong acid with a concentration of 0.68% of the total wall surface area of the building mass. Additionally, three other colors were observed on the wall surface: green, gray, and black. The green spot effect was 0.04%, the grey spot effect was 0.05%, and the black spot effect was 0.12%. These results further demonstrate the value of integrating photogrammetry with HBIM, as this study offers a more robust and functional system that allows for the continuous monitoring of structural conditions and a more comprehensive understanding of long-term deterioration trends. This methodology is therefore highly effective for heritage conservation, where the long-term preservation of historical structures is of critical importance.

As time progresses and conditions change, the complexity and difficulty of conservation practices increase [Eryudhawan, Andi 2021, pp. 43–54]. The attributes of performance and inventiveness are both inherent to the role of the conservator. The identification results may prove invaluable in determining the subsequent steps necessary to preserve and conserve the Alwatzikhoebillah Palace. In accordance with the principles of conservation, the treatment of Alwatzikhoebillah Palace must be applied to both the functional and formal elements in order to preserve the cultural significance of the building's meaning. Furthermore, this study has contributed to a broader understanding of the deterioration of wooden structures. While previous research using photogrammetry has focused on stone structures, such as that conducted by Pozo-Antonio et al. [2019, pp. 227–236] and Dörtbudak et al. [2023, pp. 62–68], Russo et al. have concentrated on masonry materials, including brick and stone. Sánchez and Quirós [2017, pp. 21–30] have primarily addressed granite surfaces. This study, however, broadens the scope by addressing wooden materials, thereby filling technological and material-type gaps left by previous studies. The collective findings of these studies provide a more comprehensive framework for the monitoring and preservation of a broader range of historical materials and deterioration processes.

Conclusions

From the observation of the identification of the building envelope, it can be seen that the latest conditions demonstrate a significant impact of this building on the roof. Other physical elements have been protected by a layer of paint, thereby preventing severe impacts. The anticipation of further actions in any given area is identified as a means of reducing the effects of deterioration on the roof of the building. It is recommended that further discussion be held with the building administrator to determine the most appropriate course of action for controlling physical elements outside the building that are significantly impacting the deterioration of the building's physical elements. Appropriate data storage in a database allows for the documentation of a building's physical elements, which can then be used to enhance the material condition of the building in the future through the implementation of a suitable preservation method, thus ensuring the continued protection of a cultural heritage site. The essential data and information derived from the identification process will inform the subsequent actions necessary for the preservation and conservation of Alwatzikhoebillah Palace.

This study has successfully integrated advanced photogrammetry with HBIM to enhance the accuracy of deterioration assessment. By extending previous methodologies, the study not only maps but also quantifies the affected areas, thereby providing a more comprehensive analysis of the building's structural health. The most significant findings indicate a pervasive deterioration of wooden elements, particularly on the roof, where fungal infestation and mechanical erosion are prominent. Conversely, other areas exhibit superior preservation due to the presence of protective paint layers. This comprehensive evaluation of the palace's condition not only documents the current state of deterioration but also establishes a foundation for future preservation efforts, thereby supporting the objective of providing precise data for the conservation of cultural heritage buildings. The precise mapping and calculation of deterioration patterns facilitate more informed decision-making with regard to the palace's maintenance, thereby ensuring the long-term preservation of the building.

References

Aływkow Krzysztof, Jasieńko Jerzy, Tarczewski Romuald, *Impact of Alterations, Deformation, and Type of Support of a Baroque Timber Truss on the Results of a Static Analysis: Case of the Evangelical Our Savior's Church in Jelenia Góra-Cieplice*, "Wiadomości Konserwatorskie Journal of Heritage Conservation" 2024, No. 78.

Ariffin WN Jazmina W., Noh Normah Awang, Azinuddin Muaz, Ibrahim Asmawi, Ghazalli Farah Syazrah, Rahim Emma Marini, *Citizen Engagement in Tangible Heritage Conservation Strategies in Terengganu*, "Planning Malaysia" 2023, Vol. 21, No. 1.

Bruno Nazarena, Roncella Riccardo, *A Restoration Oriented HBIM System for Cultural Heritage Documentation the Case Study of Parma Cathedral*, "International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences" 2018, Vol. 42, No. 2.

Chen Han, Xu Han, Zhang Yudian, *The Restoration of Garment Heritages based on Digital Virtual Technology: A Case of the Chinese Pale Brown Lace-encrusted Unlined Coat*, "Industria Textile" 2023, Vol. 74, No. 1.

Chen Siliang, Yang Haozhong, Wang Shusheng, Hu Qingwu, *Surveying and Digital Restoration of Towering Architectural Heritage in Harsh Environments: A Case Study of the Millennium Ancient Watchtower in Tibet*, "Sustainability" 2018, Vol. 10, No. 9, 3138. https://doi.org/10.3390/su10093138

Chiabrando Filiberto, Lo Turco M., Rinaudo Fulvio, *Modelling the Decay in An HBIM Starting from 3D Point Clouds. A Followed Approach for Cultural Heritage Knowledge*, "The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences" 2017, Vol. 42.

Dörtbudak Emine Beyza, Akça Şeyma, Polat Nizar, *Exploring Structural Deterioration at Historical Buildings with UAV Photogrammetry*, "Cultural Heritage and Science" 2023, Vol. 4, No. 2, pp. 62–68.

Eryudhawan Bambang, Andi Andi, *The Challenges in Conserving the Heritage based on Conservation Practice of AA Maramis Building in Jakarta*, "International Journal of Environment, Architecture, and Societies" 2022, Vol. 2, No. 1.

Firzal Yohannes, *Architectural Photogrammetry: A Low-Cost Image Acquisition Method In Documenting Built Environment*, "International Journal of Geomate" 2021, Vol. 20, No. 81, pp. 100–105.

Hanachi Pirooz, Moghimi Leila, *The Role of Physical-Visual Identity Architectural Elements of Historical Neighbourhoods as Factors for Their Sustainability*, "Current World Environment" 2017, Vol. 12, No. 2.

Kusnoto Yuver, Firmansyah Haris, *Eksistensi Istana Kerajaan Di Kalimantan Barat Sebagai Sumber Belajar Sejarah*, "Historia: Jurnal Program Studi Pendidikan Sejarah" 2016, Vol. 4, No. 1.

Nagy Gehan, Ashraf Fayrouz, *HBIM Platform and Smart Sensing as a Tool for Monitoring and Visualizing Energy Performance of Heritage Buildings*, "Developments in the Built Environment" 2021, Vol. 8, No. 1.

Nguyen Andy, Kodikara *KA Tharindu Lakshith, Chan Tommy HT, Thambiratnam David P., Deterioration Assessment of Buildings Using an Improved Hybrid Model Updating Approach and Long-term Health Monitoring Data*, "Structural Health Monitoring" 2019, Vol. 18, No.1.

Norita Norita, Zain Zairin, Purnomo Yudi, *Metode Identifikasi Kerusakan Elemen Fisik Bangunan Heritage Dengan Building Information Modeling (BIM) Studi Kasus Istana Alwatzikhoebillah Sambas*, "JMARS: Jurnal Mosaik Arsitektur" 2022, Vol. 10, No. 2.

Posha Beti Yanuri, *Sultan Muhammad Mulia Ibrahim Syafiuddin in Islamic Civilization at Sambas 1931–1943: Restructuring of Islam Government and Infrastructure Development*, "Patra Widya: Seri Penerbitan Penelitian Sejarah Dan Budaya" 2024, Vol. 25, No. 1.

Pozo-Antonio José Santiago, Puente Iván, Pereira Manuel Francisco Costa, Rocha Carla Sofia Almeida, *Quantification and Mapping of Deterioration Patterns*

on Granite Surfaces by Means of Mobile Lidar Data, “Measurement” 2019, Vol. 140.
Reinprecht Ladislav, *Wood Deterioration, Protection, and Maintenance*, London 2016.
Riggio Mariapaola, Sandak Jakub, Franke Steffen, *Application of Imaging Techniques for Detection of Defects, Damage and Decay in Timber Structures On-Site*, “Construction and Building Materials” 2015, Vol. 101, No. 2.
Russo Michele, Carnevali Laura, Russo Valentina, Savastano Davide, Taddia Yuri, *Modeling and Deterioration Mapping of Façades in Historical Urban Context by Close-Range Ultra-Lightweight UAVs Photogrammetry*, “International Journal of Architectural Heritage” 2019, Vol. 13, No. 4.
Sáiz-Jiménez C., *Biogeochemistry of Weathering Processes in Monuments*, “Geomicrobiology Journal” 1999, Vol. 16, No. 1.
Salleh Nurul Hamiruddin, Mohtar Muhammad Alif Wajdi, *Active Fire Safety Measures in the Heritage Timber Buildings in Malaysia*, “Planning Malaysia” 2020, Vol. 18, No. 2.
Sánchez Javier, Quirós Elia, *Semiautomatic Detection and Classification of Materials in Historic Buildings with Low-Cost Photogrammetric Equipment*, “Journal of Cultural Heritage” 2017, Vol. 25.
Santos-Bobadilha, Gabrielly, *Evaluation of Coatings Used for Prolonging The Durability of Cross-Laminated Timber Against Weathering and Wood Decay Fungi*, Sustainable Bioproducts Dissertation at Mississippi State University 2020.
Shang Jie, Yan Shaopeng, Wang Qiuyu, *Degradation Mechanism and Chemical Component Changes in Betula Platyphylla Wood by Wood-Rot Fungi*, “BioResources” 2013, Vol. 8, No. 4.
Tafahomi Rahman, *Application of Physical and Nonphysical Elements in the Conservation of Historic Core of City*, “South African Journal of Geomatics” 2021, Vol. 10, No. 1.
Vicente Romeu, Lagomarsino Sergio, Ferreira Tiago Miguel, Cattari Serena, Mendes da Silva J.A.R., *Cultural Heritage Monuments and Historical Buildings: Conservation Works and Structural Retrofitting* [in:] *Strengthening and Retrofitting of Existing Structures*, eds. A. Costa et al. 2018, Vol. 9.
Zabel Robert A., Morrell Jeffrey J., *Wood Microbiology: Decay and Its Prevention*, “Academic Press” India 2020.
Zain Zairin, Irwin Irwin, Andi Uray Fery, *Action on Heritage Conservation of Wooden Structures: Enhancing the Cultural Spaces of Pontianak by Reconstruction of a Traditional Malay House*, “International Journal of Environment, Architecture, and Societies” 2023, Vol. 3, No. 1.
Zain Zairin, Khaliesh Hamdil, Vica Michael, *Karakteristik Bentuk Ornamen Pada Bangunan Bersejarah Istana Kadariah Pontianak Dan Keraton Alwazikhoebillah Sambas Di Kalimantan Barat*, “Modul” 2024, Vol. 24, No. 1.
Zain Zairin, Norita Norita, Andi Andi, *Physical Elements of Heritage Buildings: Study of the Kadariah Palace in Pontianak City, West Kalimantan*, “Wiadomości Konserwatorskie Journal of Heritage Conservation” 2022, No. 72.
Zollini Sara, Alicandro Maria, Dominici Donatella, Quaresima Raimondo, Giallonardo Marco, *UAV Photogrammetry for Concrete Bridge Inspection Using Object-Based Image Analysis (OBIA)*, “Remote Sensing” 2020, Vol. 12, No. 19.

Abstract

Historic buildings in Southeast Asia, predominantly made of wood, are highly susceptible to deterioration, especially after centuries of ageing. The aim of this study is to map and calculate the area of deterioration on the envelope of a historic building using digital modelling to review the physical condition of its elements. The subject of this study is the Alwatzikhoebillah Palace in Sambas, Indonesia. In this study, photogrammetry was used to create a 3D model of the facades and roof using BIM modelling. As a result of the building envelope analysis, significant deterioration was found on the roof where 48.88% of the surface area is affected mainly by wood coloring fungi and mechanical erosion. Meanwhile, painted elements, including walls and stairs, show better preservation. This study improved on previous research by integrating photogrammetry with HBIM, allowing for more accurate tracking of deterioration and long-term monitoring, which is critical for the conservation of wooden heritage.

Streszczenie

Zabytkowe budynki w Azji Południowo-Wschodniej, w większości wykonane z drewna, są szczególnie podatne na degradację, zwłaszcza po wiekach istnienia. Celem tego badania było zmapowanie i obliczenie obszaru zniszczeń w powłoce budynku historycznego za pomocą modelowania cyfrowego, aby ponownie ocenić stan jego elementów fizycznych. Przedmiotem badania jest Pałac Alwatzikhoebillah w mieście Sambas, w Indonezji. W badaniu wykorzystano fotogrametrię do stworzenia modelu 3D fasad i dachu przy użyciu modelowania BIM. Analiza powłoki budynku wykazała znaczną degradację dachu, gdzie 48,88% powierzchni zostało uszkodzone głównie przez grzyby barwiące drewno oraz erozję mechaniczną. Z kolei elementy pokryte farbą, w tym ściany i schody, wykazują lepszą konserwację. Badanie to rozwija wcześniejsze prace poprzez integrację fotogrametrii z HBIM, umożliwiając precyzyjniejsze śledzenie degradacji i długoterminowy monitoring, kluczowy dla ochrony drewnianych zabytków.