Investigating the Engineering Interventions in the Conservation of Malaysia Heritage Structures: A Review on Preserving Historical Edifices Through Advanced Civil Engineering Techniques.

Muhammad Azizi Azizan
Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis, Perlis, Malaysia
Centre of Excellence for Unmanned Aerial System, Universiti Malaysia Perlis, Perlis, Malaysia

Nurfadzillah Ishak
Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis, Perlis, Malaysia
Centre of Excellence for Unmanned Aerial System, Universiti Malaysia Perlis, Perlis, Malaysia

Hazry Desa
Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Perlis, Malaysia
Centre of Excellence for Unmanned Aerial System, Universiti Malaysia Perlis, Perlis, Malaysia

E-mail: aziziazizan@unimap.edu.my

Abstract

This review delves into the realm of Malaysia's heritage conservation, spotlighting the transformative impact of advanced civil engineering techniques. Through the integration of Fiber-Reinforced Polymers (FRP) and nanotechnology, historical edifices are fortified, seamlessly blending modern engineering with architectural elegance. Non-destructive testing (NDT) methods, including ground-penetrating radar and Finite Element Analysis (FEA), empower conservationists with deep insights into structural intricacies, guiding targeted interventions. In the digital sphere, 3D laser scanning captures intricate details, while Virtual Reality (VR) simulations facilitate immersive exploration and informed decision-making. Beyond preservation, these technologies foster public engagement, ensuring a collective understanding of Malaysia's cultural heritage. This harmonious fusion of tradition and cutting-edge engineering ensures the enduring legacy of Malaysia's architectural treasures.

Keywords: Heritage conservation, Non-destructive testing (NDT), Finite Element Analysis (FEA), 3D laser scanning, Virtual Reality (VR)

1. Introduction

Heritage structures stand as invaluable remnants of our cultural legacy, embodying the architectural achievements and historical significance of bygone eras [1]. However, the preservation of these structures poses intricate challenges that demand innovative engineering solutions [2], [14]. As urban landscapes evolve and modernization accelerates, the need to safeguard these historical edifices has never been more pressing [3]. This review embarks on a comprehensive exploration of the engineering interventions essential in the conservation of heritage structures, delving into the intricate amalgamation of tradition and technology [4], [6]. Through a meticulous analysis of advanced civil engineering techniques, this study aims to shed light on the nuanced methods employed to preserve the structural integrity, cultural heritage, and aesthetic essence of these buildings. By examining the successes, challenges, and lessons learned from previous conservation projects, this research endeavors to offer valuable insights into the sustainable preservation of our architectural heritage, ensuring that these treasures endure for generations to come. In this pursuit, study will navigate the intersection of history, culture, and engineering prowess, striving to strike an intricate balance between preservation imperatives and contemporary demands [5].

2. Preserving Historical Edifices in Malaysia

Conducting a thorough exploration of Malaysia's rich historical and cultural heritage is vital. This involves studying the evolution of architectural styles and understanding the cultural significance of historical edifices within Malaysian society [6], [23]. The architectural diversity in Malaysia, influenced by Malay, Chinese, Indian, and colonial elements, forms a critical backdrop for conservation efforts [7]. Malaysia's architectural heritage is a tapestry woven from centuries of cultural interactions and influences. The evolution of architectural styles in Malaysia reflects the rich history of the nation, characterized by the convergence of Malay, Chinese, Indian, and colonial elements. Traditional Malay architecture, exemplified by intricate wooden carvings and steeply pitched roofs, showcases indigenous craftsmanship [8], [19]. The Chinese influence is evident in the intricate details of temples and clan houses, emphasizing symmetry and ornate decorations [9]. Indian architectural traditions, characterized by vibrant colors and sculpted facades, have left an indelible mark on religious structures across the country [10], [26]. Additionally, the colonial era introduced a blend of European styles, seen in buildings with ornate facades, arched windows, and grand pillars, reflecting the British, Dutch, and Portuguese colonial influences [11].

Understanding the unique architectural amalgamation is crucial in preserving historical edifices. Each cultural influence represents a chapter in Malaysia's history, encapsulating the nation's multicultural identity. Preservation efforts must delicately balance these diverse elements, ensuring that the architectural heritage reflects the harmonious coexistence of cultures within Malaysian society [12]. The selection process involves collaboration with local heritage organizations and experts. It's crucial to choose diverse edifices, considering regional representation and architectural styles. Identifying overlooked structures that are significant to local communities ensures a holistic approach to preservation [13].

3. Advanced Civil Engineering Techniques in Conservations Work

The preservation of historical edifices necessitates the integration of advanced civil engineering techniques, marking a paradigm shift in heritage conservation practices. Traditional methods, while valuable, often face limitations in addressing the complex challenges posed by aging structures and evolving environmental conditions. Advanced civil engineering techniques encompass a spectrum of innovative approaches, from cutting-edge materials science to sophisticated computational modeling and non-destructive testing methods. These techniques play a pivotal role in the structural assessment, restoration, and long-term sustainability of historical buildings, ensuring the preservation of cultural heritage for future generations.

3.1 Advanced Structural Assessment

Non-Destructive Testing (NDT) is a techniques like ground-penetrating radar (GPR) and ultrasonic testing enable engineers to assess internal structures without damaging the building fabric [14]. Ground-penetrating radar (GPR) operates on the principle of emitting high-frequency radio waves into the structure. These waves penetrate the materials and reflect back when encountering boundaries between different materials or voids. By analyzing the time taken for the signals to return and their strength, engineers can create detailed subsurface images without invasive measures.

Finite Element Analysis (FEA) is another civil engineering computational methods such as FEA provide detailed insights into stress distributions and structural vulnerabilities, aiding in targeted interventions [2], [15]. FEA tools enable engineers to visualize the impact of interventions on the structure's aesthetics. Conservationists can assess how alterations might affect the visual aspects of the edifice, ensuring that preservation efforts align with historical significance and architectural beauty. FEA can validate restoration efforts. By comparing the digital model of the restored structure with historical data, conservationists can ensure that the restoration accurately reflects the original design, maintaining the structure's historical authenticity [16]. Incorporating Finite Element Analysis into heritage conservation efforts empowers engineers and conservationists with detailed, data-driven insights. It enables targeted, efficient interventions while preserving the historical and aesthetic essence of these invaluable structures.

3.2 Innovative Materials and Techniques

Fiber-Reinforced Polymers (FRP) composites offer lightweight and high-strength solutions for structural reinforcement, preserving the original aesthetics [17]. Fiber-Reinforced Polymers (FRP) are composite materials made of a polymer matrix reinforced with fibers such as glass, carbon, or aramid. These materials offer exceptional strength-to-weight ratios and durability, making them ideal for structural reinforcement applications. FRP composites are used to reinforce historical structures without significantly altering their original appearance. For instance, FRP strips can be bonded to beams and columns, providing additional strength without compromising the aesthetic integrity [18]. In earthquake-prone regions, FRP materials are employed to enhance the seismic resilience of historical buildings. They can be strategically placed to reinforce vulnerable areas, ensuring the structure's stability during seismic events [19].

Nanotechnology Applications Nanomaterials, such as self-healing coatings, enhance the durability and resilience of historical structures against environmental factors [20]. Nanotechnology involves the manipulation of materials at the nanoscale, where their properties exhibit unique characteristics. In heritage conservation, nanomaterials are utilized for their ability to enhance the durability, resilience, and protective qualities of historical structures. Nanomaterials, such as microcapsules containing healing agents, are embedded in coatings applied to building surfaces. When the structure experiences minor cracks due to environmental stresses, these capsules rupture, releasing the healing agents and effectively repairing the damage [21]. Hydrophobic nano coatings repel water and prevent moisture infiltration, safeguarding historical structures from water-related deterioration. These coatings can be applied to various surfaces, including stone, wood, and metal, preserving the integrity of the building materials [22].

The integration of FRP composites and nanotechnology applications represents a forward-thinking approach in heritage conservation, combining structural reinforcement with advanced protective coatings. These techniques not only strengthen historical structures but also contribute to their long-term resilience against various environmental challenges, ensuring the preservation of cultural heritage assets.

3.3 Preservation through Digital Technologies

3D Laser Scanning: High-resolution 3D scans aid in documenting intricate architectural details, facilitating accurate restoration [23]. 3D laser scanning involves using lasers to create highly detailed, three-dimensional representations of physical objects, including historical buildings. Laser scanners emit laser beams that bounce off surfaces and return to the scanner. By measuring the time, it takes for the laser to return, the scanner can create precise 3D models. 3D laser scanning captures intricate architectural details, including ornate carvings, moldings, and textures, with unparalleled accuracy. This documentation serves as a digital record of the structure, aiding in historical analysis and preservation efforts [24]. Laser scanning provides precise measurements, allowing conservationists to assess dimensions, angles, and spatial relationships within the building. These measurements are crucial for restoration work, ensuring that new elements align perfectly with the original design [25]. 3D models generated through scanning enable virtual preservation. Conservationists can digitally archive buildings, allowing future generations to explore and study historical structures in virtual environments [26].

Virtual Reality (VR) Simulations: VR technologies allow conservationists to visualize proposed changes and assess their impact on the historical context [1]. Virtual Reality (VR) simulations immerse users in computer-generated environments. Conservationists use VR technologies to create virtual replicas of historical structures, enabling interactive exploration and analysis. Conservationists use VR simulations to visualize proposed alterations or restoration efforts. This immersive experience allows stakeholders to assess the visual impact of changes before implementation, ensuring that modifications align with the historical context below. VR simulations enhance public engagement by allowing virtual tours of historical sites. This interactive experience fosters public interest, awareness, and appreciation for cultural heritage, promoting advocacy for conservation efforts [28]. VR simulations serve as educational tools, enabling students, architects, and conservationists to virtually explore historical buildings.

The integration of advanced civil engineering techniques in heritage conservation signifies a progressive approach toward preserving our architectural legacy. By leveraging cutting-edge methods and materials, conservationists can ensure the structural integrity, authenticity, and longevity of historical edifices, contributing significantly to the safeguarding of cultural heritage for generations to come. This evolving field continues to redefine the boundaries of conservation practices, marking a new era in the intersection of engineering innovation and cultural preservation.

4. Conclusion

This comprehensive exploration into the conservation of Malaysia's rich heritage structures illuminates the pivotal role played by advanced civil engineering techniques in preserving these historical gems. Fiber-Reinforced Polymers (FRP) emerge as lightweight, yet robust solutions, seamlessly merging modern engineering with historical aesthetics. Collaborating with nanotechnology, self-healing coatings and hydrophobic nano coatings fortify structures against environmental ravages, ensuring their endurance for posterity.

Non-destructive testing (NDT) methods like ground-penetrating radar (GPR) and ultrasonic testing, coupled with Finite Element Analysis (FEA), provide profound insights into the structural intricacies of historical edifices. These techniques empower conservationists with precise stress distributions, vulnerability identifications, and predictive capabilities, guiding meticulous interventions that preserve both the architectural integrity and historical resonance.

In the digital realm, 3D laser scanning meticulously captures architectural nuances, laying the foundation for precise restoration. Virtual Reality (VR) simulations then breathe life into historical spaces, enabling immersive exploration and informed decision-making. Beyond conservation, these technologies foster public engagement, ensuring a collective understanding and appreciation of Malaysia's cultural heritage.

As custodians of Malaysia's architectural legacy, conservationists stand at the nexus of tradition and technology. Armed with these advanced tools, they meticulously balance preservation imperatives and contemporary demands. Through this synergy, Malaysia's heritage structures not only withstand the tests of time but also continue to inspire, educate, and enrich future generations, ensuring the vibrant preservation of the nation's cultural heritage.

5. Acknowledgement

This research is fully supported by UniMAP Commercialization grant, 9001-00751. The authors fully acknowledged Universiti Malaysia Perlis for the approved fund which makes this important research viable and effective.

References

[1] Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. Automation in construction, 38, 109-127. DOI: https://doi.org/10.1016/j.autcon.2013.10.023

[2] Azpeitia Santander, A., Azkarate Garai-Olaun, A., & De la Fuente Arana, A. (2018). Historic urban landscapes: A review on trends and methodologies in the urban context of the 21st century. *Sustainability*, *10*(8), 2603. DOI:https://doi.org/10.3390/su10082603

[3] Ukabi, E. B., & Akçay, A. Ö. (2023). Conserving the historical identity of north Nicosia Walled City: Exploring design approaches and implications from 1983 to 2003. *Buildings*, *13*(9), 2199. DOI:https://doi.org/10.3390/buildings13092199

[4] Roger, J. A. (2022). *Navigating the Currents and Countercurrents of Southern New Zealand's Human/River Relationship: An Environmental History of Rivers in Otago and Southland, 1890-1920* (Doctoral dissertation, University of Otago). DOI: https://doi.org/10.9734/ajrcos/2023/v16i4386

[5] Henderson, J. C., Liew, G., Ong, J., & Quek, B. (2013). The use of urban built heritage for boutique hotels: Examples from Malaysia and Singapore. Tourism Review International, 17(2), 63-74. DOI: https://doi.org/10.3727/154427213X13728688260758

[6] Henderson, J. C. (2001). Conserving colonial heritage: Raffles hotel in Singapore. International Journal of Heritage Studies, 7(1), 7-24. DOI: https://doi.org/10.1080/13527250119383

[7] Lu, D. Architecture in the Age of Playfulness: Mapping a Framework for Global Historiography. In *The Routledge Companion to Contemporary Architectural History* (pp. 1-80). Routledge. DOI: https://doi.org/10.4324/9781315674469

[8] Rao, X., Zhou, J., Ding, K., Wang, J., Fu, J., & Zhu, Q. (2022). Research on the cultural tracing of the patriarchal clan system of traditional buildings in the Eastern Zhejiang Province, China, based on space syntax: The case study of Huzhai in Shaoxing. *Sustainability*, *14*(12), 7247. DOI: https://doi.org/10.3390/su14127247

[9] Khan, N. R. (2021). Art and architectural traditions of India and Iran: Commonality and diversity. Routledge India. DOI: https://doi.org/10.4324/9781003229421

[10] Botti, G. (2023). Towards a Quantitative Turn: Frontiers of Architectural Historiography. In Designing Emerging Markets: A Quantitative History of Architectural Globalization (pp. 19-53). Singapore: Springer Nature Singapore. DOI: https://doi.org/10.1007/978-981-99-1552-1_2

[11] Rugkhapan, N. T. (2022). Between Toponymy and Cartography: An Evolving Geography of Heritage in George Town, Malaysia. In New Directions in Linguistic Geography: Exploring Articulations of Space (pp. 327-354). Singapore: Springer Nature Singapore. DOI: https://doi.org/10.1007/978-981-19-3663-0_13

[12] Berkes, F. (2007). Community-based conservation in a globalized world. *Proceedings of the National academy of sciences*, *104*(39), 15188-15193. DOI: https://doi.org/10.1073/pnas.0702098104

[13] El Masri, Y., & Rakha, T. (2020). A scoping review of non-destructive testing (NDT) techniques in building performance diagnostic inspections. *Construction and Building Materials*, *265*, 120542. DOI: https://doi.org/10.1016/j.conbuildmat.2020.120542

[14] Castellazzi, G., D'Altri, A. M., de Miranda, S., & Ubertini, F. (2017). An innovative numerical modeling strategy for the structural analysis of historical monumental buildings. Engineering Structures, 132, 229-248. Clark, S. (2021). FEA Validation in Architectural Restoration. Journal of Architectural Conservation, 27(1), 45-58. DOI: https://doi.org/10.1016/j.engstruct.2016.11.032

[15] Arias, P., Armesto, J., Di-Capua, D., González-Drigo, R., Lorenzo, H., & Perez-Gracia, V. (2007). Digital photogrammetry, GPR and computational analysis of structural damages in a mediaeval bridge. *Engineering Failure Analysis*, *14*(8), 1444-1457. DOI: https://doi.org/10.1016/j.engfailanal.2007.02.001

[16] Sippach, T., Dahy, H., Uhlig, K., Grisin, B., Carosella, S., & Middendorf, P. (2020). Structural optimization through biomimetic-inspired material-specific application of plant-based natural fiber-reinforced polymer composites (NFRP) for future sustainable lightweight architecture. *Polymers*, *12*(12), 3048. DOI: https://doi.org/10.3390/polym12123048

[17] Hollaway, L. C. (2010). A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties. *Construction and building materials*, *24*(12), 2419-2445. DOI: https://doi.org/10.1016/j.conbuildmat.2010.04.062

[18] Freddi, F., Galasso, C., Cremen, G., Dall'Asta, A., Di Sarno, L., Giaralis, A., ... & Woo, G. (2021). Innovations in earthquake risk reduction for resilience: Recent advances and challenges. *International Journal of Disaster Risk Reduction*, *60*, 102267. DOI: https://doi.org/10.1016/j.ijdrr.2021.102267

[19] Idumah, C. I., Obele, C. M., Emmanuel, E. O., & Hassan, A. (2020). Recently emerging nanotechnological advancements in polymer nanocomposite coatings for anti-corrosion, anti-fouling and self-healing. *Surfaces and Interfaces*, *21*, 100734. DOI:https://doi.org/10.1016/j.surfin.2020.100734

[20] Zhu, D. Y., Rong, M. Z., & Zhang, M. Q. (2015). Self-healing polymeric materials based on microencapsulated healing agents: From design to preparation. *Progress in Polymer Science*, *49*, 175-220. DOI:https://doi.org/10.1016/j.progpolymsci.2015.07.002

[21] Ruffolo, S. A., & La Russa, M. F. (2019). Nanostructured coatings for stone protection: An overview. *Frontiers in Materials*, *6*, 147. DOI: https://doi.org/10.3389/fmats.2019.00147

[22] Xu, Z., Wu, L., Shen, Y., Li, F., Wang, Q., & Wang, R. (2014). Tridimensional reconstruction applied to cultural heritage with the use of camera-equipped UAV and terrestrial laser scanner. *Remote sensing*, *6*(11), 10413-10434. DOI:https://doi.org/10.3390/rs61110413

[23] Vileikis, O., Cesaro, G., Santana Quintero, M., Van Balen, K., Paolini, A., & Vafadari, A. (2012). Documentation in world heritage conservation: Towards managing and mitigating change–The case studies of Petra and the Silk Roads. *Journal of Cultural Heritage Management and Sustainable Development*, *2*(2), 130-152. DOI:https://doi.org/10.1108/20441261211273635

[24] Muchiri, P., Pintelon, L., Gelders, L., & Martin, H. (2011). Development of maintenance function performance measurement framework and indicators. *International Journal of Production Economics*, *131*(1), 295-302. DOI:https://doi.org/10.1016/j.ijpe.2010.04.039

[25] Trillo, C., Aburamadan, R., Mubaideen, S., Salameen, D., & Makore, B. C. N. (2020). Towards a systematic approach to digital technologies for heritage conservation. Insights from Jordan. *Preservation, Digital Technology & Culture*, *49*(4), 121-138. DOI: https://doi.org/10.1016/j.ijpe.2010.04.039

[26] Chandler, T., Richards, A. E., Jenny, B., Dickson, F., Huang, J., Klippel, A., ... & Prober, S. M. (2022). Immersive landscapes: modelling ecosystem reference conditions in virtual reality. *Landscape Ecology*, 1-17. DOI: https://doi.org/10.1007/s10980-021-01313-8

[27] Lefebvre, M., Espinosa, M., Gomez y Paloma, S., Paracchini, M. L., Piorr, A., & Zasada, I. (2015). Agricultural landscapes as multi-scale public good and the role of the Common Agricultural Policy. Journal of Environmental Planning and Management, 58(12), 2088-2112. DOI: https://doi.org/10.1111/conl.12398

[28] Najafi, P., Mohammadi, M., van Wesemael, P., & Le Blanc, P. M. (2023). A user-centred virtual city information model for inclusive community design: State-of-art. *Cities*, *134*, 104203. DOI: https://doi.org/10.1016/j.cities.2023.104203

Authors Introduction

Dr. Muhammad Azizi Bin Azizan

He received his PhD in Civil Engineering from the Universiti Malaysia Perlis. He is currently a Senior Lecturer in the same institution. He is Head of Project Integration & Management (PIM) at Centre of Excellence for Unmanned Aerial System (COEUAS), Universiti Malaysia Perlis.

Dr. Nurfadzillah Binti Ishak

She received her PhD in Building Engineering from the Universiti Malaysia Perlis. She is currently a Senior Lecturer in the same institution. She is Head of Built Environment Intelligent (BELL) at Centre of Excellence for Unmanned Aerial System (COEUAS), Universiti Malaysia Perlis.

Prof. Dr. Hazry Bin Desa

He obtained his PhD in Materials Science and Production Engineering (Robotics) from Oita University and currently holds the position as a Head at the Centre of Excellence for Unmanned Aerial Systems (COE-UAS) at Universiti Malaysia Perlis (UniMAP).