IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Effective Building Surveying Using Laser Scanning for Heritage Building Documentation

Shahrul Yani Said[1*], Muhammad Shahir Shahrin[2], Muhammad Naqiuddin Johari[1], Ahmad Shahrim Abdullah[3], Siti Norlizaiha Harun[1], Zulkiflee Abd Latif[3], Nurul Hamiruddin Salleh[4], Jonny Wongso[5]

[1]Sustainable Heritage Environment Research Group, College of Built Environment, Universiti Teknologi MARA, Shah Alam, Selangor, 40450, MALAYSIA

[2]Post Graduate Studies, College of Built Environment, Universiti Teknologi MARA, Shah Alam, Selangor, 40450, MALAYSIA

[3]College of Built Environment, Universiti Teknologi MARA, Shah Alam, Selangor, 40450, MALAYSIA

[4]Department of Architecture, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Jalan Gombak, 53100, Kuala Lumpur, MALAYSIA

[5]Faculty of Civil Engineering and Planning, Universitas Bung Hatta, Ulak Karang, Padang, 25133, INDONESIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.05.008
Received 01 May 2023; Accepted 06 August 2023; Available online 31 October 2023

Abstract: In conservation works, a thorough pathology survey is required to identify building defects. Early detection of defects can prevent the increase in cost during conservation works. Conventionally, common defects that occur in heritage buildings can be observed and recorded during a walk-by inspection; however, the process is often time consuming. Furthermore, all recorded defects require a precise but conventional data collection to identify, test, and observe the level of defects. This study aims to compare the effectiveness of manual walk-in building condition assessment with the point cloud data analysis that utilises the Light Detection and Ranging (LiDAR) technology. A building condition assessment was conducted involving the Ipoh Town Hall and Post Office, Galeri Kraftangan Seremban, and Bangunan Dato' Jaafar in Johor Bahru using both conventional walk-in survey and the laser scanning process. This study concludes that combining digital tools with the traditional methods promotes a more accurate and effective assessment for heritage building assessment, which is crucial for ensuring the sustainability of historic structures. Additionally, 3D point cloud data allows the exploration of building deterioration from a wider perspective.

Keywords: LiDAR survey, building condition, TLS, point cloud analysis

**Corresponding author: shahrulyani@uitm.edu.my*

1. Introduction

Heritage buildings often undergo a variety of standard building condition surveys. The main goal of such assessment is to create a report regarding a building's general status, including its dilapidation, damages, and features. It is the initial step before any proposal for conservation or maintenance work can be put forward. To achieve such purpose, building surveyors typically conduct the Building Condition Assessment (BCA), which requires trained individuals to undertake a walk-by inspection of a building. Every deterioration of the structure will be assigned with a physical tag and documented with images and drawings. BCA offers thorough data gathering and documentation, in which each instance of deterioration and damage is categorised and rated. This not only provides insights on the condition of heritage buildings but also stands as a decision-making matrix for stakeholders to prioritise crucial conservation works by determining the dilapidation of heritage buildings.

In Malaysia, the *Garis Panduan dan Penilaian Keadaan Bangunan 21602-004-13* released by *Jabatan Kerja Raya* (JKR) serves as the official BCA guideline that is frequently utilised for local building condition surveys. The BCA data gathering involves dimensional measurements and photography, including lengths, thermal imaging, and visual inspection with pictorial evidence. However, the implementation of BCA requires a large number of staff and extensive working hours for walk-by inspections, particularly as site visits are the only way to measure and assess the degree of dilapidation. These limitations may restrict the walk-by inspections to capture relevant data and information.

Another issue of BCA is that the data collected can be prone to human error and bias. Assessing building dilapidation requires a thorough inspection from multiple angles of view. Therefore, capturing dilapidation in a 3D model has been propounded as a hypothetical solution to eliminate the need for walk-by inspections. As argued by Khalil et al. (2020), advanced 3D imaging technologies stand as an advantage in heritage building documentation as it allows the capturing of complex buildings and structures. This is further supported by state-of-the-art computer systems that provide the capacity to federate and analyse large datasets.

The technological advancement subsequently promotes the potential of Light Detection and Ranging (LiDAR) for assessing building conditions. Aside from its technological advantages, LiDAR has recently become more accessible and cost-effective for professional use. To date, the utilisation of LiDAR primarily revolves on land surveys, Geographical Information System (GIS), forestry, engineering, and architectural archiving. Furthermore, empirical papers on the technology have been focusing on the engineering aspects of condition analysis (Dawood et al., 2017; Hoensheid, 2012; Hou et al., 2017) while other fields of research remain unexplored.

As an effort to address the literary gap, this study aims to explore the potential of LiDAR for building dilapidation assessment and analysing the intricate ornamentations of heritage buildings. Past literature posits that LiDAR data can provide high accuracy in measuring the volume, area, and length of dilapidation. When combined with BCA analysis, such data will enable a thorough and comprehensive analysis of various building dilapidations (e.g., concrete spalls, rust, and cracks) from various angles. Following this argument, the present study proposed the idea of utilising LiDAR as a comprehensive data collection tool for heritage building assessment combined with the existing BCA framework, subsequently eliminating the need for walk-by inspections. The proposed method’s efficacy was then tested through case studies involving three heritage buildings in Malaysia, namely Ipoh Town Hall and Post Office, Galeri Kraftangan Seremban, and Bangunan Dato’ Onn in Johor Bahru.

The point cloud data from the LiDAR survey allows for a simple analysis of the physical architectural and structural components of the heritage buildings. Studies on LiDAR and heritage do exist; however, many have focused on preservation, presentation, documentation, and augmented reality (AR). This study investigated the concept using Built Heritage Assessment, which is a novel methodology to evaluate historic buildings thoroughly. The findings hope to contribute to the field of cultural and built heritage by serving as a fundamental basis to create a framework for heritage building assessment. Conversely, stakeholders including local governments, planners, architects, history and heritage organisations, students, surveyors, and GIS will be benefited from this research. Historically-rich districts can also utilise heritage building assessment via 3D LiDAR data to identify the key areas that house valuable heritages. This will not only assist in preservation efforts but also enhance the districts’ tourism image, subsequently diversifying the local economic income.

2. Overview of Heritage Buildings Conservation Documentation Practice

The science of heritage building conservation comprises the diversified aspects of surveying, engineering, arts, humanities, culture, and history. Heritage is characterised as having both material (e.g., constructed environment, archaeological sites, submerged sites, and natural environment) and intangible components (e.g., dances, artistic creations, cuisine, martial arts, and languages). An urban environment's built heritage stands as a crucial component that adds charm and attracts tourists. The aesthetics of the built heritage must be properly preserved and protected to establish a strong sense of community and identity among the locals.

The naming of Penang and Melaka as World Heritage Sites by UNESCO in 2006 highlighted the cultural and economic significance of Malaysia's legacy. Conversely, *Jabatan Warisan Negara* (JWN) was established by the federal government as a dedicated agency to promote and oversee conservation initiatives and research. This includes creating conservation manuals and heritage management plans, hiring conservators, and inventorying tangible and intangible cultural materials.

Prior to the establishment of JWN, *Jabatan Muzium Negara* (JMM) was the sole government agency in charge of conservation management in Malaysia. Subsequently, the implementation of the National Heritage Act (Act 645) has set a new pace for protecting the country's cultural treasures. This is further advocated by the appointment of the Heritage Commission, which has led to the introduction of numerous significant operational and monitoring conservation practices. Nevertheless, these practices necessitate thorough documentation of heritage assets. Such responsibility is placed on JWN where documentation is essential to establish a conservation management plan for buildings that have been gazetted by the agency. Ultimately, this ensures that the heritage buildings will never be endangered by the conservation works done.

2.1 Current Practice in Heritage Building Recording

In Malaysia, the current practice for submitting conservation proposals for Planning Permission to JWN requires a detailed set of Measured Drawing and Dilapidation Reports. This recording stage is known as Heritage Architectural Building Surveying (HABS 1), which consists of three (3) phases: pre-conservation, during conservation, and after conservation records and reports. To prepare such documents, a heritage building survey is conducted by heritage experts, registered conservators, and building surveyors to determine the current condition of the building as well as its history and design. As mentioned earlier, BCA is a pathology survey used for more technical engineering like structural and mechanical issues, including the interior of a building for heritage building restoration.

BCA is often conducted using the JKR guidelines that utilise a matrix to classify building dilapidation for better decision-making. Classifying dilapidation according to its priority of work will enable construction and repair works to be done economically, safely, and systematically. The data is collected through walk-by inspection using the Building Rating System (BARIS), in which every dilapidation is measured, tagged with photographs, and undergoes material analysis.

As for heritage building documentation, a report consisting of statements of significance and a historic background survey is often prepared by a conservator or/and historian. This part of the study focuses more on intangible aspects, although it still includes building use and architecture and presents data describing the building. This research, however, takes both types of study into account but only focuses on the built heritage aspect.

Heritage building assessment in heritage urban areas mainly revolves on aesthetic damage of the architectural exterior as well as engineering and structural defects. It uses a more integrated way of collecting data. This is because walk-by inspection by multiple personnel may lead to human error and bias, hence standing as one of the main issues in renovation works and heritage building restoration (Dann & Worthing, 2005; Mohd Noor et al., 2019). Subsequently, heritage building assessment collects data regarding the architectural style, building use, building defect, ornamentations, building elements, aesthetic damage, building history, and building cultural impact. This is followed by the development of an appropriate methodology to systematically collect, categorise, and process the building data.

2.2 Challenges of BCA for Heritage Buildings

BCA is considered inadequate for heritage building assessment due to a lack of benchmarking for heritage buildings (Mohd Noor et al., 2019). Structural dilapidation faced by historical buildings vastly differs from modern buildings due to the material, workmanship, and aesthetic differences. However, the building surveying industry did not satisfy the concept of building conservation due to its sole focus on repairing structural dilapidation without considering preserving the original built work (Dann & Worthing, 2005; Mohd Noor et al., 2019). Researchers pointed out that most condition survey reports have been focusing too much on repair works rather than regular maintenance works, resulting in less organised survey works and the format of information collected does not enable effective data storage (Dann & Worthing, 2005).

Heritage value standards in the BCA have several shortcomings because the building's rating is only based on the assessed parts, making the assessment process subjective. This is because such goods and building components are not elaborated upon; in other words, there are no assessment levels or rubrics. As a result, the building may lose its legacy because there are no clear indicators of what is excellent or bad. Regarding heritage buildings, the BCA score may indicate that the structure has to be changed because it is in poor condition. Nevertheless, an assessment should be done for each architectural element to follow the principles of minimal intervention in building conservation. This will create a thorough analysis of the building, and the overall assessment outcome will differ from that of traditional evaluation.

Moreover, historical preservation helps people to comprehend the origins and roots of civilisation by preserving the originality of the materials, hence contributing to the value of heritage structures (Dann & Worthing, 2005; Lang et al., 2017). Lang et al. (2017) specifically emphasised the word "value", arguing that it has "meaning" for the heritage groups as well as economic value. However, Dann and Worthing (2005) drew attention to the financial aspect of heritage building maintenance where regular maintenance must be prioritised in heritage building surveys because it is far more financially advantageous to conduct scheduled maintenance on deteriorating building materials.

2.3 Digital Documentation using Light Direction and Ranging (LiDAR)

Similar to the concept of Radio Detection and Ranging (RADAR), Light Direction and Ranging (LiDAR) utilises light pulses to track the position of an object in 3D space. LiDAR equipment comes in many forms, manufacturers, types, and versions that differ in specifications, accuracy, and data acquisition. LiDAR works by scattering light pulses on the whole surface of an object. These light pulses will then return to the LiDAR machine to be received and its relative distance is calculated by the time-of-flight, material reflectivity, and texture. These data can be mapped into stereographic 3D visualisation as a point cloud (Zohdi, 2020). For example, the wall of a building's shape and form can be identified by scattering billions of light pulses, forming it in the form of scattered dots with high accuracy. LiDAR can also be embedded in photography with a DSLR (Digital Single-Lens Reflex) camera. After the point cloud data is taken, the camera will take photographs of the surveyed area and map the photograph's colours into the point cloud, creating photogrammetry for much richer data.

Despite not being a particularly innovative technology, Malaysia has mostly used LiDAR for forestry and land surveying. Due to its high-precision laser measurements, LiDAR has gained popularity in heritage conservation and urban surveying to acquire 3D spatial information, ultimately enhancing decision-making, identifying building dilapidations, and producing thorough documentation (Dawood et al., 2017; Hoensheid, 2012; Hou et al., 2017).

Furthermore, LiDAR has recently been utilised in Building Information Modelling (BIM) and urban planning by utilising the perspective of stereoscopic 3D data for high-accuracy categorisation of architectural elements (Pirasteh et al., 2019; Usmani et al., 2019). The technology is mainly useful for identifying a building's borders and detecting building modifications (Pirasteh et al., 2019). Conversely, Usmani et al. (2019) propounded the advice of adopting cutting-edge techniques like LiDAR to conduct quicker and more up-to-date studies. The authors further emphasised the importance of merging BIM with AR to provide facility managers with better documentation and data (Usmani et al., 2019).

LiDAR is also used as an AR solution in heritage conservation and heritage tourism for visualising and documenting heritage monuments. Smartphone 3D applications can display the AR visual data created from the 3D point-cloud data from the LiDAR scanner. Shih et al. (2019) highlighted the colour accuracy and how 3D imaging helps with the full-scale experience of the building, along with the structural and visual information that can assist in remote cultural exploration and learning on-site by merging stereographic point-cloud data. The exceptional accuracy of LiDAR and its incorporated geolocation in 3D space allow for capturing heritage sites with colour accuracy (Shotton, 2018). Such accuracy also facilitates the capturing of minute details of stonework at a historical location with very steep elevation changes, which would be challenging for conventional surveying techniques (ibid).

Most authors agreed that LiDAR is accurate and provides valuable data through stereoscopic point-cloud visualisations. However, it is important to note that most of these findings are produced from terrestrial LiDAR with extremely high point density. Many researchers agreed that terrestrial LiDAR is not only limited to forestry and topographical use but also built environment use, specifically heritage sites (Aljumaily et al., 2017; Bassier et al., 2018; Rubinowicz & Czyńska, 2015). However, existing studies on the use of LiDAR in building condition assessment remain limited to spall damage and structural in nature (Dawood et al., 2017; Hoensheid, 2012; Hou et al., 2017). The majority of these studies are focused on documentation, presentation, and solely historical research. However, no existing research exploits the LiDAR technology in determining heritage buildings' dilapidation by analysing the ornamentations, stucco work, and building elements.

3. Methodology

This study involved a pathology survey that was conducted on the Ipoh Town Hall and Post Office, Galeri Kraftangan Seremban, and Bangunan Dato' Onn in Johor Bahru as part of the preparation for the Conservation Management Plan for the three buildings. These case studies involved two major phases of data collection (Table 1). The first dataset was collected using a manual on-site survey while the second dataset was retrieved from a laser scanning survey. All data was then triangulated, analysed, and interpreted. To conduct building recording/surveying works, site visits and detailed recording of building elements on-site were crucial to report the condition of the building.

A manual on-site survey was done across the three case studies to document, identify, and evaluate the buildings' current state. An overall building condition report for each building was created using a thorough inspection and photographic evidence gathered during the manual survey. To support the assessment, on-site non-destructive testing, such as crack measurement and thermal reading, was conducted. On the base plan, physical flaws were noted followed by the production of a thorough report.

The second dataset was gathered concurrently using the laser scanning method. Each structure was scanned using a Terrestrial Laser Scanner: RieGL VZ400 (TLS). The scanner was mounted with a Nikon DSLR to acquire colour 3D photos of the scanned region. The LiDAR survey collected 3-D point cloud data of each case study. First, the survey work areas were drafted following the initial base plan. The surveying process began by establishing a control point, from which a chain of stations was targeted to perform a 360-degree scan of each station. These stations considered the tie-point scan and backsighting to ensure that all data collected from different scan positions could be tied together. The proprietary software for each LiDAR gear was then used to process the LiDAR data, which involved converting the raw data into usable information.

Due to LiDAR’s waveform limitation to be reflected off the surface, TLS scan stations were established on site every 10 metres from each station and 5 metres away from existing walls and surfaces. A station was sent to the TLS location for scanning. A tripod was used to support the apparatus. Even though the unit's tilt correction for processing point clouds was limited, it was properly levelled to guarantee the tripod's stability and the data's accuracy. High-intensity 360-degree panorama and high-density TLS settings were employed to ensure that every aspect of the building surface was captured during scanning. The attached camera system recorded colour data while scanning for more thorough data processing.

The raw RXP file from RIEGL VZ-400 was first processed and registered using RiscanPro before it was converted into a PTX file for Autodesk ReCap. The customisable spectrum mapping, GPS support, clipping, plane detection, and section views of Autodesk ReCap were used to perform data analysis. whereas, Python programming was utilised to assess the data further and manipulate the datasets with algorithms. These quantitative statistics were processed to determine LiDAR's advantages and disadvantages in conducting heritage building assessments.

4. Results and Discussion

The results of this study showed disparities between the two approaches in evaluating the heritage buildings' conditions across the three case studies. All three selected buildings were constructed as residential and institutional structures during the British colonial times. These structures are over a century old and have undergone numerous repairs and changes in use to enable them to stand strong to this day. Nevertheless, flaws can be found with careful examination. The outcome of the laser scanning evaluation and the walk-in assessment highlights the value of combining technology and conventional assessment methods that complement one another in terms of precision and expertise.

4.1 Ipoh Town Hall and Post Office Building

Despite being connected, Ipoh Town Hall (Figure 1) is currently used as a hall while the post office was abandoned during the time of the survey. Most of the Ipoh Town Hall building was in good shape; however, there were minor flaws in the ceiling, exterior, internal walls, doors, windows, stairs, and columns. Among the more prevalent flaws were cracks in the wall plaster, paint-related issues (peeling, spalling, and blistering), decaying window and door frames, moisture, and damaged ceiling panels. During the walk-in survey, there were no significant issues with the building's structural integrity.

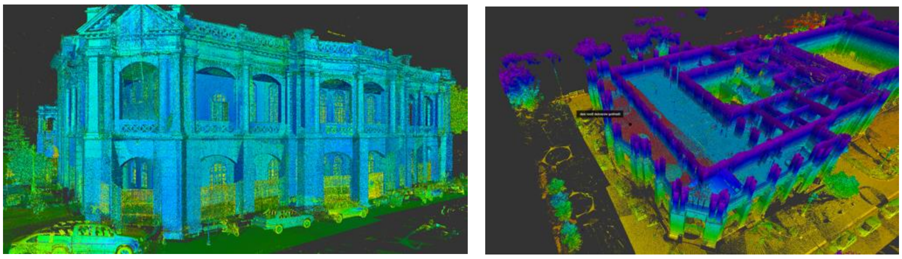

Fig 1 - Point-cloud image of Ipoh town hall and post office

Due to its abandonment, the post office had more flaws than the town hall. The façade, roof, ceiling, floor, doors, and windows were the primary areas of the building where defects were found during the walk-in survey. The most prevalent flaws in this structure were cracks, moisture, leaks in the roof and ceiling, leaky waterproofing on the roof slab, broken decorative elements on parapet walls, mould growth, and paint-related defects (peeling, spalling, and blistering). Moreover, the first level's timber floor was buckling and the concrete floor had a structural crack (Figure 2). The crack was observed during the walk-in survey and noted alongside the falling ceiling.

Fig 2 - Structural crack, slanting of floor slab, and fallen ceiling detected during the walk-in survey

Analysis of the laser scanning image further indicated the structural problems of the floor based on the level of sloping indicated through level analysis. A 3D rendering of the building was produced via laser scanning and it depicted every little aspect of the façade, including cracks and growth. According to the TLS study, the post office's veranda slab sloped significantly towards the building's southeast corner. Conversely, TLS created an elevation heat map from the roof floor and slanting veranda to find any issues and the source of deterioration (Figure 3). It also precisely recreated a building's section in order to show the slant and inclination. Further forensic analysis by structural engineers is recommended to ensure the structure's integrity.

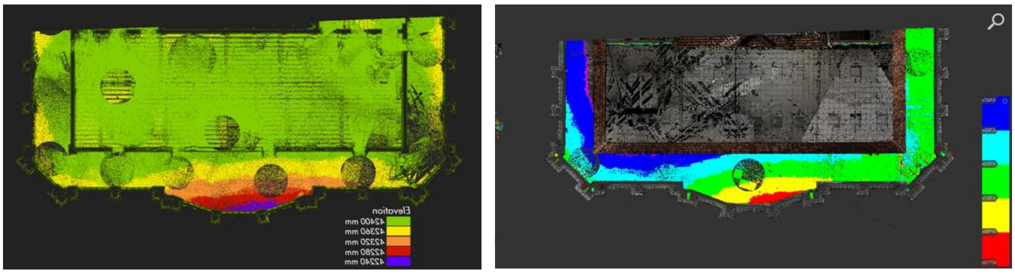

Fig 3 - Heat analysis from scanned images showed differences in height (represented by colours), confirming the slanting of the floor

4.2 Galeri Kraftangan Seremban

The Galeri Kraftangan Seremban building was left unoccupied during the surveying process. The main areas where faults were discovered during the walk-in survey were the façade, roof, ceiling, lighting and electrical systems, floor, doors, and windows. The most common defects in this building were cracks, wetness, roof and ceiling leaks, mould development, paint-related flaws (peeling, spalling, and blistering), and the structural integrity of the hardwood floor structure on the first level. Moreover, the structural integrity of the timber floor was compromised in some areas, making it dangerous for anyone to be within. Some aspects of the floor structure could not be identified by a walk-in survey but were detected through the TLS analysis. Analysed images from the laser scanning detected structural deformation of the floor slab that could lead to collapse (Figure 4). Both surveys detected that the building had experienced a fire, as evidenced by the fire marks on the wall (Figure 5) and the main switchboard. The affected area required repair work.

a) b) c)

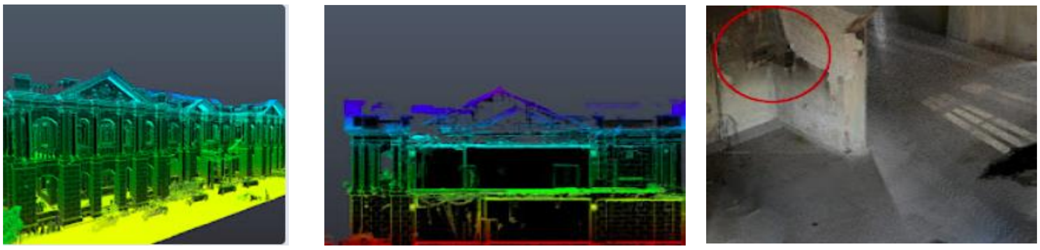

Fig 4 - (a) Point cloud data for Galeri Kraftangan Seremban; (b) section through scanned image showed deformation on the floor that was alarming; (c) fire marks from the laser scanning photo image

4.3 Bangunan Dato' Jaafar

Bangunan Dato' Jaafar (Figure 5) was a mansion owned by the former Johor Chief Minister, Dato' Jaafar. It is currently used as a museum after being handed to *Yayasan Warisan Johor* as the caretaker. The key areas where defects were found during the walk-in survey were the façade, floor, ceiling, HVAC system, lighting system, electrical system, plumbing, doors, windows, and landscaping. The most frequent flaws in this structure were termite infestations, mould growth, moisture, floor slanting, paint and wallpaper-related flaws (peeling, spalling, and blistering), and cracks (Figure 6). The severity was assessed and noted during the walk-in survey; nevertheless, a more accurate assessment of the severity was achieved with the help of TLS. For instance, TLS allowed the precise angle of stairs and cantilevered floor slanting to be ascertained. Other than that, both walk-in survey and non-destructive test were used to assess the condition of the building.

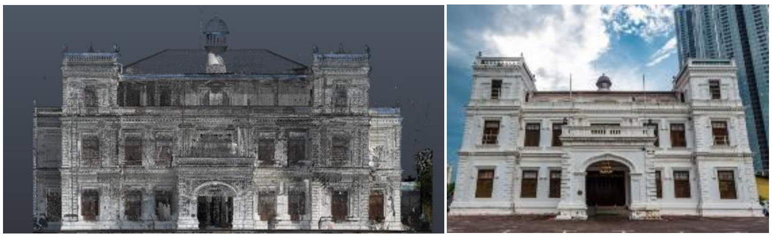

Fig 5 - Point-cloud image and photo image of Bangunan Dato' Jaafar

Fig 6 - Defects that were detected during the walk-in survey (dampness) and could be tested using a non-destructive test

4.4 Effective Heritage Building Assessment

In short, there is no right or wrong in the selection of assessment for building conditions. Integrating digital tools and conventional assessment provide more effective and precise results on the building condition. What important is the details of the report and the stakeholders' judgment calls to ensure the sustainability of heritage buildings. Table 1 illustrates the comparison between the two approaches used in the case studies.

Table 1 - Comparison of findings from the case studies

Variables	**Case Studies**		
	Ipoh Town Hall and Post Office	Galeri Kraftangan Seremban	Bangunan Dato' Jaafar
Building Typology	Two-Storey British Colonial Institutional Building	Two-Storey British Colonial Institutional Building	Three-Storey British Colonial Residential Building
Area (sqm)*	GF: 2356.54 1F: 2266.58 Total Building Area: 4623.12 Site Area: 6852.43	GF: 1012.40 1F: 830.83 Total Building Area: 1843.23 Site Area: 3916.60	GF: 1306.01 1F: 694.34 2F: 637.48 Total Building Area: 2637.83 Site Area: 7764.24
Lidar-Based Survey Using Laser Scanner			
Site survey duration	7 days (80 hours)	4 days (28 hours)	9 days (45 hours)
Data processing and image cleaning duration	21 days	7 days	21 days
Defects identified through processed laser scanning images	Sloping floor Collapsed ceilings Sagging timber floor Falling damp Harmful growth (mould and plants) Peeling paint	Sloping floor Collapsed ceilings Burnt fuse box Rotten timber flooring Flooding Harmful growth (mould and plants) Peeling paint	Cracked floor tiles Falling damp Harmful growth (mould and plants) Peeling paint

On-Site Manual Survey			
Duration	14 days	4 days	8 days
Analysis of the results and report on the assessment	45 days	21 days	45 days
Defects identified through walk-in survey	<u>Town Hall</u> Cracks on wall plaster Paint-related defects (peeling, spalling, and blistering) Rotten window and door frames Dampness Broken ceiling panels No major defects that involved the structure <u>Post Office</u> Structural cracks Dampness Leaking in the roof and ceiling, waterproofing leaking on roof slab, broken decorative element on parapet walls Mould growth Paint-related defects (peeling, spalling, and blistering) Sagging of the first floor wooden floor and structural crack on the concrete floor	Cracks Dampness Leaking in the roof and ceiling, mould growth Paint-related defects (peeling, spalling, and blistering) Structural integrity of the first-floor wooden floor structure. Some parts of the wooden floor's structural integrity were compromised and unsafe for occupants.	Cracks Dampness Floor slanting Paint and wallpaper-related defects (peeling, spalling, and blistering) Mould growth Termite attacks

The data in Table 1 indicated that the laser scanning process took a shorter time than the conventional method. Nonetheless, a detailed technical inspection should never rely merely on the images gathered through the laser scanning process. This is because on-site visits often allow for a more detailed inspection by the experts. Although laser scanning stores all the data needed and is accessible anytime, it does function as an x-ray tool that can provide data on the structural integrity of a building, nor that it comes with thermal imaging components for early detection of rising dampness and irregularity in the structure. These aspects must be examined and assessed by the experts. For the three case studies, the structural irregularity and integrity of the buildings could be examined in detail using 3D point cloud data that was obtained via LiDAR. The sloping floor could be an isolated instance of dilapidation that affected the flat roof and the first floor of the veranda, as evidenced by the flat roof, collapsing ceilings, and spalling floor slab.

Findings from the case studies suggest that LiDAR is indeed a powerful tool for conducting BCA, especially in heritage buildings due to their nature of dilapidation. It also provides accurate and fast measurement of the building elements, such as the façades, ornamentations, windows, and doors. Furthermore, LiDAR’s capability of measuring slopes and reflectance offers a different perspective in surveying a building. However, the technology requires higher upfront costs compared to conventional methods; but LiDAR will soon become more accessible as it matures over time. Another downside of adopting LiDAR is the file size of point cloud data can be as large as 400 megabytes per scan station of a building, ultimately necessitating a larger investment for long-term file storage. Regardless, this study demonstrates that LiDAR is a worthwhile investment and deserves significant attention for future building surveying methods.

When compared to traditional methods, LiDAR’s speed to scan sloping floor defects significantly boosts the decision-making process. LiDAR's sensitivity and accuracy to identify changes in a floor's elevation enables precise measurements to stop additional structural damage to a building. Additionally, fewer people are needed to perform a LiDAR scan than it would take to measure and survey a building of this size via traditional methods. Building deterioration can also be investigated from a wider angle using 3D point cloud data. Furthermore, LiDAR can be deployed with unmanned systems, making it possible to undertake building dilapidation surveys in risky locations like inside a structure that requires structural integrity maintenance. Future directions in this field include evaluating point cloud data using machine learning and building dilapidation with autonomous systems.

Acknowledgement

The authors would like to thank the Ministry of Higher Education (MoHE) for funding this research through the Fundamental Research Grant Scheme (FRGS/1/2021/WAB09/UITM/02/2). A heartfelt gratitude also goes to Universiti Teknologi MARA (UiTM) for the continuous support to this project.

References

Aljumaily, H., Laefer, D., and Cuadra, D. (2017). *Urban Point Cloud Mining Based on Density Clustering and MapReduce*. Journal of Computing in Civil Engineering, 31(5), doi: 10.1061/(ASCE)CP.1943-5487.0000674

Bassier, M.; Vincke, S.; De Lima Hernandez, R.; Vergauwen, M. *An Overview of Innovative Heritage Deliverables Based on Remote Sensing Techniques*. Remote Sens. 2018, *10*, 1607. https://doi.org/10.3390/rs10101607

Dann, N. and Worthing, D. (2005), *Heritage organisations and condition surveys*, Structural Survey, Vol. 23 No. 2, pp. 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(August 2016), 149–160.

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

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: Journal of the International Measurement Confederation, 108, 77–90.

Khalil, H.A.; Darwish, S.; Ibrahim, Y.M.; Hassan, O.F. (2020) *3D-MRI Brain Tumor Detection Model Using Modified Version of Level Set Segmentation Based on Dragonfly Algorithm*. Symmetry *12*, 1256. https://doi.org/10.3390/sym12081256

Lang, L., Liu, J., & Wang, S. (2017). Understanding and Assessing Modern Architectural Heritage : Value-Oriented Contextual Interpretation Based on Dalian (China) Case Study. International Journal of Built Environment and Sustainability, 2, 1–6.

Mohd Noor et al (2019) *Heritage building condition assessment: a case study from Johor Bahru,Malaysia* IOP Conf. Ser.: Earth Environ. Sci. 220 01202

Pirasteh, S.; Rashidi, P.; Rastiveis, H.; Huang, S.; Zhu, Q.; Liu, G.; Li, Y.; Li, J.; Seydipour, E. *Developing an Algorithm for Buildings Extraction and Determining Changes from Airborne LiDAR, and Comparing with R-CNN Method from Drone Images*. *Remote Sens.* 2019, 11, 1272. https://doi.org/10.3390/rs11111272

Rubinowicz, P. and Czyńska, K.: *Study of City Landscape Heritage Using LiDAR Data and 3d-City Models*, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-7/W3, 1395–1402, https://doi.org/10.5194/isprsarchives-XL-7-W3-1395-2015, 2015.

Shih, N.J.; Diao, P.H.; Chen, Y. *ARTS, an AR tourism system, for the integration of 3D scanning and smartphone AR in cultural heritage tourism and pedagogy*. Sensors 2019, 19, 3725.

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.

Usmani, A. R. A., Elshafey, A., Gheisari, M., Chai, C., Aminudin, E. B., & Tan, C. S. (2020). A scan to as-built building information modeling workflow: a case study in Malaysia. Journal of Engineering, Design and Technology, 18(4), 923–940.

Zohdi, T. I. (2020) *Rapid simulation-based uncertainty quantification of flash-type time-of-flight and LiDAR-based body-scanning processes.* Computer Methods in Applied Mechanics and Engineering 359: 112386.