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Preserving Heritage Buildings with Building Information Modelling: Addressing the Challenges and Opportunities

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Abstract

Preserving heritage buildings presents unique challenges in building conservation, demanding a comprehensive understanding of issues and strategic measures for long-term sustainability. The aim of this paper is to analyze the interrelationships among these organizations. The paper utilizes Cronbach's alpha reliability test, normalized mean ranking, overlap analysis, Kruskal-Wallis test, and Spearman's rank correlation for systematic data analysis. The findings of this paper will provide practical insights for organizational practitioners in identifying critical challenges and opportunities when preserving heritage buildings with Building Information Modelling (BIM). The paper illuminates both similarities and differences in preservation difficulties and approaches among organizations, offering profound insights into sectoral connections within the construction industry. Beyond addressing critical problems in building maintenance, this document serves as a guide for organizations navigating and overcoming hurdles in conserving heritage structures. The research outcomes offer strategic insights, promoting the development of a post-project maintenance-oriented culture. Ultimately, this contributes to enhancing the durability, efficiency, and cost-effectiveness of cultural structures in both public and private sectors.

Keywords: Building Information Modelling, Preserving Heritage Buildings, Key Challenges and Opportunities

Introduction

The background of the paper emphasizes the significance of heritage structures in Malaysia and the challenges they face in terms of conservation. Defined by the National Heritage Act 2005 [1], heritage includes both cultural and natural elements, ranging from tangible structures to intangible aspects like language and artistic expressions. Despite criteria for designating properties as national heritage, many historical buildings are at risk of deterioration, underscoring the need for effective preservation methods. Building Information Modelling (BIM) emerges as a contemporary solution, providing a digital model with intelligent components and data attributes [2]. Recognized in the construction sector, BIM is not just a software tool but a comprehensive concept, offering potential to enhance construction procedures and contribute to the conservation of historical buildings by reducing errors and conflicts [3, 4].

The problem lies in preserving heritage structures due to challenges like inadequate documentation, a shortage of skilled personnel, and financial constraints [5]. Building Information Modelling (BIM) emerges as a promising solution, offering comprehensive digital models to enhance documentation, enable virtual evaluations, and streamline processes. The research aims to explore challenges, assess BIM benefits, and establish a model connecting challenges and opportunities in using BIM for heritage preservation.

The study seeks to examine the correlation between obstacles and potential in the conservation of heritage structures through the utilization of Building Information Modelling (BIM). The objective is to explore how BIM might effectively tackle challenges such as insufficient documentation, a scarcity of qualified staff, and financial limitations by offering a digital platform for extensive modeling and cooperation among stakeholders. The project aims to acquire a detailed knowledge and create a model that outlines the relationship between difficulties and possibilities in the context of preserving heritage buildings using Building Information Modeling (BIM).

This paper utilizes a questionnaire survey to investigate the difficulties and advantages of using Building Information Modelling (BIM) in the conservation of historical buildings. The survey aims to gather a minimum of 120 responses from a wide range of BIM users, such as architects, engineers, contractors, facility managers, developers, and preservation professionals. In addition, a comprehensive literature analysis will be undertaken to construct a cohesive model that depicts the intricate relationship between the obstacles and prospects associated with utilizing Building Information Modeling (BIM) for the preservation of historical structures.

This paper emphasizes the significance of heritage building preservation and investigates how Building Information Modeling (BIM) might help overcome obstacles. Despite challenges such as a lack of data, BIM provides major benefits to academics, businesses, and the Malaysian government. BIM delivers 3D models for historical research and collaborative learning in the classroom. BIM contributes to heritage preservation, tourism, cultural identity, administrative efficiency, and sustainable development on a national scale. Using BIM is critical for successful historical preservation and the long-term legacy of architectural history.

Literature Review

Building Information Modelling Studies

The literature demonstrates a strong emphasis on Building Information Modeling (BIM) in new buildings, with less attention paid to its use in older structures [6]. Existing research frequently focuses on components or cross-sectional difficulties, usually in the context of new constructions. In the engineering sector, BIM is recognized as both a potential and a difficulty, requiring significant time, financial resources, and human training [7]. Despite its revolutionary potential, the implementation of BIM in historic structures is limited by the characteristics of heritage buildings, despite growing scientific interest in this area.

Historic Building Information Modelling Studies

Historic Building Information Modelling (HBIM) is a multidisciplinary technique to digitally represent heritage structures that incorporates geometric and alphanumeric variables, object knowledge, and metadata. The scientific literature indicates efforts to apply BIM technology efficiently in heritage preservation, enabling activities such as digital restoration, structural evaluation, sustainability assessments, and workplace safety simulations. HBIM is critical for cultural heritage digitization because it collects historical data, creates geometric models, and fosters cross-disciplinary collaboration.

Laser and Photo-modelling Recording Systems

Terrestrial Laser Scanning (TLS) technology uses laser beams to capture comprehensive 3D measurements of a physical environment, resulting in point cloud data [8]. These point clouds capture the spatial properties of the building's surfaces and geometry, allowing for the creation of extremely realistic digital renderings.

TLS can capture millions of unique data points in seconds, yielding complete and accurate representations of historic structures. This data includes external and interior aspects such as facades, decorative embellishments, structural elements, and spatial configurations. The high level of detail in TLS allows for reliable investigation, appraisal, and modelling of historic structures.

TLS in HBIM aids in the recording and preservation of heritage buildings by providing a digital record of their current condition. By combining TLS data with BIM software, heritage buildings can be visualized, analyzed, and changed in a virtual environment. This integration enables structural flaw diagnosis, detection of deformations or damages, and simulation of repair scenarios. TLS's rapid data acquisition capabilities eliminate the need for manual measurements, reducing data collection time.

Within the framework of Heritage Building Information Modelling, the combination of laser scanning, and digital imaging techniques plays a critical role in capturing and representing the visual and geometric aspects of heritage buildings (HBIM).

Structural Deterioration and Aging

Throughout time, these structures are subjected to a variety of physical and environmental conditions, which can compromise their integrity and jeopardise their long-term stability. Understanding the causes and mechanisms of structural degradation is critical for developing appropriate preservation solutions. Building Information Modelling (BIM) can aid in the resolution of these issues by enabling the reliable evaluation, analysis, and monitoring of structural concerns in historic structures.

BIM Implementation in Heritage Building Preservation

Building Information Modelling (BIM) has emerged as a significant technology and approach for the preservation of historic structures [9, 10]. BIM implementation in heritage building preservation entails the use of digital models and data management methods to document, analyse, and manage the various features of historic structures. This method offers numerous benefits and opportunities for addressing the issues of heritage structure preservation and protection.

Challenges of Maintaining Historical Structure

Preserving historical structures is a difficult task due to a variety of issues such as deteriorating wood, obsolete construction techniques, dampness, and other issues that commonly affect aging structures [11]. When it comes to preserving heritage buildings, the process of making decisions during the initial phase of design by relying on assumptions can present challenges. Inadequate preservation decisions during the design phase can result from a lack of accurate information [12]. Due to the acquisition and retrieval of information, conducting a Life Cycle Impact Assessment (LCIA) to evaluate the environmental impact of mechanical apparatus within these buildings can be difficult.

Methodology

Survey Development

A systematic literature review and a structured survey instrument have been used to develop a survey to study the challenges and opportunities in preserving heritage buildings with Building Information Modelling (BIM). The first step in the methodology is to conduct a systematic literature review followed by a survey. The survey was divided into three sections: Section A to collect respondents' profiles, Section B to investigate the challenges of preserving heritage buildings with BIM, and Section C to investigate the opportunities in this domain. The survey has been sent to a specific group of experts in heritage preservation and BIM implementation.

Data Collection

The primary method used to collect data for this paper was an online survey created using Google Forms. The paper focused on the primary stakeholders in the construction industry, who were the target participants for this research. The questionnaire was designed to gather relevant information about BIM from the participants. Moreover, the data collection process involved encouraging participants to forward the questionnaire and web link to other qualified individuals.

Data Analysis

The Kruskal-Wallis test is a non-parametric statistical test that is used to compare the medians of two or more groups [13]. The Kruskal-Wallis test ranks the data and compares the sums of ranks between groups to see if there are any statistically significant differences [14]. It has been used in various studies to analyse non-parametric or ordinal data [15].

Normalization methods are used to adjust for systematic biases and technical variations in data analysis, particularly in RNA-seq data analysis. RNA-seq data has different characteristics compared to microarray data, so normalization methods specific to RNA-seq data are required. Normalization ensures that the data is comparable across samples and allows for accurate differential expression analysis. Different normalization methods have been developed and applied in RNA-seq data analysis to account for factors such as library size, gene length, and composition biases.

Factor analysis is a statistical method for identifying underlying factors or latent variables that explain patterns of correlations between a set of observed variables [16]. It is commonly used in social sciences and psychology to uncover the underlying dimensions of a construct or to reduce the dimensionality of a dataset [17, 18]. Factor analysis can help identify the key factors that contribute to the variation in the data and can be used for data reduction, hypothesis testing, and model building [19, 20].

Results and Discussion

Survey Questionnaire

The survey questionnaire results are extensively discussed in this paper. A large group of 127 people took part in the survey poll, which sought opinions on the challenges and opportunities of implementing BIM as shown in Figure 1. The data from this survey has been critical in guiding strategic decisions, improving services, and expanding the body of knowledge in the construction sector.

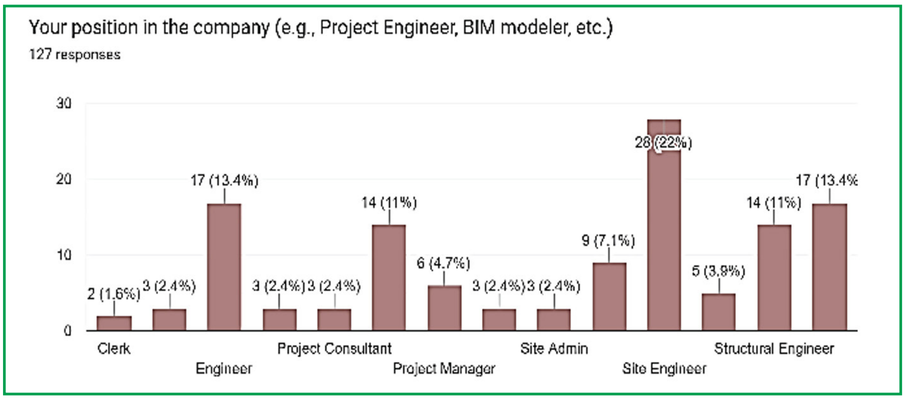

Figure 1. Demographic of respondents

Reliability Analysis

Reliability analysis is determined by how consistently it produces results when measurements are taken regularly. The process of calculating the amount of systematic variation in a scale, which can be done by examining the relationship between scores from different scale administrations, is known as reliability analysis. The data obtained in this paper yielded a Cronbach's Alpha value of 0.739, making it interpretable.

Kruskal-Wallis Method

The Kruskal-Wallis method is a nonparametric technique that is used to determine whether two samples came from the same distribution. A broad description of the essential elements frequently discovered in a hypothesis test report is shown in Table 1.

Table 1. Kruskal-Wallis method

CONSTRUCTION					CONSULTANT					DEVELOPER					CODE	p-value
VARIABLE	MEAN	STD	NV	RANK	VARIABLE	MEAN	STD	NV	RANK	VARIABLE	MEAN	STD	NV	RANK		
F16	4.601695	0.491637	1	1	F11	5	0	1	1	F10	4.520833	0.504852	1	1	F1	0.12
F14	4.533898	0.844107	0.955056	2	F12	4.625	0.517549	0.884615	2	F9	4.458333	0.503534	0.97	2	F2	<0.01
F13	4.483051	0.70083	0.921348	3	F14	4.625	0.517549	0.884615	2	F17	4.458333	0.503534	0.97	2	F3	0.45
F9	4.186441	0.77293	0.724719	4	F15	4.625	0.517549	0.884615	2	F8	4.375	0.703336	0.93	4	F4	0.003
F8	4.169492	1.056563	0.713483	5	F16	4.625	0.517549	0.884615	2	F13	4.354167	0.483321	0.92	5	F5	0.037
F11	4.144068	0.78746	0.696629	6	F17	4.625	0.517549	0.884615	2	F14	4.333333	0.78098	0.91	6	F6	0.009
F10	4.050847	0.950461	0.634831	7	F5	4.375	0.517549	0.807692	7	F12	4.208333	0.898186	0.85	7	F7	0.012
F12	4.025424	1.04972	0.617978	8	F10	4.25	1.035098	0.769231	8	F16	4.208333	0.742576	0.85	7	F8	0.841
F17	4.008475	0.710071	0.606742	9	F13	4.25	1.035098	0.769231	8	F15	4.166667	0.85883	0.83	9	F9	0.198
F15	3.966102	1.003687	0.578652	10	F9	3.875	1.552648	0.653846	10	F11	4.0625	0.632666	0.78	10	F10	0.023
F2	3.745763	1.288917	0.432584	11	F8	3.5	2.070197	0.538462	11	F7	3.854167	1.16673	0.68	11	F11	0.002
F4	3.737288	1.592869	0.426966	12	F7	2.5	1.309307	0.230769	12	F5	3.729167	1.332724	0.62	12	F12	0.257
F5	3.59322	0.944958	0.331461	13	F2	2.375	1.685018	0.192308	13	F6	3.583333	0.794485	0.55	13	F13	0.159
F6	3.457627	0.853791	0.241573	14	F3	2.375	1.685018	0.192308	13	F3	2.916667	1.26883	0.23	14	F14	0.114
F3	3.389831	1.456104	0.196629	15	F4	2.375	1.685018	0.192308	13	F4	2.833333	1.883109	0.19	15	F15	0.14
F7	3.29661	1.445945	0.134831	16	F6	2.125	1.246423	0.115385	16	F1	2.6875	1.307202	0.12	16	F16	0.005
F1	3.09322	1.426173	0	17	F1	1.75	1.38873	0	17	F2	2.4375	1.109078	0	17	F17	<0.01

The paragraph presents a table displaying the outcomes of the Kruskal-Wallis technique for three demographic variables: individuals from construction, consulting, and developer organizations. The table contains the average, variability, and standardization values for these variables. Questions are prioritized according to their normalization values (NV) for each demographic. In addition, the table visually emphasizes the convergence of viewpoints across the three populations by utilizing dark orange and red hues. This indicates regions of common perspectives that will be explored in more detail.

Overlap Analysis

Overlap analysis is a valuable tool for gaining a deeper understanding of the extent of resource overlap and the distinctions and similarities across many databases or collections. Gaining knowledge about the intersection between collections can assist in making informed choices regarding acquisitions, renewals, terminations, or adjustments to access levels. Overlap diagrams in Figure 2 illustrated the intersection of important factors in the data that align with the three demographic characteristics of the respondents.

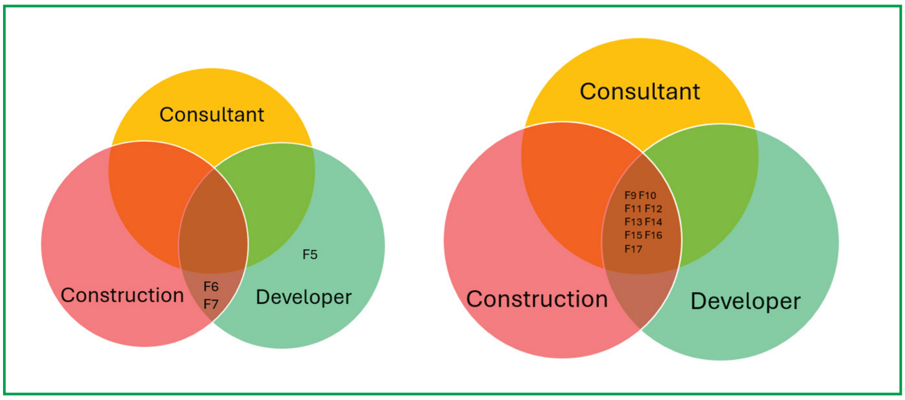

Figure 2. Overlap analysis for the challenges and opportunities

Correlation Analysis

Bivariate analysis, often known as correlation analysis, primarily focuses on determining the presence and magnitude of a relationship between variables, as well as understanding its nature. To succinctly characterize the correlation coefficient of the collected data, it can be stated that the respondents' viewpoints vary since there is not a substantial number of questions that exhibit a strong correlation.

Based on Figure 3 and Table 2, the diagram shows the correlation between the challenges of implementing BIM; there is a moderate correlation between the questions; this implies that the respondents reasonably agree on the challenges of implementing BIM in heritage buildings restoration efforts as a whole. Another factor to consider is there is little to no correlation between the lack of expertise in BIM and the other challenges. This indicates that whether or not the respondents agree on the other challenges doesn't directly affect their opinions on the issue.

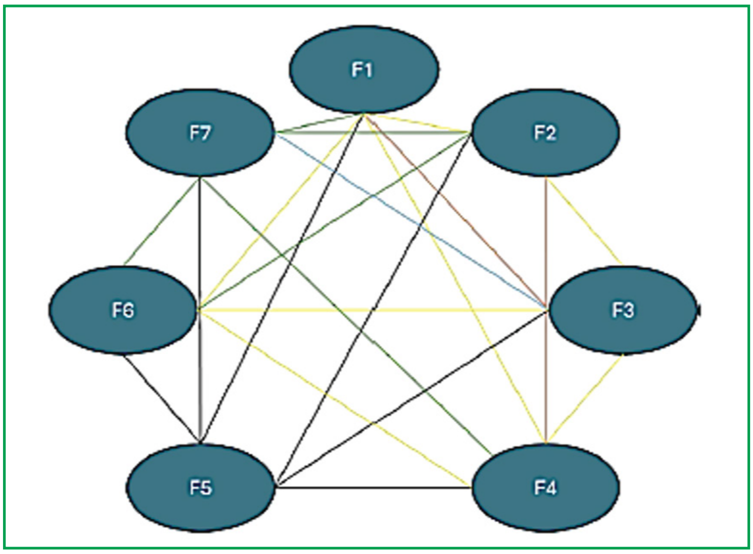

Figure 3. Correlation diagram on the challenges of implementing BIM

Table 2. Correlation table on the challenges of implementing BIM

			Challenges
Little Correlation	0	0.29	1
Low Correlation	0.3	0.49	5
Moderate Correlation	0.5	0.69	7
High Correlation	0.7	0.89	2
V. High Correlation	0.9	1	0
No Correlation	<0.0		6
		TOTAL	21

Figure 4 and Table 3 show the correlation graph for opportunities in implementing BIM. When discussing the opportunities for the Implementation of BIM, most opportunities have little or low correlation, indicating varying degrees of opinions on the benefits, with the improved productivity having little effect on the other opportunities.

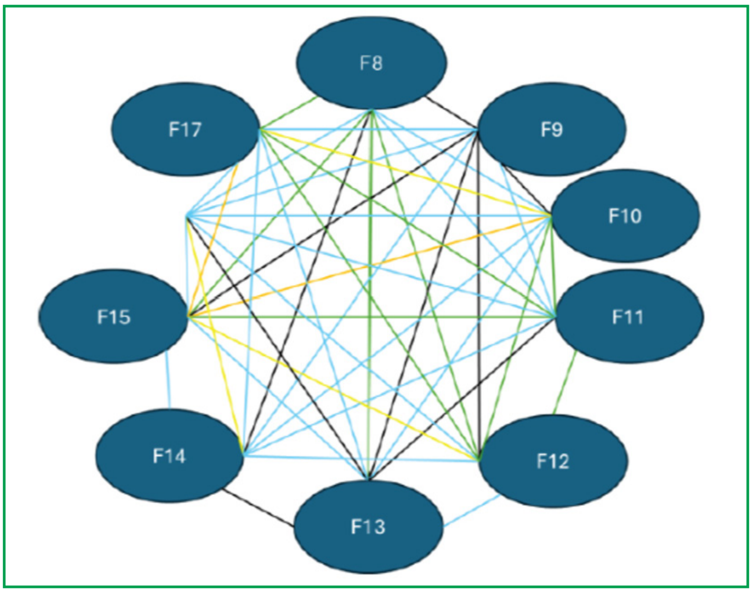

Figure 4. Correlation diagram on the opportunities of implementing BIM

Table 3. Correlation table on the opportunities of implementing BIM

			Oppurtunities
Little Correlation	0	0.29	21
Low Correlation	0.3	0.49	10
Moderate Correlation	0.5	0.69	3
High Correlation	0.7	0.89	2
V. High Correlation	0.9	1	0
No Correlation	<0.0		9
		TOTAL	45

The correlation in Figure 5 and Table 4 shows the correlation graph for challenges and opportunities in implementing BIM. In the correlation diagram for both challenges and opportunities in implementing BIM in the restoration endeavours of heritage buildings and sites, it can be seen that the level of correlation between the variables remains low. This could indicate that there are still differing opinions on this subject, and debate and discourse are still ongoing regarding its importance and effects on the construction industry as a whole.

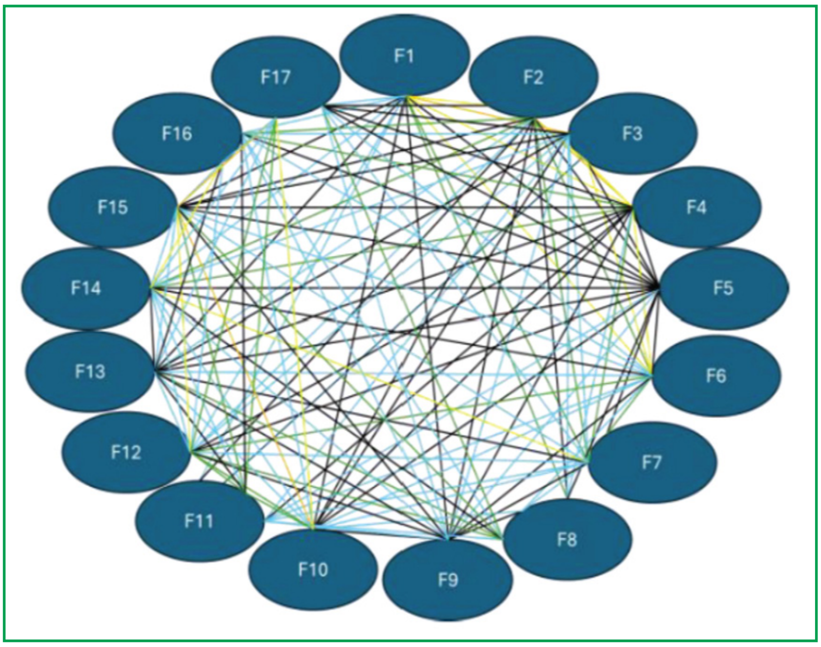

Figure 5. Correlation diagram on the challenges and opportunities in implementing BIM

Table 4. Correlation table on the challenges and opportunities in implementing BIM

			Both
Little Correlation	0	0.29	51
Low Correlation	0.3	0.49	20
Moderate Correlation	0.5	0.69	12
High Correlation	0.7	0.89	4
V. High Correlation	0.9	1	0
No Correlation	<0.0		48
		TOTAL	135

Conclusion

The result underscores the transformative capacity of employing Building Information Modelling (BIM) in the restoration of heritage buildings, underlining its potential and distinct advantages. The paper examines the potential benefits and difficulties of using Building Information Modeling (BIM) in heritage structures. It finds that there is consensus on the advantages of BIM across different industries. However, there is uncertainty about the specific problems, which are believed to differ depending on the organization and kind of project. Therefore, some initiatives are required to ensure the successful implementation of BIM in the restoration of heritage buildings. These initiatives encompass investing in extensive education and training, formulating customized BIM standards, encouraging multidisciplinary cooperation, advancing research and development, building supporting frameworks with regulatory agencies, and resolving reoccurring technological challenges.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

Mohamad Lokman Idris: writing, original draft preparation. **Abdul Rahimi Abdul Rahman:** writing, original draft preparation, and editing. **Bala Ishiyaku:** reviewing and editing. **Ahmad Rizal Alias:** reviewing and editing.

Data Availability Statement

The data used to support the findings of this study are included within the article.

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