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APPLICATION OF DIGITAL TWIN TECHNOLOGY FOR STRUCTURAL HEALTH INSPECTION OF PIERS USING TERRESTRIAL LASER SCANNING

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ABSTRACT

Monitoring the condition of structures like piers is important to ensure their safety and durability. Traditional inspection techniques are often time-consuming and lack precision in detecting early-stage deformations. This study explores the use of Terrestrial Laser Scanning (TLS) and Digital Twin (DT) technologies to generate a high-fidelity 3D model of a pier structure. TLS was used to collect detailed point cloud data, which was then processed to generate models of the pier from two different years, 2022 and 2025. By comparing these models, changes in the structure and surface flatness were identified. The results show that TLS provides highly detailed scans, which improve the ability to detect small deformations. The study finds that using TLS together with digital models is a dependable and efficient way to assess structural health without damaging the structure. Future research should focus on long-term monitoring with more frequent scans and combining TLS with other non-destructive testing techniques.

1.0 INTRODUCTION

Elevated infrastructure, such as transportation systems and pedestrian walkways, requires strong and reliable support structures. Piers, typically constructed from reinforced concrete, serve as the primary foundation elements for these structures. They are designed to bear heavy loads, including the weight of the structure itself, people using the facility, and environmental forces such as wind and rain. Engineers consider several factors, such as the type of soil at the construction site, the amount of weight the pier must support, and the potential for natural events like earthquakes, to ensure that the piers can withstand various demands throughout the lifespan of the structure [1]. TLS is a non-destructive, high-precision measurement method based on laser beams that allows for highly accurate, discrete 3D point cloud data to be obtained. TLS makes it possible to quickly acquire information from the surface of a pier, including the geometric details of cracks, corrosion, and deformations [2-5]. The analysis of the large dataset provides valuable insights into the structural condition of the pier. This information can be used to detect and evaluate potential issues in the structure at an early stage. In contrast, Digital Twin technology provides a virtual model of a physical structure, such as a pier. By integrating data collected in real time with modelling and simulation methods, it creates an up-to-date digital version of the structure. It allows the pier to be monitored under different loading conditions, helps predict its future performance, and supports the planning of effective maintenance strategies [6-7].

Piers are subjected to dynamic loading, environmental loading, and long-term wear. These factors may have an impact on their structural strength over time. Conventional inspection methods of piers usually involve visual inspection with or without the use of simple measurement instruments, which may not provide accurate and detailed data, especially when confronted with early stages of deformation. In

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addition, these methods have proved to be labour-intensive, time-consuming, and pose safety problems to inspectors when inspecting close to the operative structure [8-9]. In response to the problem, demand for inspections of piers as well as structural condition monitoring that can be performed more efficiently, accurately and without destructiveness is needed. With DT technology empowered by TLS, a modern solution is now available, as DT enables the generation of highly detailed 3D models that can be updated and analysed to examine the current situation over time [10-12]. This study explores how DT technology can be used to assess the structural condition of piers by using high-resolution data collected from TLS. The combination of DT and TLS presents an effective method for inspecting and monitoring critical infrastructure, such as piers. By collecting accurate and detailed spatial data, this approach allows engineers to track changes over time, identify possible structural problems, and make better decisions about maintenance and safety. The study has two main objectives: To generate a detailed 3D DT of a pier using TLS data and to examine structural assessment by comparing initial and updated data. This research aims to show that DT supported by TLS can serve as a reliable and practical tool for the long-term monitoring of pier structures.

2.0 METHODOLOGY

2.1 Study Area

The pier that has been chosen for this research is the LRT pier at LRT 3 Klang Station. Initial data of this pier was collected in the year 2022. Therefore, the data that will be obtained from this research can be compared with the previous data to detect any sctrutural deformation to the pier by comparing new data acquired through TLS. The piers numbered 27, 28 and 29 are the piers that have been selected for this research as they are adjacent to each other and structurally similar. Before setting up the instrument for data acquisition, site reconnaissance will be done to ensure the site is in good condition and free from disturbances that could cause problems with the TLS scanning, such as rain, heavy wind, and vehicles. Figure 1 shows the pier of the site that will be used in data acquisition.

Figure 1. LRT piers

For the setup configuration, there are four total setups of TLS for the three piers that need to be covered to scan the entire pier area thoroughly. There must be no disruption during the scan to make the result more accurate. The illustration of the setup configuration is based on Figure 2.

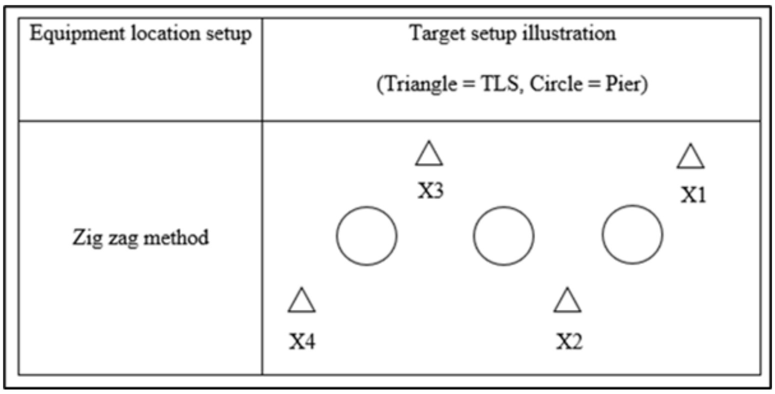

Figure 2. Setup configuration

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2.2 Data acquisition

TLS technology will be used in this research to obtain 3D point cloud data of the LRT 3 Klang Station pier structure with high resolution, using the TLS model Leica RTC360 as shown in Figure 3. By using various setup positions, the point cloud data will be collected to generate a detailed 3D model of the pier [13-14]. To maintain data accuracy and reliability, quality control procedures such as regular calibration of the equipment and validation of the collected data will be implemented. These steps are important for producing an accurate digital representation of the pier's shape and condition, with data acquisition managed through Cyclone Field 360 software.

Figure 3. TLS Leica RTC360

2.3 Data processing

The raw point cloud data collected using the TLS must first be imported into Cyclone Register360 software, as shown in Figure 4, for further processing on a high-performance laptop. Once imported, the software displays the information, including the number of scan setups, the links between them, and the full extent of the scanned area. Each setup requires manual visual alignment to ensure the scans are correctly positioned relative to one another. After alignment, the software provides error statistics that indicate the accuracy of the alignment. The lower error values reflect higher precision. Once alignment is complete and verified, the dataset is exported in .lgs format, which is compatible with Cyclone 3DR for detailed data analysis. The processed point cloud is then used to generate a 3D digital representation of the piers.

Figure 4. Cyclone Register360

2.4 Data analysis

The TLS data collected will then be analysed to provide the relevant information on the structural condition of the pier using Leica Cyclone 3DR, as shown in Figure 5. This requires careful preprocessing of the data and changing the file type. lgs to do data analysis using specific software. Following that, relevant pier structure information, including surface areas, volumes, and geometric dimensions, will be extracted from the processed point cloud data. By using scans taken at two different times, in 2022 and 2025, it can identify any differences in the pier's geometry, such as displacements, rotations, cracks, deformations, or any changes in the area that may have developed. It will allow for the identification, assessment, and comparison of the degree to which damage can occur according to location, size, and severity. To effectively express the pier's state to the appropriate condition, the analysis results will be presented through clear and informative visualisations, such as 3D models in suitable software.

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Figure 5. Cyclone 3DR

Understanding the different types of damage that can affect structural components is used for practical inspection, maintenance, and safety evaluation. Structures such as piers are exposed to physical, environmental, and operational forces throughout their lifespan, which can lead to various forms of damage. Common types of damage include surface cracks, spalling, changes in shape, rusting of steel reinforcements, ground settlement, and shifts in the structure's position [15]. Each type of damage may affect the structure in different ways and may require specific methods for detection and evaluation. Accurately identifying and measuring these damages is important to assess their severity and determine the need for repairs.

3.0 RESULTS AND DISCUSSION

3.1 3D Model

The Cyclone Register 360 helps to manage and register 3D point clouds, where it was used to manage, register and process raw TLS data to create the first stage of DT. In order, to guarantee full surface coverage and reduce obstruction, the TLS data was gathered from many scanning locations around the area. There are two sets of data that have been processed, which are the initial and updated 3D point cloud data as shown in Figure 6.

Pier Number	Initial 3D Point Cloud (2022)	Updated 3D Point Cloud (2025)
27		
28		

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Pier Number	Initial 3D Point Cloud (2022)	Updated 3D Point Cloud (2025)
29		

Figure 6. Initial and updated 3D point cloud

Based on the 3D model that has been generated from all the datasets. The condition and environment of each data point are different, with clear images showing the differences between the years. The initial low-resolution image already gives a representative overview of the pier. However, such a model is lacking in detail and small deforming or surface abnormalities, which make it hard to observe. In contrast, the initial high resolution provides a far finer and more precise model of the pier, including finer surface texture and geometry. This level of detail is important for accurate surface-level analysis and to detect minor structural changes.

3.2 Quality of Point Cloud

Cyclone Register360 is known for its ability to process and analyze point cloud data with high precision and accuracy, which leads to improved modelling quality. It offers vivid colours for realistic colourization, powerful quality assurance tools for verifying registration and understandable reporting. Other than that, in Cyclone Register360, a bundle represents a collection of registered 3D scans that are linked to one another. Bundles are used for managing and optimizing large scanning projects, which include features like error analysis and optimization. Table 1 below shows the quality data for each point cloud bundle for the specific data.

Table 1. Quality of point cloud data

Data	Setup count	Link count	Point cloud count	Bundle error (m)	Overlap (%)	Strength (%)	Cloud-to-cloud (m)
Initial Low	4	3	22,888,936	0.002	35	38	0.002
Initial High	4	3	314,509,831	0.001	50	37	0.001
Updated Low	4	3	23,229,971	0.001	43	30	0.001
Updated High	4	3	302,157,449	0.001	53	28	0.001

3.3 Structural Assessment

Structural assessment focuses on evaluating the condition, performance, and safety of infrastructure. Traditional inspection methods, while widely used, have limitations. They are often time-consuming and may only detect noticeable or small-scale structural changes. This study explores a more advanced and data-driven approach through the application of DT technology. This virtual model reflects the real-time state of a physical structure. By utilising TLS, which captures accurate and detailed 3D point cloud data, a 3D model of the piers and their surroundings can be generated. This research involves comparing high-resolution TLS data captured at different times to identify and analyze structural changes effectively. Based on the inspection made from the initial high-resolution inspection.

Figure 7 shows that moss is present on the top of the pier. Moss that grows concrete can cause structural issues. It can also lead to cracks, spalling, and increased moisture content, which could shorten the concrete lifespan. Based on the inspection made from the updated high-resolution image, Figure 8 shows that there is no moss present on the top of the pier. The scanned surface shows no indication of moss on the updated data because the moss got removed over the years. It shows that there are differences between initial and updated scans that could be detected when inspecting.

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Figure 7. Moss on Pier 27 initial data

Figure 8. No moss on Pier 27 updated data

Other than that, Figure 9 shows that there are large quantities of construction waste from 2022 in the initial point cloud data. It caused, during that year, the pier was still under construction, which resulted in much waste that could be captured using the TLS. It shows that the TLS is not just able to detect and capture the pier's structure but also the area around the pier, which shows that it can scan and detect anything within its reach as long as it is visible to the machine itself. Next, the TLS can detect a crack on Pier 28, as shown in Figure 10. With this, engineers can detect cracks and the exact location of the crack on the pier without the need for contact with the pier itself. It is beneficial in hard, inaccessible places where the traditional method is complex and potentially hazardous. By using this method, it can easily inspect and plan to avoid any more problems.

Figure 9. Construction Waste at Pier 27 point cloud initial data

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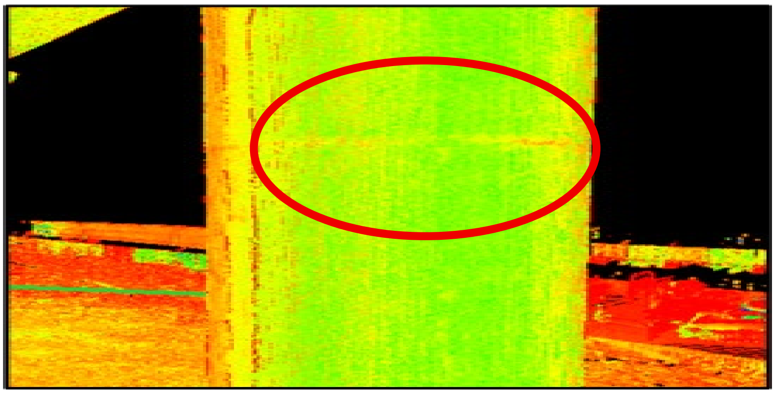

Figure 10. Crack at Pier 28

4.0 CONCLUSIONS

Based on the objectives of this research, which is to generate a detailed 3D DT of a pier using TLS data and to examine the structural assessment by comparing initial and updated model data. Some conclusions can be made according to each objective. The point cloud data derived from the TLS was used to create a detailed 3D model containing comprehensive structural information. This data was processed using Cyclone Register360, which converted the raw scans into an accurate and interactive 3D representation. The resulting model effectively represents physical structure in a virtual format. Moreover, digital representation enhances visualization and serves as a reliable reference for further structural analysis and comparative studies. Other than that, the structural assessment evaluation contributes to the safety, reliability and durability of the structure. Through that process, engineers can better understand physical changes and surface conditions over time. Differentiating the information between scanning time and minor changes visible during visual inspection. In conclusion, the structural inspection illustrated the importance of applying new technologies for structure monitoring and maintenance to execute maintenance and safety operations.

5.0 CONFLICT OF INTEREST

The authors declare no conflicts of interest.

6.0 AUTHORS CONTRIBUTION

Wan Mohamed Sabri, W. M. S. (study conception and design; data collection; draft manuscript preparation; software processing; analysis and interpretation of results; draft manuscript preparation)
Ismail, N. (data collection; study conception and design; analysis and interpretation of results)
Roshdan, M. H. A. (data collection; software processing)
Mohd Isnan, S. S. (draft manuscript preparation; analysis and interpretation of results)
Abdul Rahman, A. H. (analysis and interpretation of results; draft manuscript preparation)

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List of Reference

[1] Wu, C., Yuan, Y., Tang, Y., & Tian, B. (2022). Application of Terrestrial Laser Scanning (TLS) in the architecture, engineering and construction (AEC) industry. *Sensors. 22*(1), MDPI.
[2] Mohammadi, M., Rashidi, M., Mousavi, V., Karami, A., Yu, Y., & Samali, B. (2021). Quality evaluation of digital twins generated based on UAV photogrammetry and TLS: Bridge case study. *Remote Sensing. 13*(17).
[3] Beshr, A. A. A., Ghazi, Z., & Heneash, U. (2025). Condition assessment and inspection of highway bridges using terrestrial laser scanner. *World Journal of Engineering.*

*Corresponding Author | Wan Mohamed Sabri, W. M. S. | wmsyafuan@upnm.edu.my

[4] Blaskow, R., & Maas, H.-G. (2024). Structural Health Monitoring of Bridges with Personal Laser Scanning: Segment-based Analysis of systematic Point Cloud Deformations. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-2–2024, 9–16.

[5] Tzortzinis, G., Filippatos, A., Wittig, J., Gude, M., Provost, A., Ai, C., & Gerasimidis, S. (2024). Structural integrity of aging steel bridges by 3D laser scanning and convolutional neural networks. *Communications Engineering. 3(*1), 106.

[6] Huang, J., Wu, P., Li, W., Zhang, J., & Xu, Y. (2024). Exploring the Applications of Digital Twin Technology in Enhancing Sustainability in Civil Engineering: A Review. *SDHM Structural Durability and Health Monitoring. 18*(5), 577–598. Tech Science Press.

[7] Sun, Z., Jayasinghe, S., Sidiq, A., Shahrivar, F., Mahmoodian, M., & Setunge, S. (2025). Approach Towards the Development of Digital Twin for Structural Health Monitoring of Civil Infrastructure: A Comprehensive Review. *Sensors. 25*(1), 59.

[8] Jiang, F., Ma, L., Broyd, T., & Chen, K. (2021). Digital twin and its implementations in the civil engineering sector. *Automation in Construction. 130*, Elsevier B.V.

[9] Faris, N., Zayed, T., & Fares, A. (2025). Review of Condition Rating and Deterioration Modeling Approaches for Concrete Bridges. *Buildings, 15*(2), 219.

[10] Franciosi, M., Kasser, M., & Viviani, M. (2024). Digital twins in bridge engineering for streamlined maintenance and enhanced sustainability. *Automation in Construction, 168.*

[11] Jiménez Rios, A., Plevris, V., & Nogal, M. (2023). Bridge management through digital twin-based anomaly detection systems: A systematic review. *Frontiers in Built Environment. 9*, Frontiers Media S.A.

[12] Michael, J., Blankenbach, J., Derksen, J., Finklenburg, B., Fuentes, R., Gries, T., Hendiani, S., Herlé, S., Hesseler, S., Kimm, M., Kirchhof, J. C., Rumpe, B., Schüttrumpf, H., & Walther, G. (2024). Integrating models of civil structures in digital twins: State-of-the-Art and challenges. *Journal of Infrastructure Intelligence and Resilience. 3*(3), Elsevier B.V.

[13] Mousavi, V., Rashidi, M., Mohammadi, M., & Samali, B. (2024). Evolution of Digital Twin Frameworks in Bridge Management: Review and Future Directions. *Remote Sensing. 16*(11), Multidisciplinary Digital Publishing Institute (MDPI).

[14] Wang, J., Wu, K., He, Y., Zhou, D., Li, L., Diao, X., & Cai, J. (2023). Detection and Digital Representation of Ancient Architecture Damage Based on Laser Point Cloud: Case Study of the Zhengding Ancient City Wall. International Geoscience and Remote Sensing Symposium (IGARSS), 2023-July 2313–2316.

[15] Mohammadi, M., Rashidi, M., Azandariani, M. G., Mousavi, V., Yu, Y., & Samali, B. (2023). Modern damage measurement of structural elements: Experiment, terrestrial laser scanning, and numerical studies. *Structures, 58*.

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