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Integrating BIM and Laser Scanning Technologies for Efficient and Effective Restoration of Heritage Structures in the Context of Post-disaster Recovery

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Abstract
The restoration of heritage structures in the aftermath of disasters presents a complex challenge that demands innovative solutions. This research explores the synergies between Building Information Modeling (BIM) and Laser Scanning Technologies to enhance the efficiency and effectiveness of heritage structure restoration within the context of post-disaster recovery. BIM, with its capacity for comprehensive digital representation, facilitates collaborative planning and coordination among diverse stakeholders involved in the restoration process. Laser scanning technologies, on the other hand, offer precise and detailed 3D data capture, enabling accurate documentation of the existing conditions of heritage structures. The integration of these technologies not only aids in the creation of detailed as-built models but also streamlines decision-making processes, minimizes errors, and improves communication among interdisciplinary teams. This study delves into case studies and practical applications to assess the impact of BIM and Laser Scanning Technologies on the restoration of heritage structures, highlighting their role in preserving cultural heritage while ensuring the resilience and sustainability of these structures in the face of disasters. The findings contribute valuable insights to the field of heritage conservation and disaster recovery, advocating for the adoption of integrated technologies to advance the restoration processes for resilient and sustainable outcomes.

Keywords
Heritage, Restoration, Building Information Modeling (BIM), Laser Scanning (LS), Post Disaster Recovery.

1. Introduction

Preserving architectural heritage poses a significant challenge for contemporary society, requiring the attention of governments and local administrations to safeguard unique sources of aesthetic, historical, and cultural values (Cursi et al., 2015, cited in Ferro et al., 2023). The impact of globalization has rapidly transformed cities, emphasizing the importance of a considerate approach to cultural heritage and conservation culture. Heritage awareness is crucial, particularly as natural disasters often damage heritage sites. Restoring the cultural history of a site is a key strategy for preservation, aiming to return it to its original state from archaeological, historical, and technical perspectives. Heritage buildings, often characterized by complex (non-parametric) geometries, face challenges in digitization through conventional methods, leading to inaccuracies and time-consuming processes. Numerous studies are exploring the integration of cultural heritage protection with modern technologies like video, virtual reality, and 3D models to ensure the protection and inheritance of cultural heritage.

In the field of cultural heritage documentation, Building Information Modeling (BIM) has witnessed growth over the past decade, disrupting the way experts document and preserve historical monuments (Nasir et al., 2022). This methodology extends to the digitization of building heritage, improving processes related to the management and monitoring of historical-cultural heritage assets (Moyano et al., 2022, cited in Ferro et al., 2023). BIM tools contribute to three-dimensional architectural reconstruction, incorporating benefits such as design calculations, cost estimates, material quantifications, data management, as-built documentation, constructive state analysis, execution plans, and more (Rocha et al., 2020).

Thapa et al. (2022) highlight that BIM, integrated with 3D laser scanning (LIDAR) and photogrammetry technologies, has revolutionized the documentation and restoration of heritage sites, introducing Heritage Building

Information Modeling (HBIM). The scan-to-BIM approach is a relatively new methodology, transforming raw data from Terrestrial Laser Scanner and photogrammetric survey acquisitions into a smart structured model linked to a digital information system, allowing the effective management, extraction, and updating of geometric and non-geometric information of existing buildings (Arico et al., 2022).

While various studies explore digitization approaches in different contexts, there is a lack of a comprehensive and systematic study of digital heritage technologies in post-disaster recovery settings. Therefore, this research aims to develop a digitization approach to preserve and promote local cultural heritage, addressing how to preserve, maintain, and promote cultural heritage post-disaster. The digital shift, particularly linked with BIM technology, can offer a new level of understanding, accessibility, and progress. The study's focus on enhancing Scan to BIM Heritage methodologies presents a valuable instrument in addressing building degradation due to natural disasters. This research paper conducts a systematic literature review to comprehensively understand the integration's significance in the field of heritage restoration.

The primary objectives of this research endeavor are to conduct a comprehensive examination of existing literature about various digital technologies, with a specific focus on Building Information Modeling (BIM) and Laser Scanning (LS), and their applications in the post-disaster recovery of cultural heritage. The research endeavors to delve into the significance of cultural heritage and digital heritage technologies in the aftermath of disaster scenarios, aiming to discern their roles and contributions. Furthermore, the research places particular emphasis on a meticulous investigation of the integration of BIM and LS technologies to facilitate the efficient and effective restoration of cultural heritage structures. The overarching research question guiding this inquiry is as follows: "How does the integration of Building Information Modeling (BIM) and Laser Scanning Technologies contribute to the efficient and effective restoration of heritage structures as part of the post-disaster recovery process?"

2. Literature Review

2.1 Digital Heritage Technologies: Laser Scanning, BIM and HBIM

Digital Heritage, a rapidly growing field, fosters novel collaborations across diverse sectors by integrating cutting-edge technologies with heritage information. It plays a crucial role in global accessibility to cultural and historical information, preserving it for posterity while leveraging modern technology to deepen our understanding and appreciation of shared history and culture. Technologies like Laser Scanning and Building Information Modeling (BIM) contribute significantly to the restoration of heritage structures, documenting them in their current state.

Laser scanning, as defined by Costa et al. (2017), involves using a laser device to collect 3D coordinates systematically and rapidly, generating real-time results. This emerging digital tool revolutionizes how heritage professional documents build resources, producing accurate 3D models of spaces through point clouds. These point clouds enable the creation of diverse deliverables such as video walkthroughs, orthographic images, architectural drawings, models, and engineering plans, making 3D laser scanning an efficient solution for documenting various heritage resources within tight time constraints.

BIM, or Building Information Modeling, represents the digital portrayal of an object's physical and functional characteristics, forming a shared information resource throughout its life cycle. The Level of Development (LOD) in BIM determines the required graphic and non-graphic information for an element at specific developmental stages. The six basic LODs, specified by BIM Forum (2021), range from LOD100 to LOD500, ensuring effective project planning, 3D coordination, and information transfer.

2.2 Integration of BIM and Laser Scanning

The emergence of technologies like Laser Scanner coupled with Building Information Modeling (BIM) presents a potent means to enhance efficiency, delivering precise data in less time. Introducing digital technologies, particularly BIM, in documenting built heritage enables the creation of 3D parametric models serving as efficient communication tools. These models encapsulate historical data, conservation status, material specifics, and construction techniques. BIM's capacity to integrate diverse layers of information facilitates cross-industry, community, and educational collaboration with flexibility and timeliness surpassing traditional methods.

In the context of existing structures, Gorkovchuk and Gorkovchuk (2022) outline tasks in BIM implementation for reconstruction, including recovering lost documentation, converting 2D documents into BIM format, updating models from surveys, new BIM modeling, and implementing automated real estate management systems.

Liu et al. (2021) emphasize the symbiosis of BIM and 3D laser scanner point clouds, highlighting their utility in construction tracking, quality control, site safety, structural health monitoring, disaster recovery, energy modeling, and management for existing buildings. The integration of BIM and Laser Scanning Technologies is particularly pivotal in the efficient restoration of heritage structures during post-disaster recovery. Given the historical and architectural significance of heritage structures, these advanced technologies emerge as indispensable tools for meticulous and effective restoration efforts. (Aburamadan et al., 2022; Gorkovchuk & Gorkovchuk, 2022; Liu et al., 2021).

2.3 Scan–To–BIM process

Scan-to-BIM is a workflow transforming laser scanning data into a structured and semantic digital information system, as defined by Volk et al. (2014, cited in Arico et al., 2022). This process integrates photogrammetry and laser scanning, capturing physical spaces to create a smart model using BIM software (Rashdi et al., 2022). Laser scanning employs a scanning head emitting a laser beam, producing a point cloud that represents the entire space scanned. The speed of the scanning head, reaching up to 1 million points per second, depends on the type of scanner (pulse or phase) (Uchański & Karsznia, 2018). Following the laser scan, a three-dimensional model is created with a communication code based on standardized classification plans. The process involves filtering registered data, indexing clouds in Autodesk RECAP 360, implementing them into Autodesk REVIT, and developing project documentation, including unit price lists, quantity take-offs, and technical data sheets (Utica et al., 2017).

Case studies, such as "The Lyric Theater of Milan," demonstrate the effectiveness of combining laser scanner technology with BIM. This Scan-to-BIM methodology yields faster and more accurate surveys, consistent 3D models based on laser scanning, and cohesive project documentation derived from a single database. While highly efficient, the methodology faces challenges in parametric modeling for heritage buildings due to their inherent structural and architectural complexities (Arico et al., 2022). Thus, Scan-to-BIM, utilizing 3D laser scanning and BIM, offers a powerful and efficient tool for integrating multidisciplinary information of heritage structures into a unified digital environment.

3. Methodology

A systematic literature review was carried out as a research methodology. According to Khan et.al. (2003), the first and foremost thing done during this literature review was to frame the research questions. Once, the research questions were outlined, relevant publications were identified through identification, screening, and inclusion. Thematic analysis is used for the synthesis of data. The data extraction and synthesis process for thematic synthesis utilizes thematic analysis; themes are extracted from the literature, clustered, and eventually synthesized into analytical themes. These analytical themes, similar in their construction to third-order constructs, are then used to answer the research question (Xiao & Watson, 2019). Google Scholar, and One Search –Library Online Database was mainly used and Research-Gate was used as a supplement to obtain journal articles and research papers.

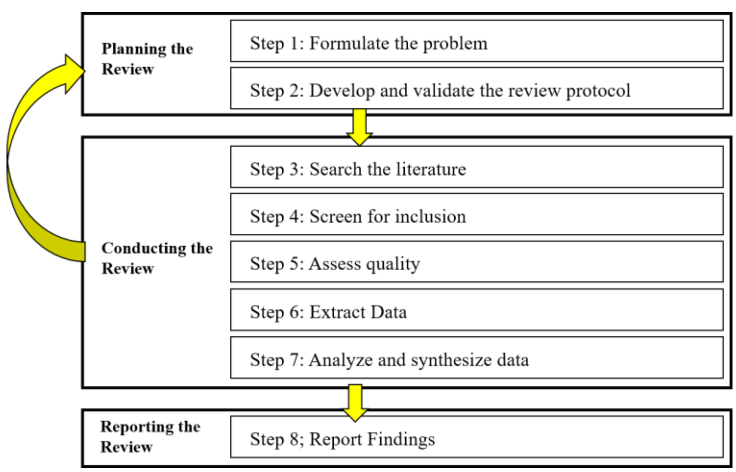


Fig. 1. Process of Systematic Literature Review (Source: Xiao & Watson, 2019).

An extensive search of keywords is carried out to systematically find the existing data from several databases to comply with the research questions. The titles and keywords were used in the search process to find resources on the exact research topics. I used retrieval formula "((TITLE (("point cloud" OR "laser scan*") AND "BIM") OR KEY (("point cloud" OR "laser scan*") AND "BIM")) AND PUBYEAR > 2009)" to conduct literature search. Also, Boolean operators were used to collect data for this review appropriate to the topic. Table 1 lists the Boolean Operators and the terms used.

Table 1. Boolean Operators

Key Terms	Boolean Operators
Restoration	"Reconstruction" **OR** "Rebuilding" **OR** "Rehabilitation"
Post Disaster Recovery	"Disaster management" **OR** "Disaster Mitigation" **OR** "Disaster Relief"
Integration	"Integration" **OR** "Incorporating" **OR** "Incorporation"
Laser Scanning	"LiDAR" **OR** "Terrestrial Laser Scanning"

In addition, the language was restricted to English and only research papers & journal articles were selected. As shown in Figure 2, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram was used for performing a systematic analysis. After using the keywords and terms, resources identified through database searching were 60. Out of which, after removing the duplicates the resources screened were 50. Finally, through reading the abstract and keywords, the 40 met the inclusion criteria and formed the basis of this systematic literature review. The 40 research resources had 22 journal articles and 18 research papers. These include 15 works of literature that had Scan – to – BIM methodology, 12 literatures that focus on the integration of BIM and LS on applications in the life cycle of building, 5 kinds of literature on HBIM and its application, 5 kinds of literature on application of BIM for the disaster recovery, and 3 kinds of literature on use of BIM for other purposes like 3D printing, VR & community engagement.

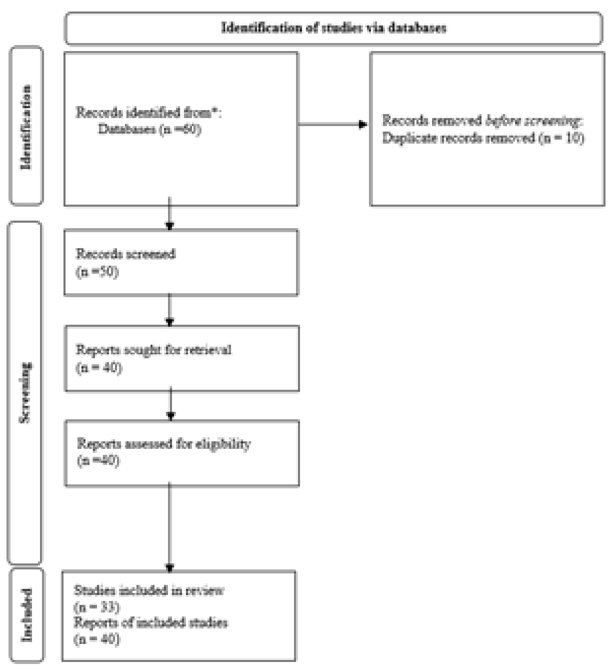
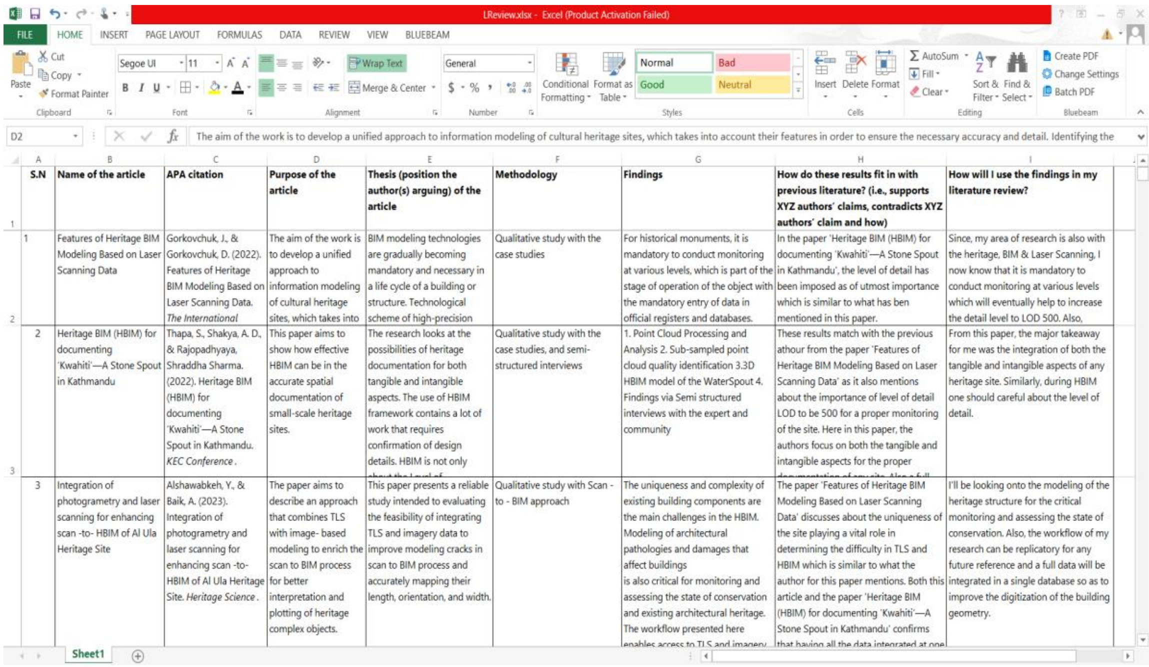


Fig. 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Flow Diagram

As suggested by Galvan, J. & Galvan, M. (2017), a spreadsheet as shown in Figure 3 was created for the thematic analysis of the resources, and 33 of these literature are used as references. We can see that literatures mostly involve Post Disaster Recovery, Cultural Heritage, and Digital Heritage Technologies BIM and LS. These articles inspire the methodology and process of study.



S.N	Name of the article	APA citation	Purpose of the article	Thesis (position the author(s) arguing) of the article	Methodology	Findings	How do these results fit in with previous literature? (i.e., supports XYZ authors' claims, contradicts XYZ authors' claim and how)	How will I use the findings in my literature review?
1	Features of Heritage BIM Modeling Based on Laser Scanning Data	Gorkovchuk, J., & Gorkovchuk, D. (2022). Features of Heritage BIM Modeling Based on Laser Scanning Data. *The International*	The aim of the work is to develop a unified approach to information modeling of cultural heritage sites, which takes into	BIM modeling technologies are gradually becoming mandatory and necessary in a life cycle of a building or structure. Technological scheme of high-precision	Qualitative study with the case studies	For historical monuments, it is mandatory to conduct monitoring at various levels, which is part of the stage of operation of the object with the mandatory entry of data in official registers and databases.	In the paper 'Heritage BIM (HBIM) for documenting 'Kwahiti'—A Stone Spout in Kathmandu', the level of detail has been imposed as of utmost importance which is similar to what has ben mentioned in this paper.	Since, my area of research is also with the heritage, BIM & Laser Scanning, I now know that it is mandatory to conduct monitoring at various levels which will eventually help to increase the detail level to LOD 500. Also,
2	Heritage BIM (HBIM) for documenting 'Kwahiti'—A Stone Spout in Kathmandu	Thapa, S., Shakya, A. D., & Rajopadhyaya, Shraddha Sharma. (2022). Heritage BIM (HBIM) for documenting 'Kwahiti'—A Stone Spout in Kathmandu. *KEC Conference*.	This paper aims to show how effective HBIM can be in the accurate spatial documentation of small-scale heritage sites.	The research looks at the possibilities of heritage documentation for both tangible and intangible aspects. The use of HBIM framework contains a lot of work that requires confirmation of design details. HBIM is not only	Qualitative study with the case studies, and semi-structured interviews	1. Point Cloud Processing and Analysis 2. Sub-sampled point cloud quality identification 3.3D HBIM model of the WaterSpout 4. Findings via Semi structured interviews with the expert and community	These results match with the previous athour from the paper 'Features of Heritage BIM Modeling Based on Laser Scanning Data' as it also mentions about the importance of level of detail LOD to be 500 for a proper monitoring of the site. Here in this paper, the authors focus on both the tangible and intangible aspects for the proper	From this paper, the major takeaway for me was the integration of both the tangible and intangible aspects of any heritage site. Similarly, during HBIM one should careful about the level of detail.
3	Integration of photogrametry and laser scanning for enhancing scan -to- HBIM of Al Ula Heritage Site	Alshawabkeh, Y., & Baik, A. (2023). Integration of photogrametry and laser scanning for enhancing scan -to- HBIM of Al Ula Heritage Site. *Heritage Science*.	The paper aims to describe an approach that combines TLS with image- based modeling to enrich the scan to BIM process for better interpretation and plotting of heritage complex objects.	This paper presents a reliable study intended to evaluating the feasibility of integrating TLS and imagery data to improve modeling cracks in scan to BIM process and accurately mapping their length, orientation, and width.	Qualitative study with Scan - to - BIM approach	The uniqueness and complexity of existing building components are the main challenges in the HBIM. Modeling of architectural pathologies and damages that affect buildings is also critical for monitoring and assessing the state of conservation and existing architectural heritage. The workflow presented here	The paper 'Features of Heritage BIM Modeling Based on Laser Scanning Data' discusses about the uniqueness of the site playing a vital role in determining the difficulty in TLS and HBIM which is similar to what the author for this paper mentions. Both this article and the paper 'Heritage BIM (HBIM) for documenting 'Kwahiti'—A Stone Spout in Kathmandu' confirms	I'll be looking onto the modeling of the heritage structure for the critical monitoring and assessing the state of conservation. Also, the workflow of my research can be replicatory for any future reference and a full data will be integrated in a single database so as to improve the digitization of the building geometry.

Fig. 3. Thematic Analysis Using Spreadsheet

4. Results and Findings

According to UNISDR (2009), disasters are abrupt events causing disruptions in societies, leading to losses in human lives, material assets, and the environment. Over recent decades, the frequency of natural disasters has surged, resulting in substantial human and economic losses. Events such as the 2004 Indian tsunami, 2005 Hurricane Katrina in New Orleans, 2010 earthquake in Haiti, 2010 floods in Pakistan, 2013 fire in China, and 2015 earthquake in Nepal have profoundly impacted countries, challenging their development on a large scale. During major disasters, cultural heritage emerges as a crucial component, offering familiarity and reassurance to affected communities (Spennemann & Graham, 2007, cited in K.C. et al., 2019). It becomes a key element in assisting communities to cope with the psychological impact of the disaster. Preserving cultural heritage in the aftermath of a disaster becomes integral for the emotional well-being of the affected community during the recovery phase. The post-disaster recovery and reconstruction process is a vital component of mitigating the impact of calamities on communities and infrastructure. Following Alexander's (2002) framework, which identifies four phases—mitigation, preparedness, response, and recovery—the focus of this discussion centers on the recovery phase, particularly in the context of building assessment and repair strategies after a disaster. Building assessment emerges as a critical activity during the short-term recovery phase, as highlighted by FEMA (2019). This initial step plays a pivotal role in determining the strategic approach to building repairs. Effective building assessment ensures that resources are directed where they are most needed, optimizing the recovery process.

The application of technology emerges as a powerful solution for the conservation of cultural heritage in the recovery process. Technological advancements offer innovative methods for documenting, preserving, and restoring cultural artifacts and sites. These technologies not only aid in conservation efforts but also contribute to the dissemination of cultural knowledge and history. Emerging technologies in the construction sector, such as Building Information Modelling (BIM), image processing, and artificial intelligence, offer significant potential in addressing challenges related to post-disaster recovery (Pizzi et al., 2020, cited in Oktavianus et al., 2022). The integration of BIM with Laser Scanning (LS) emerges as a particularly effective approach in assessing and reconstructing buildings damaged in disasters. Examples include the Notre Dame Church, in Paris as shown in Figure 4 which was unfortunately destroyed by tragic fire. In this case, digital technologies, specifically laser scanning, played a crucial role in the reconstruction process. After the devastating fire in 2019, laser scanning data facilitated the creation of a highly detailed 3D model of the structure. This data not only assisted in assessing the damage but also became a valuable resource for architects and engineers during the reconstruction. The 3D model allowed for precise measurements and analysis, streamlining the restoration efforts and contributing to the accuracy and efficiency of the reconstruction process.

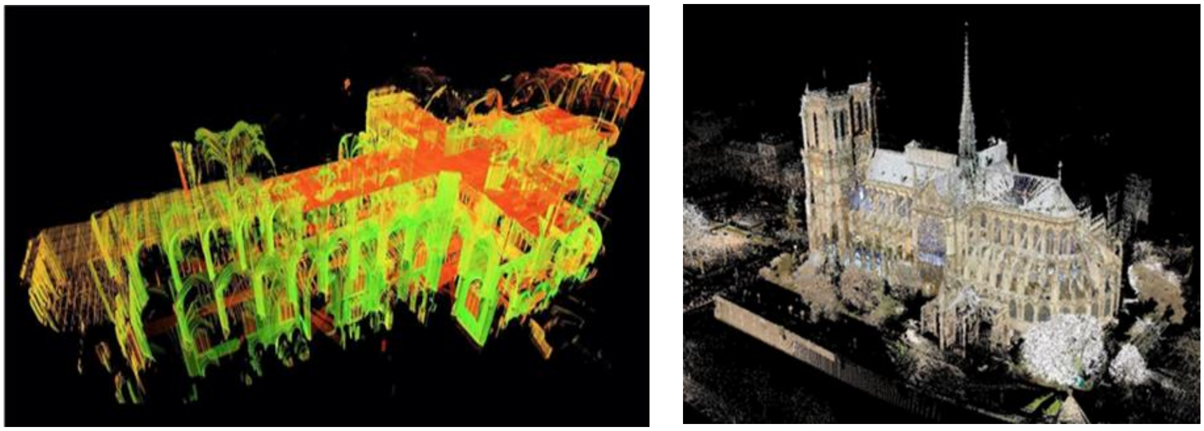


Fig. 4. 3D-Model of Notre Dame, Paris (Source: https://www.cnn.com/style/article/notre-dame-andrew-tallon-laser-scan-trnd/index.html)

The utilization of Scan-to-BIM, incorporating 3D laser scanning and BIM, provides a potent and effective method for consolidating multidisciplinary information related to heritage structures in a cohesive digital setting. This approach streamlines the development of documentation that can be easily updated and expanded. Additionally, BIM and laser scanning play a crucial role in preserving historical accuracy by documenting architectural features in a digital environment, serving as a valuable reference for ongoing maintenance and preservation. BIM further supports structural analysis and testing, ensuring compliance with modern building codes and safety standards. Real-time monitoring capabilities empower restoration teams to make prompt adjustments, and the BIM model continues to serve as a comprehensive record post-restoration. The digital record created by these technologies also acts as a resource for future preservation, facilitating potential restoration efforts. The collaborative nature of BIM enhances coordination among stakeholders, contributing to a streamlined and efficient restoration process. The suggested workflow is outlined in the chart as shown in Figure 5.

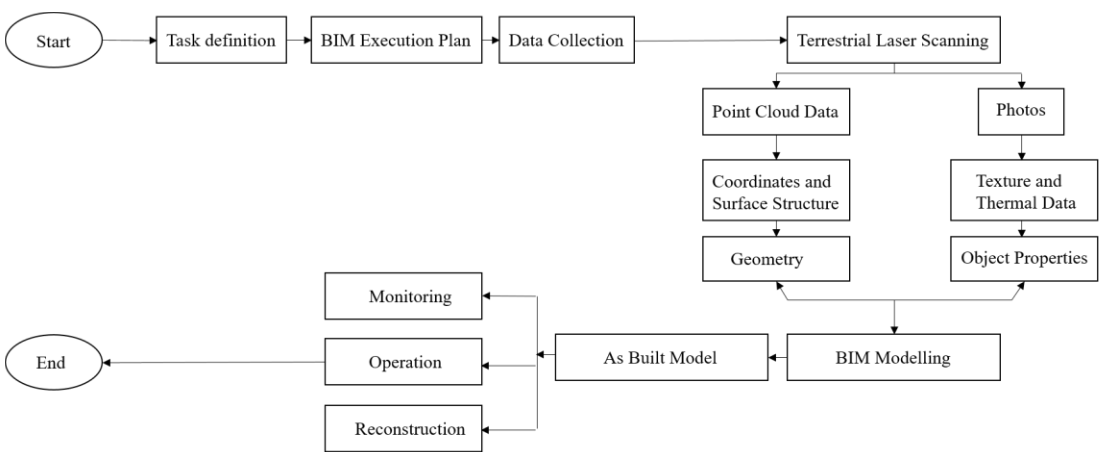


Fig. 5. Proposed BIM model Workflow

However, challenges remain, particularly in addressing the complexities of parametric modeling for heritage buildings. Apart from that, the initial expenses linked to the adoption of BIM and Laser Scanning Technologies may pose challenges for certain restoration endeavors. A shortage of proficient professionals skilled in both BIM and laser scanning technologies could impede the effective deployment of these tools. The training necessary for heritage restoration specialists to adeptly utilize these technologies is time-intensive and may encounter resistance from individuals accustomed to conventional methods.

5. Conclusions

In conclusion, the integration of Building Information Modeling (BIM) and Laser Scanning Technologies stands as a transformative force in the realm of heritage structure restoration within the context of post-disaster recovery. This research has unveiled the multifaceted advantages and synergies derived from the collaborative use of these advanced technologies. By seamlessly combining the comprehensive digital representation capabilities of BIM with the precise and detailed 3D data capture provided by laser scanning technologies, a new paradigm emerges for the efficient and effective restoration of heritage structures.

The creation of accurate as-built models through this integration facilitates a holistic understanding of the existing conditions of heritage structures, empowering restoration teams with unparalleled insights. This, in turn, streamlines decision-making processes, minimizes errors and fosters enhanced collaboration among diverse stakeholders involved in the restoration journey. The case studies and practical applications explored in this research underscore the tangible benefits of adopting integrated technologies, showcasing their pivotal role in preserving cultural heritage while ensuring the resilience and sustainability of these structures in the face of disasters.

Moreover, as the global community grapples with the increasing frequency and intensity of natural disasters, the findings of this study underscore the urgency of embracing technological advancements to fortify heritage conservation efforts. The symbiotic relationship between BIM and Laser Scanning Technologies not only accelerates the restoration process but also contributes to the long-term resilience and sustainability of heritage structures. As we stand at the intersection of tradition and innovation, this research advocates for the widespread adoption of integrated technologies, fostering a future where heritage structures not only withstand the challenges of disaster but emerge stronger, preserving our cultural legacy for generations to come.

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