Comprehensive Advanced Heritage Building Defect Assessment and Procedures Using LiDAR and Photogrammetry Towards the Sustainability of Cultural Heritage

Shahrul Yani Said [1,2], Muhammad Shahir Shahrin [2]

[1] Institut Seni Kreatif Nusantara (INSAN), Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia -shahrulyani@uitm.edu.my
[2] Faculty of Built Environment, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia – shahrulyani@uitm.edu.my, mshahirshahrin@gmail.com

Keywords: LiDAR, Photogrammetry, Heritage Building Assessment, Building Condition Assessment, 3D Point Cloud, Conservation Management

Abstract

Heritage buildings are valuable cultural assets that require meticulous conservation strategies to ensure their sustainability. Traditional Building Condition Assessment (BCA) techniques, which rely heavily on manual walk-by inspections, are often time-consuming, labour-intensive, and prone to human error. This study presents a comprehensive and advanced methodology integrating Light Detection and Ranging (LiDAR) and photogrammetry for heritage building defect assessment. By leveraging 3D point cloud data and laser scanning technology, this research aims to enhance defect identification accuracy, improve efficiency in documentation, and support informed decision-making for conservation efforts. Case studies conducted on heritage buildings, including Ipoh Town Hall and Post Office, Galeri Kraftangan Seremban, and Bangunan Dato’ Jaafar in Johor Bahru, demonstrate the effectiveness of this approach in detecting architectural and structural deterioration. The study also proposes a structured framework for integrating LiDAR with conventional BCA, providing best practices for heritage documentation and conservation planning. The findings highlight the potential of digital tools in revolutionizing heritage surveying, ensuring precise defect assessments, and promoting sustainable cultural heritage management.

1. Introduction

Heritage buildings hold significant historical, architectural, and cultural values. However, their conservation presents challenges due to the inherent structural vulnerabilities, material deterioration, and the limitations of traditional survey methods. Conventional BCA involves labour-intensive visual inspections, manual measurements, and subjective evaluations, often leading to inconsistencies and inefficiencies in heritage conservation efforts. Adopting digital technologies such as LiDAR and photogrammetry has been identified as a potential solution to overcome these limitations (Dawood et al., 2017). This study explores integrating these advanced methodologies into heritage building assessment to improve conservation practices’ accuracy, efficiency, and sustainability.

A mixed-method research approach was adopted, combining qualitative and quantitative techniques to assess heritage building defects. The study was conducted in three phases. The first phase involves a Desk-Based Research and Pilot Study from literature to identify the limitations of traditional BCA and the advantages of LiDAR and photogrammetry. Pilot studies were conducted to compare manual surveying techniques with digital scanning methods.

The second phased is Data Collection Using LiDAR and Photogrammetry: Three heritage buildings were selected as case studies. LiDAR scanning was performed using a Terrestrial Laser Scanner (TLS) mounted with a DSLR camera to capture detailed point cloud data. And the third phase is the Data Processing and Analysis. The collected point cloud data was processed using RiScan Pro and converted into CAD-compatible formats for defect analysis. Structural deformations, moisture damage, and material degradation were analysed. Comparisons were made between LiDAR-based assessments and traditional BCA findings to determine effectiveness and accuracy.

The study’s findings revealed significant advantages of integrating LiDAR and photogrammetry into heritage building assessment. It enhanced the accuracy and efficiency in providing a precise identification of building defects, including structural cracks, sloping floors, and material deterioration. The method reduced the survey time and manpower: Unlike traditional methods requiring extensive on-site manpower, LiDAR scans were completed in significantly less time with fewer personnel (Said et.al, 2023). Besides that, the automated data capture process eliminated subjectivity, ensuring consistent assessments across multiple case studies. Lastly, the detailed defect reports and 3D visualisations facilitated better decision-making for conservation authorities, aligning with national guidelines and international heritage preservation standards (Yashwant, 2022).

This study demonstrated that integrating LiDAR and photogrammetry with conventional BCA can significantly improve heritage building defect assessments. The findings emphasize the potential of digital tools in heritage conservation, promoting more accurate, efficient, and sustainable documentation practices (Shahrin el al., 2023). Future research should explore the application of artificial intelligence (AI) and machine learning in analysing point cloud data for automated defect detection. Additionally, the policy frameworks should be developed to standardize LiDAR-based heritage assessments to support long-term conservation strategies. By integrating advanced technologies, heritage conservation efforts can be streamlined, ensuring that historical structures are preserved for future generations while reducing costs and human errors associated with traditional survey methods.

2. Overview on Heritage Buildings in Malaysia

Heritage buildings conservation is a part of science that involves building surveying, engineering, arts and humanities, culture and history. Heritage is defined to be in two forms, tangible and intangible. Tangible heritage examples include built heritage, archaeological sites, underwater archaeological sites, and natural heritage. Intangible heritage examples include activities such as dances, artistic works, food, martial arts, and language such old manuscripts. Built heritage is an important part of an urban environment that brings character and tourism.

2.1 Definition of Heritage

Heritage is defined to be in two forms, tangible and intangible (ICOMOS, 2003; Mohd Noor et al., 2019). According to Jabatan Warisan Negara; tangible heritage examples include built heritage, archaeological sites, underwater archaeological sites, and natural heritage (Jabatan Warisan Negara, 2005). Intangible heritage examples include activities such as dances, artistic works, food, martial arts, and language such old manuscripts. Built heritage is an important part of an urban environment that brings character and tourism. The aesthetics of the built heritage needs to be properly maintained and protected to ensure a strong township identity for the local people. Furthermore, heritage is national identity and treasure that define a nation and its citizens. Edstrom and Lang agreed that heritage further provide valuation towards appreciation of origin and roots of a country and culture through preservation of architectural features (Affelt et al., 2015; Lang et al., 2017).

2.2 Heritage in Malaysia

Malaysian heritage is supervised and managed by *Jabatan Warisan Negar*a (National Heritage Department). It has legal power over heritage assets of Malaysia according to Act 645 National Heritage Act 2005. Before *Jabatan Warisan Negara* was established in 2007, national heritage was under the supervision of *Jabatan Muzium Negara* (National Museum Department). *Jabatan Warisan Negara* maintains a list of inventories of potential heritage building, and gazetted buildings designated as "Heritage Building". Heritage Buildings are divided into two types, National Heritage Building (*Warisan Negara*) and Heritage Building (*Warisan Kebangsaan*).

2.3 Heritage Conservation using BCA

Heritage Conservation has seen many improvements over the years since the establishment of Jabatan Warisan Negara in 2007. This is including the enforcement of listing and documentation of heritage buildings. Building Condition Assessment (BCA) is carried out by qualified professionals, to identify building dilapidation and damage. Both cosmetic and structural defects are rated thoroughly and documented for perusal of construction industries and especially in heritage conservation works.

According to Mohd Noor et. al. type of study in Built Environment and Asset Management is BCA (Building Condition Assessment) that identifies structural conditions of a building. These structural conditions are conducted to find key issues in the building to avoid unnecessary risk and priority of work in restoring a building. Mohd Noor et. Al (2019) further highlights the importance of old and historical buildings as physical evidence for future generation about ancient history and knowledge, and to further defined themselves within social, political and cultural context.

BCA in Malaysia adapts the JKR (Jabatan Kerja Raya) Garis Panduan dan Penilaian Keadaan Bangunan 21602-004-13. These rating systems will become the basis of the study to rate the building condition in detail. While BCA does not necessarily study the heritage value in detail, the standard of JKR 21602-004-13 will be this study foundation in forming its research methodology in terms of visual identification of building dilapidation.

Building Condition Survey relies on conventional tools and methods for data collection. This includes visual inspection from photography, measurements using rules, measuring tapes, micrometres. More sophisticated technologies include utilizing XRF, XRD machines to analyse salt formation on walls, thermal camera to detect leakages, but these machines are not explicitly recommended in BCA guideline documentation. BCA guidelines recommend a certified surveyor to perform walk-by inspection, and to determine the defects in person on-site. In this paper, however, explores the usage of LiDAR scanning techniques to augment BCA works for better accuracy in preserving cultural heritage.

2.4 Challenges in Carrying out BCA

BCA has inadequate for heritage building assessment, due to lack of benchmarking for heritage buildings (Mohd Noor et al., 2019). Structural dilapidation faced by historical building are vastly different compared to modern buildings, due to the material, workmanship, and aesthetic differences. This is further elaborated by both S. Mohd Noor et. Al and Dann, pointing out the industry of building surveying did not satisfy the concept of building conservation, due to its sole focus on repair structural dilapidation without considering preserving original built work (Dann & Worthing, 2005; Mohd Noor et al., 2019). Dann points out most condition survey reports focused too much into repair work, rather than regular maintenance work, survey work are less organized, and the format information collected does not enable effective storage of data (Dann & Worthing, 2005). While Mohd Noor points out BCA deficiencies in heritage valuations criteria in BCA, however this study refutes Mohd Noor's discussion on its findings for replacement work on dilapidated solely based on BCA scores. This is due to lack of elaboration on such items and building elements, may lead to the building lose its heritage value due to foreign and new elements are implemented onto the building.

Dann and Lang point out the importance to retain originality of materials of the heritage buildings' value, the historical preservation leads to understanding of their origins and roots of a society (Dann & Worthing, 2005; Lang et al., 2017). Lang explicitly stresses on the keyword "value" debating that it's not solely for economic value, but "meaning" for the heritage groups (Lang et al., 2017). Dann, however, points out the economical perspective on maintenance of heritage buildings, in which regular maintenance must be given priority in heritage building survey as it is much better economically to run scheduled maintenance on aging building materials.

2.5 LiDAR Scanning in BCA

LIDAR stands for Light Direction and Ranging. Utilizing the same concept of RADAR (Radio Detection and Ranging), LIDAR uses light pulses to track a position of an object in 3D space. LIDAR come in many forms, and different manufacturer, types and versions differ from each other in terms of specifications, accuracy, data acquisitions, etc. This paper discusses on using LiDAR scanning techniques for BCA.

By scattering light pulses on the whole surface of an object, those light pulses will then return to the LIDAR machine to be received, and its relative distance is calculated by its time-of-flight, material reflectivity, texture, all can be mapped into the stereographic 3D visualization in form of point cloud (Zohdi, 2019). For example, a wall of a building shape and form can be identified by scattering billions of light pulses, forming the wall in form of scattered dots with high accuracy. LIDAR can also be embedded with photography for coloured data. After the point cloud data has been taken, the camera will then take photographs of the surveyed area, then map the photograph's colours into the point cloud, creating photogrammetry for much richer data.

2.6 Types of LiDAR

Mainly there are two types of LIDAR, TLS (Terrestrial Laser System) and MLS (Mobile Laser System) system (Rodríguez-González et al., 2017). TLS is a LIDAR surveying system that focuses on high density PPM (Points per Metre) in order to capture accurate and high-resolution 3D model. TLS system is mounted on a tripod, and levelled, then rotates on its base as it sweeps 360 degrees around and scanning the objects in the area (Rodríguez-Gonzálvez et al., 2017). TLS is usually used in forestry work, where trees, rocks and topography of the forest can be recorded in 3D data. Based on various literatures, TLS are also used being adapted into various industries, such as engineering, architecture, urban planning, mechanical engineering for pipelines, and others due to its accuracy and 3D data presentation that offers wider perspective in data analysis (Bassier et al., 2018; Rodríguez-Gonzálvez et al., 2017; Rubinowicz & Czyńska, 2015).

MLS is another major subset of LIDAR surveying system, in which the LIDAR scanning unit is constantly moving and scanning, and does not require a static mounting point, such as a tripod. MLS is mounted on a moving equipment, such as a rail system, automobiles, or handheld mounted. MLS provides the advantage of faster scanning work compared to TLS, but with lower point density and shorter range (Aljumaily et al., 2017; Rodríguez-Gonzálvez et al., 2017). They utilize SLAM (Simultaneous Localization and Mapping) technique to record LiDAR data via onboard IMU (Inertial Measurement Unit) and GNSS (Global Navigation Satellite System) to track its movement as it continuously scans objects into point cloud data.

2.7 Point Cloud Data

Point cloud data is a data visualization method comprised of points in space. Multiple dots, in a 3D space with 3 axes coordinate system is plotted from the LIDAR scanning system. These dots will form a 3D stereoscopic image of the object. These dots can also be embedded with colour, which retrieve the colour data from an external camera mount to create a photogrammetric 3D image for better visualization and depth of data. Based on Hou, Aljumaily and Hoensheld writings, through specific algorithms, the coordinate of each dots scanned by the LIDAR system can be analysed to determine accuracy and detectability of building dilapidation, in which the authors focuses on the concrete spall damage (Aljumaily et al., 2017; Hoensheid, 2012; Hou et al., 2017).

This study tries to explore the idea, but with novel intention in heritage building defects instead with different building materials, such as timber. Point cloud data can be stored in various formats, however, the most used format used for easier integration with BIM and CAD software for cultural heritage conservation are .las and .e57. One of the key problems identified in using point cloud data for BCA is interoperability of point cloud data to work with various people and on-the-cloud solution, such as CAD, Autodesk ReCap, BIM and Cloud compared to name a few.

2.8 LiDAR Application Related to Heritage Conservation

LIDAR is being used in BIM and urban planning in recent years, by exploiting the perspective of stereoscopic 3D data for high accuracy classification of building elements (Pirasteh et al., 2019; Usmani et al., 2019). According to Pirasteh, LIDAR is suitable to detect changes in buildings and determining borders of a building (Pirasteh et al., 2019). Moreover, Usmani further recommends that learning to use modern tools like LIDAR is vital in performing faster and modern analysis. Usmani further elaborates the significance of combining BIM and AR, to combine both high-tech methods in providing better documentation and data for the facilities manager (Usmani et al., 2019).

In heritage conservation and heritage tourism side of study, LIDAR is adapted as AR solution in visualizing and documenting heritage sites. Shih utilizes 3D point-cloud data from LIDAR scanner and developed a smartphone-based AR based Tourism System. By combining stereoscopic point-cloud data, Shih points out the color accuracy and how the 3D imaging helps with the full-scale experience of the building, with the structural and visual detail can help with remote cultural exploration and learning on-site (Shih et al., 2019). E. Shotton exploits similarly by using LIDAR in capturing heritage sites, due to its high accuracy and embed geolocation in 3D space (Shotton, 2018). E. Shotton further elaborates that a heritage site with very steep elevation changes would be hard for conventional surveying methods and points out LIDAR's accuracy in stonework fine details (Shotton, 2018).

Most authors agreed that LIDAR is accurate and brings out valuable data in form of stereoscopic point-cloud visualizations, however, it is important to note most of these findings are produced from terrestrial LIDAR with very high point density. Many authors agreed on terrestrial LIDAR not only limited to forestry use and topographical use, but also built environment use and specifically heritage sites (Aljumaily et al., 2017; Bassier et al., 2018; Rubinowicz & Czyńska, 2015). However, from the literature review conducted there are studies of dilapidation using LIDAR, specifically focusing on spall damage and structural in nature (Dawood et al., 2017; Hoensheid, 2012; Hou et al., 2017).

3. Case Study and Equipment Overview

This section explains in detail for the case studies selected for this research, and methodology of carrying out the data collection process. This is a multiple case, multiple study type where each point cloud data will be analysed and

3.1 Case Studies

This paper selects 3 case studies to study LiDAR adaptation in BCA for cultural heritage buildings; all of them are in Malaysia. One of the criteria for selecting a case study is choosing a building with similar typology and architectural style. In this case, Victorian architectural style built from the British colonial era is chosen for this study. In addition, every building are designated as national heritage of Malaysia, gazetted by National Heritage Department of Malaysia.

3.1.1 Ipoh Town Hall, Perak

The Ipoh Town Hall is one of three prominent colonial-era buildings designed by the esteemed architect Arthur Benison Hubback in 1914 (Ipoh Municipal Council, 1962). The other two structures—the Ipoh High Court and the Ipoh Railway Station—

are situated nearby and exhibit similar architectural features. Originally conceived as a municipal administrative centre to accommodate Ipoh's rapid urban growth in Perak, the Town Hall played a pivotal civic role from its inception.

Figure 1. Ipoh Town Hall LiDAR scan.

This building initially served as the Telegraph Office and continued in this administrative capacity until 1948. During the Japanese occupation of Malaya, it was repurposed as the headquarters for the police, a function it retained until 1962. Subsequently, the structure was converted into a public hall following the relocation of the police department to a new facility.

Renovation and upgrading works were undertaken around 1965, encompassing both the Town Hall and the adjacent Post Office. Presently, the Town Hall continues to operate as a public hall, whereas the Post Office section functioned as the Perak State Tourism Information Centre until its closure in 1995. In recognition of its historical and architectural significance, the building was officially designated as a heritage site in 2015, under Gazette Number: Warisan: P.U (B) 499/28 Dis 2015.

3.1.2 Galeri Kraftangan Seremban, Negeri Sembilan

Galeri Kraftangan Seremban (Seremban Art and Crafts Gallery) is a heritage building located in Seremban, Negeri Sembilan. It features common colonial era building architectural ornamentation with Victorian architecture layout, it was built in 1912 as the official residence of the British Resident, Captain Murray.

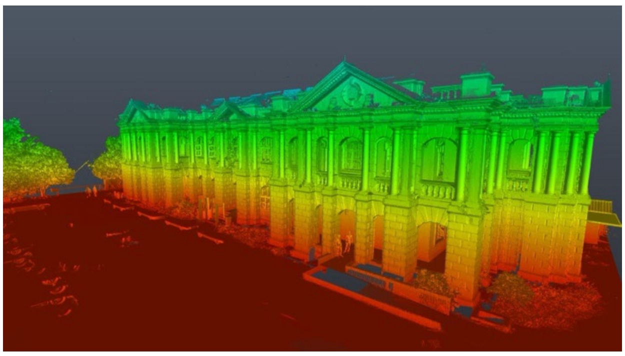

Figure 2. Galeri Kraftangan Negeri Sembilan LiDAR scan.

It was then converted for use by the Local Authority of Seremban municipal office and surveyor's department. The building was officially recognized as a heritage site under Gazette Number: Warisan P.U. (B) 357/14 Apr 1983

3.1.3 Bangunan Dato' Jaafar, Johor Bahru

Figure 3. Bangunan Dato Jaafar LiDAR scan.

Bangunan Dato Jaafar was built as a manor for Johore Chief Minister, Dato Jaafar. He was a close confidant of then Sultan Abu Bakar of Johore. The design was inspired by Harwick Hall and Riber Castle Matlock which Dato Jaafar visited during his tour to Royal Palaces in England with the Sultan. Dato' Ja'afar also named his house 'House of Smiles'. This building currently serves as a museum.

3.2 Methodology

This section describes in detail on equipment, methodology, control and procedure.

3.2.1 Equipment

Figure 4. VZ-400 TLS unit scanning the roof of Dato' Jaafar Building, Johor Bahru.

LIDAR scan is conducted using TLS unit VZ-400 from Riegl for the whole building in order to produce a dilapidation survey and measured drawing for the heritage restoration project. A tripod is used for mounting the TLS unit, and a triangle ground spreader for attaching the tripod on very slick surfaces such as tiled flooring, marble flooring and smooth concrete finishes.

3.2.2 LiDAR surveying setup

The TLS system is set on Panorama40 setting with 360 degrees for all scan stations. GPS setting is set at high accuracy to ensure accurate registration process of each scan stations, to calculate the compass direction and to detect yaw and roll of the TLS unit. The accuracy of GPS is set at 10m, which is within tolerance for registration purposes as this research are not aiming to geolocate the LIDAR scan results. Distance settings are set at High Speed instead of Long Range, because of the distance between the TLS and the building surveyed is already short enough for taking high density point cloud. High speed setting also allows faster data acquisition and smaller point cloud data size for processing. All scan station utilizes the same setting across all case study as control.

3.2.3 LiDAR surveying work

To operate the equipment, a team of 3-person crew is utilized to collect the equipment. All LiDAR scanners are different in terms of capabilities and operation. The VZ-400 TLS unit can scan up to 700m in high-speed mode, which is mainly used in the data collection process.

The 3-person crew carries the equipment and the tripod to ensure faster data collection due to their heavy weight. This study again, clarifies different TLS unit may have different weight and operation, the VZ-400 with its DSLR and battery attachment weighs 30kg and the tripod weighs 5kg. PPE (Personal Protective Equipment) is equipped throughout the data collection to ensure the safety of scanning crew, such as highly reflective vests and hard hat due to dilapidation in some parts of the cultural heritage buildings.

3.2.4 Point Cloud Data processing

The LiDAR scan data is then processed through the proprietary RiscanPro application to register each scan position, and to apply color data collected from the DSLR. Since the scan is conducted without any control points or reflectors, the point cloud is registered using automated registration method. Manual intervention is applied whenever needed. The data is then cleaned up by removing noise such as human figures and vehicles using manual selection. The data is then further refined using MSA (Multi Station Adjustments). Point cloud data is then verified regularly in every step to ensure its accuracy and avoid data corruption. The point cloud data is then exported into E57 point cloud file, which is then further processed in Autodesk ReCap for analysis.

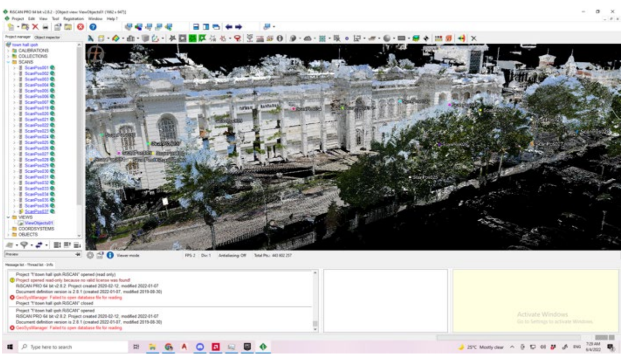

Figure 5. Registering all scan positions into a single point cloud data. Shown in figure is Ipoh Town Hall and Post Office.

From Autodesk ReCap, further cleanup process is done on the .e57 point cloud data, and cropped to ensure a more efficient file for analysis. This is due to the size of point cloud data, which is very large and taxing on the computer system RAM (Random Access Memory) and processor. For processing works, this study utilizes an i9-14900k CPU, RTX4070 SUPER graphics card, and 64 gigabyte RAM to run all the software mentioned above. To give a basic perspective, a 64 gigabyte of RAM can process point cloud data smaller than 50 gigabytes. In the next chapter, the file size of each pointcloud will be described in detail, in which Bangunan Dato’ Jaafar being the largest building in terms of volume and total area among the 3 case studies is 30 gigabytes in size.

3.2.5 Measured drawing and dilapidation survey

A measured drawing is produced from the processed Point Cloud Data. The Point Cloud Data is then further analysed to identify dilapidations in better accuracy using Cloud Compare and Rstudio. The results of these dilapidation identification and its findings is shared in the next chapter of this paper.

4. Findings and Discussion

4.1 Case Studies Data Collection

In this section, the study will describe all the case studies data collection process in terms of how many resources were needed to perform a LiDAR survey. Table 1 shows the data for each case study. All data collection are done with a team of 3-person crew, and total time shows the scanning work time exclusive of breaks and rest hour. Datapoints is the total amount of points after registration into a single pointcloud. File size is rounded to the nearest gigabyte. And lastly is the GFA (Gross Floor Area), excluding balconies, terrace and landscape.

Table 1: Comparison of all case study data collection

Case Study	Scanning Time (hours)	Datapoints (points)	File Size (GB)	GFA (sqm)
Ipoh Town Hall	16 hours	1.46 billion	35 GB	2826.4
Galeri Kraftangan Seremban	12 hours	1.07 billion	22 GB	1595.1
Bangunan Dato’ Jaafar	18 hours	1.21 billion	32 GB	2068.2

4.2 Measured Drawing

By using point cloud data acquired from LiDAR survey, a measured drawing can be produced. The .rcp (recap) file is then transferred into AutoCAD for measured drawing production. The dimension of the buildings is oriented in accurate orientation, allowing building surveyors to quickly establish north point of the building. Figure 6 shows Bangunan Dato’ Jaafar’s point cloud data for the ground floor.

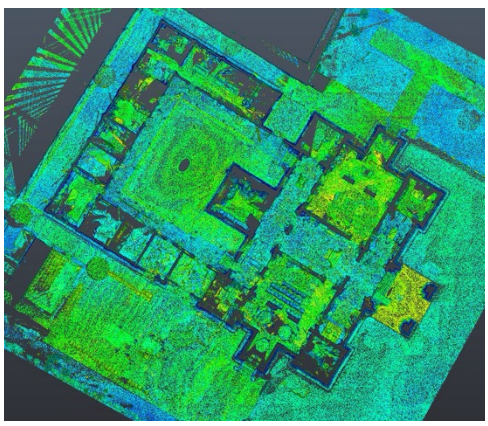

Figure 6. Plan view of LiDAR scan for Bangunan Dato’ Jaafar.

https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-1317-2025

4.2.1 Intensity visual mode

In using point cloud data, an intensity visual mode is used to better roughly classify each building elements to differentiate surfaces and materials when producing measured drawings.

Figure 7. Differentiation of various surfaces using intensity view mode.

From this simple "classification" of different reflectance of materials, a floor plan can be drafted with clarity. As the point cloud data is transferred into AutoCAD, all the measurements are accurate without any modification; only limited by the TLS unit accuracy by the manufacturer. The VZ-400 offers 6mm accuracy which is more than enough for BCA inspection and documentation.

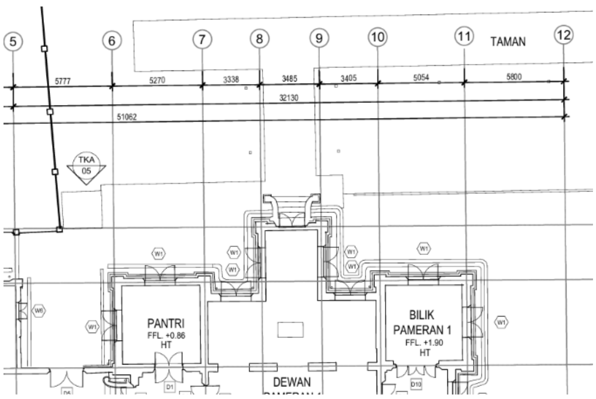

Figure 8. Part of floor plan drafted from LiDAR scan.

4.2.2 RGB visual mode

In addition to intensity, the RGB data in the point cloud also allows the drafting of building façade much quicker by visualizing the geometry of intricate ornamentations. This further assist the visual inspection included in BCA of cultural heritage buildings.

Figure 9. Accurate of point cloud data with RGB visual of Bangunan Dato' Jaafar.

Figure 10. Measured drawing of Bangunan Dato' Jaafar front façade.

This flexible nature of point cloud data can be further utilized for quick construction drawing in heritage conservation projects. For example, in Ipoh Town Hall, a roof of a building can be proposed quickly by superimposing a new roof truss on top of the point cloud data. This further helps in visual communication between construction team members such as engineers and architects to quickly discuss a solution with an accurate point cloud data.

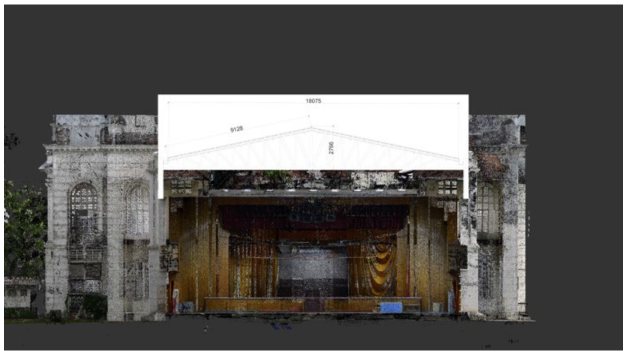

Figure 11. Ipoh Town Hall section view with a superimposed new roofing solution.

4.2.3 Normal and Elevation visual mode

Furthermore, in normal visual mode of the point cloud, the scan angle of the LiDAR scan can further visualize building elements such as windows and doors. These are typically categorized and specifically drawn into schedules of door and windows for conservation purposes. In this point cloud data from Galeri Kraftangan Seremban, a dilapidated window can be extracted. While elevation visual mode assists in different height of ornamentation as shown in Figure 12 for extracting the section profile of the cornice.

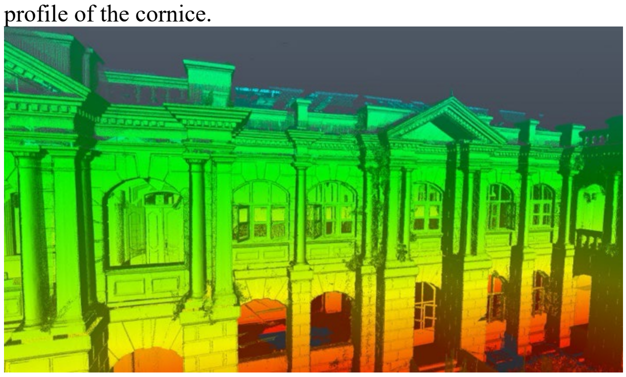

Figure 12. Elevation mode view for row of windows at Galeri Kraftangan Seremban front façade.

Figure 13. Normal view for row of windows at Galeri Kraftangan Seremban front façade.

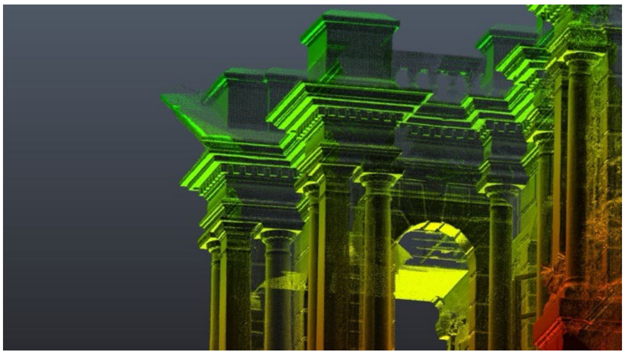

Figure 14. Galeri Kraftangan Seremban cornice design.

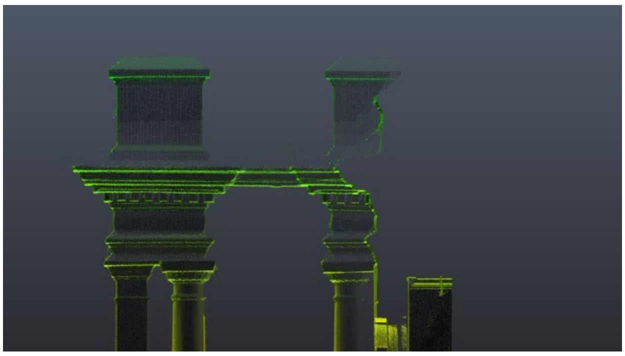

Figure 15. Extracting the sectional profile of Galeri Kraftangan Seremban cornice design.

4.3 Condition Survey

Along with measured drawing, condition survey is also included in BCA (Building Condition Assessment). Condition survey refers to building defects that occur on the building with varying levels of damage which are systematically recorded and tabulated to provide an insight on the building’s current health. This section of the study discusses the utilization of point cloud data to improve insight and accuracy of the defects recorded in the cultural heritage buildings.

4.3.1 Sloping floor

Sloping floor is a building defect where a floor is sloping towards a certain direction, creating unevenness of the surface. This usually indicates a defect in the building structure, floor slab or floor finish and typically present in older, cultural heritage buildings due to age and construction technology available at the time.

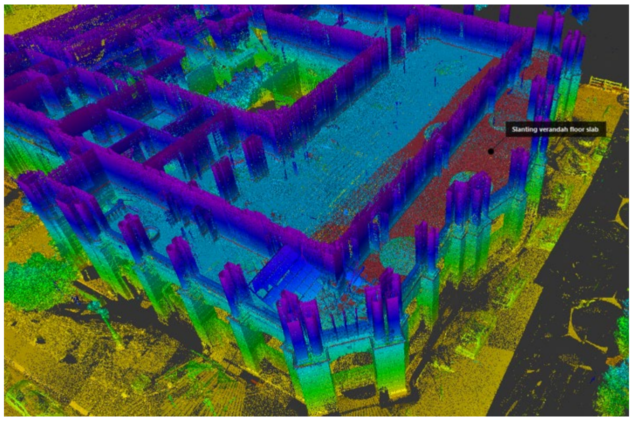

Figure 16. Sloping floor of verandah in Ipoh Town Hall and Post Office in point cloud data.

Figure 17. Sloping floor of verandah in Ipoh Town Hall and Post Office on site.

In this example of Ipoh Town Hall, the veranda section of the building appears to be listing towards a single column. By using the point cloud data and programming, the defect can be visualized clearly. Where Z value is the height of each points from the ground. Then a contour is then visualized to further exaggerate the direction of the sloping floor to identify the building defect.

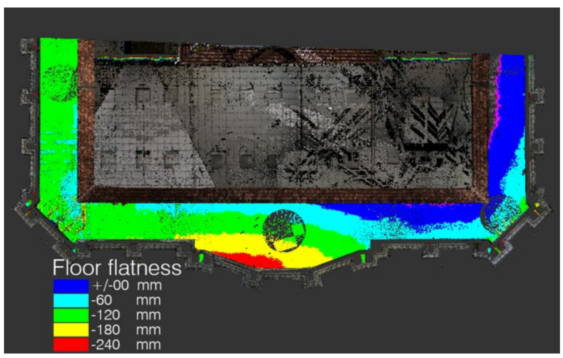

Figure 18: Sloping floor direction of the Ipoh Town Hall Veranda

With these data output, this study again stresses the importance of swiftness in decision making with various team members through BCA by providing a clear visual on various defect with the help of point cloud data as shown in figure 19. By providing clarity to a problem, concise communication among professionals can be detrimental in a heritage conservation work.

https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-1317-2025 | © Author(s) 2025. CC BY 4.0 License.

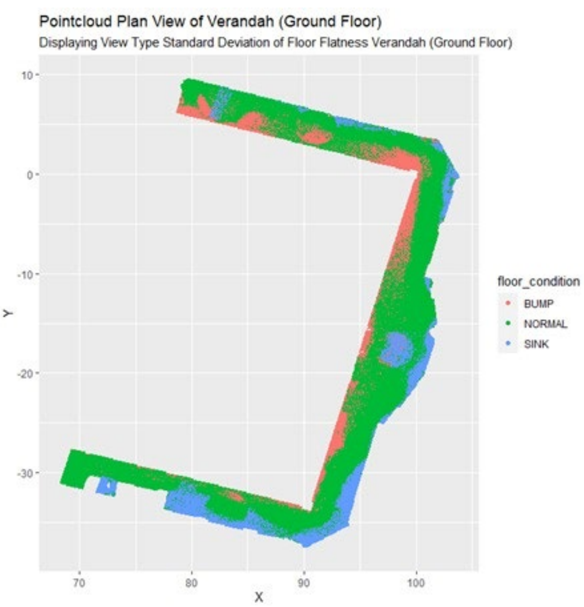

Figure 19. Classifying point cloud data to identify bumping, normal and sinking surfaces of affected sloping floor.

4.3.2 Spall and cracking

Spalling, minor and major cracks are common defects that occur in both old and new buildings for concrete based flooring and walls. In cultural heritage buildings however, old construction methods and materials may cause the defects to appear more often due to wear and incorrect building conservation practices. In this example of Dato’ Jaafar Building, spalling and cracks occur regularly in courtyard section of the building indicated by the red dots.

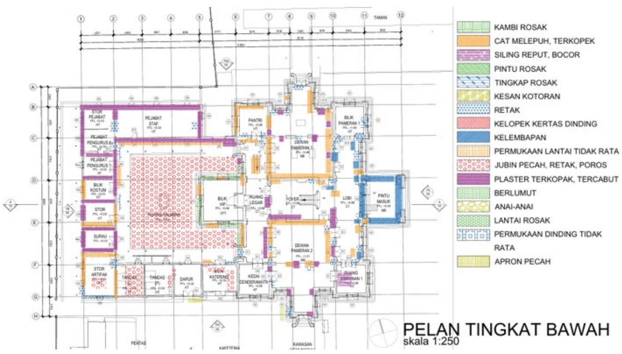

Figure 20. Building defect mapping for ground floor of Dato’ Jaafar Building. The red dots indicate spalling, crack and porous stone tiles that occurred in the outdoor courtyard section.

By using the previous sloping floor defect analysis, it can be concluded the surface of the courtyard is sufering from major groundwater issue due to bad drainage.

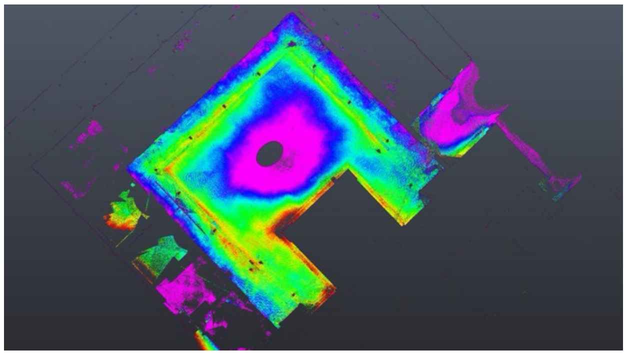

Figure 21. Heatmap shows the occurences of cracking, spalling and porousity on its surface.

4.3.3 Harmful growth and surface defects

Harmful growth and surface defects are common defect in cultural heritage buildings. This is due to their exposure in the elements without any preventative care for the buildings. By using point cloud, the surface area can be identified easily by using intensity analysis. In this example of Galeri Kraftangan Seremban, harmful growth can be identified by filtering the affected intensity through the software Cloud Compare.

Figure 22. RGB data for on the façade of Galeri Kraftangan Seremban.

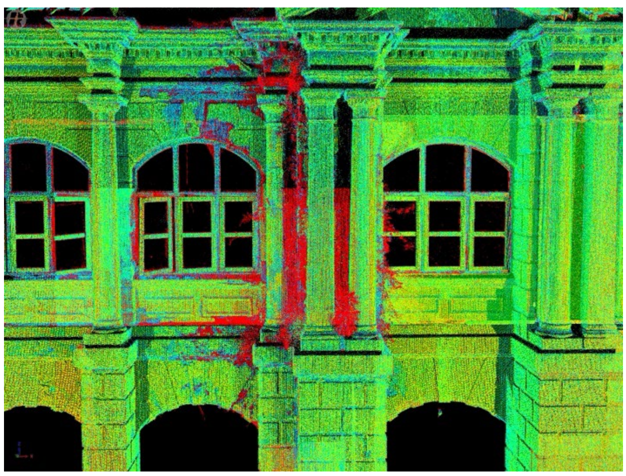

Figure 23. Through intensity analysis, a harmful growth such as plants can be classified visually in highlighted in red as shown.

https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-1317-2025 | © Author(s) 2025. CC BY 4.0 License.

Not only plants, but mould and moss can also be classified for surface growth as shown in Figure 23 that may indicate falling or rising dampness which is a common occurrence in cultural heritage buildings.

4.4 Synthesis and Discussion

From all the findings, and data collected from the point cloud data, this study concluded there are major output that can be extracted from point cloud data which are practical in the heritage conservation work. These data have tremendously helped in producing BCA for each of the case studies which are part of the CMP (Conservation Management Plan) in order to preserve and maintain cultural heritage sites.

In addition, with the resource of a team of 3-person, a lot of data has been extracted for use regardless of size of the building. However, utilizing LiDAR requires higher skilled workers to operate the machine and costly in terms of technology acquisition that may be set back. Regardless, the benefits outweigh the shortcoming as shown in previous section where analysis can be done swiftly and be shared across a heritage conservation team to provide better communication and visual clarity of the current condition of the building.

5. Conclusion

LiDAR is a technology that is rapidly developing ever since its inception. Due to its high cost to acquire it, the technology has been turned away from being used in industries. However, this is slowly changing as the technology matures and more affordable equipment being offered in the market. From this study, it is a clear conclusion that LiDAR technology is the way forward for cultural heritage conservation. Due to its multi-faceted data from point cloud that can be used to perform multiple analysis, point cloud data is the perfect medium in recording and archiving existing cultural heritage and futureproofing as the world heads towards AI-based technologies and big data processing.

This study would recommend the cultural heritage conservation industry, academicians, professionals and embrace technological shift as part of the evolution in surveying techniques to ensure reliability, accuracy and sustainability especially regarding remote sensing technology like LiDAR. This study aims to open perspective towards using LiDAR and its benefits that far outweighs the conventional surveying methods which the paper have discussed at length in conducting BCA for a cultural heritage building.

This study recommends further studies into synthesising various point cloud data to train artificial intelligence to learn various cultural heritage to automatically classify buildings into different data sets. Furthermore, as LiDAR data becomes more integrated with the industry, education and daily life, LiDAR technology should be implemented in various levels of education just as photography

Acknowledgement

The authors acknowledge the Ministry of Higher Education (MoHE) and Universiti Teknologi MARA (UiTM) for supporting this research through the Fundamental Research Grant Scheme (FRGS/1/2021/WAB09/UITM/02/2).

References

Affelt, W. J., Almonaitytė-Navickienė, V., van Bers, M., Čepaitienė, R., Čepėnaitė, A., Daubarytė, K., & Del Bianco, P. (2015). How to assess built heritage? Assumptions, methodologies, examples of heritage assessment systems.

Aljumaily, H., Laefer, D. F., & Cuadra, D. (2017). Urban point cloud mining based on density clustering and MapReduce. Journal of Computing in Civil Engineering, 31(5), 1–11. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000674

Bassier, M., Vincke, S., de la Hernandez, R., & Vergauwen, M. (2018). An overview of innovative heritage deliverables based on remote sensing techniques. Remote Sensing, 10(10). https://doi.org/10.3390/rs10101607

Dann, N., & Worthing, D. (2005). Heritage organisations and condition surveys. Structural Survey, 23(2), 91–100. https://doi.org/10.1108/02630800510593666

Dawood, T., Zhu, Z., & Zayed, T. (2017). Machine vision-based model for spalling detection and quantification in subway networks. Automation in Construction, 81, 149–160. https://doi.org/10.1016/j.autcon.2017.06.008

Edström, M. (2015). Understanding architectural heritage values – Three case studies, lessons to learn. In B. Szmygin (Ed.), How to assess built heritage? Assumptions, methodologies, examples of heritage assessment systems (pp. 139–148). Lublin: International Scientific Committee for Theory and Philosophy of Conservation and Restoration ICOMOS.

Hoensheid, R. C. (2012). Evaluation of surface defect detection in reinforced concrete bridge decks using terrestrial LiDAR (Master's thesis)], p. 155.

Hou, T. C., Liu, J. W., & Liu, Y. W. (2017). Algorithmic clustering of LiDAR point cloud data for textural damage identifications of structural elements. Measurement, 108, 77–90. https://doi.org/10.1016/j.measurement.2017.05.032

ICOMOS. (2003). ICOMOS Charter: Principles for the analysis, conservation and structural restoration of architectural heritage. ICOMOS.

Jamaludin, B. (2020). Once loved Pura Tanjung Sabtu now abandoned and decaying. BERNAMA. http://www.bernama.com/en/news.php?id=1806817

Lang, L., Liu, J., & Wang, S. (2017). Understanding and assessing modern architectural heritage: Value-oriented contextual interpretation based on Dalian (China) case study, 2, 1–6.

Mohd Noor, S., Shing Mei, C., Ibrahim, I. S., Sarbini, N. N., Osman, M. H., & Khiyon, N. A. (2019). Heritage building condition assessment: A case study from Johor Bahru, Malaysia. IOP Conference Series: Earth and Environmental Science, 220(1). https://doi.org/10.1088/1755-1315/220/1/012024

Pirasteh, S., Rashidi, P., Rastiveis, H., Huang, S., Zhu, Q., Liu, G., Li, Y., Li, J., & Seydipour, E. (2019). Developing an algorithm for buildings extraction and determining changes from airborne LiDAR, and comparing with R-CNN method from drone images. Remote Sensing, 11(11). https://doi.org/10.3390/rs11111272

Rodríguez-Gonzálvez, P., Fernández-Palacios, B. J., Muñoz-Nieto, Á. L., Arias-Sánchez, P., & Gonzalez-Aguilera, D. (2017). Mobile LiDAR system: New possibilities for the documentation and dissemination of large cultural heritage sites. Remote Sensing, 9(3), 1–17. https://doi.org/10.3390/rs9030189

Rubinowicz, P., & Czyńska, K. (2015). Study of city landscape heritage using LiDAR data and 3D-city models. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 40(7W3), 1395–1402. https://doi.org/10.5194/isprsarchives-XL-7-W3-1395-2015

Said, S. Y., Shahrin, M. S., Johari, M. N., Abdullah, A. S., Harun, S. N., Latif, Z. A., Salleh, N. H., & Wongso, J. (2023). Effective building surveying using laser scanning for heritage building documentation. International Journal of Sustainable Construction Engineering and Technology.

Shahrin, M. S., Said, S. Y., Latif, Z. A., Harun, S. N., & Sulaiman, M. S. (2023). Measuring sloping floor of heritage building using point cloud data from LiDAR survey. IOP Conference Series: Earth and Environmental Science, 1240(1), 012001. https://doi.org/10.1088/1755-1315/1240/1/012001

Shih, N. J., Diao, P. H., & Chen, Y. (2019). ARTS, an AR tourism system, for the integration of 3D scanning and smartphone AR in cultural heritage tourism and pedagogy. Sensors (Switzerland), 19(17). https://doi.org/10.3390/s19173725

Shotton, E. A. (2018). Living in the clouds: Conceptual reconstructions of harbour structures. Journal of Cultural Heritage Management and Sustainable Development, 8(4), 405–419. https://doi.org/10.1108/JCHMSD-08-2017-0052

Usmani, A. R. A., Elshafey, A., Gheisari, M., Chai, C., Aminudin, E. B., & Tan, C. S. (2019). A scan to as-built building information modeling workflow: A case study in Malaysia. Journal of Engineering, Design and Technology. https://doi.org/10.1108/JEDT-07-2019-0182

Waykar, Y. (2022). A comparative analysis of photogrammetry and LiDAR technology for heritage site conservation. International Journal of Scientific Research in Engineering and Management, 10.55041/IJSREM15684.

Zhao, L., Wong, W. B., & Hanafi, Z. B. (2019). The evolution of George Town's urban morphology in the Straits of Malacca, late 18th century–early 21st century. Frontiers of Architectural Research. https://doi.org/10.1016/j.foar.2019.09.001

Zohdi, T. I. (2019). Rapid simulation-based uncertainty quantification of flash-type time-of-flight and LiDAR-based body-scanning processes. Computer Methods in Applied Mechanics and Engineering. https://doi.org/10.1016/j.cma.2019.03.056