UNIVERSITI TEKNOLOGI MARA

HISTORIC-BUILDING INFORMATION MODELLING (HBIM)-RETROFIT AS A FRAMEWORK FOR ENHANCING THE PERFORMANCE OF HERITAGE BUILDING CONSERVATION PROJECTS IN MALAYSIA

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CONFIRMATION BY PANEL OF EXAMINERS

I certify that a Panel of Examiners has met on 30th April 2026 to conduct the final examination of Khairool Aizat bin Ahmad Jamal on his Doctors of Philosophy thesis entitled "Historic-Building Information Modelling (HBIM)-Retrofit As A Framework for Enhancing The Performance of Heritage Building Conservation Projects in Malaysia" in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiners recommends that the student be awarded the relevant degree. The Panel of Examiners was as follows:

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I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the results of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any degree or qualification.

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ABSTRACT

Malaysia's heritage-built environment faces increasing conservation pressures associated with ageing buildings, deteriorating performance, fragmented practices, and growing sustainability demands. These challenges extend beyond environmental performance and include project delays, inefficient decision-making, poor coordination, and inadequate building documentation, which collectively reduce the effectiveness of heritage conservation projects. Although Historic Building Information Modelling (HBIM) demonstrates significant potential to support retrofit and conservation processes through improved information management and collaboration, its application in Malaysia remains limited. Furthermore, there is a lack of clear HBIM-retrofit concepts and characteristics, limited empirical understanding of the relationship between HBIM-retrofit and project performance, and the absence of a structured HBIM-retrofit framework to support heritage building conservation practice in Malaysia. Therefore, this study aims to develop a HBIM-integrated retrofit framework to enhance the performance of heritage building conservation projects in Malaysia. The objectives are to: (1) investigate HBIM-retrofit concepts and characteristics, (2) analyze the relationship between HBIM-retrofit and project performance, and (3) formulate a structured HBIM-retrofit framework. A quantitative research approach was adopted through literature review, questionnaire surveys, and expert validation involving conservation professionals in Malaysia. Data were analyzed using Partial Least Squares Structural Equation Modelling (PLS-SEM) and the Analytical Hierarchy Process (AHP). The findings confirmed significant relationships between HBIM-retrofit constructs and project performance, validating forty-three (43) indicators as the core components of the proposed framework. The study successfully achieved its aim through the development of a structured HBIM-retrofit framework consisting of prioritized retrofit indicators, hierarchical retrofit stages, and an operational decision-support system for retrofit planning and management. The AHP results further generated weightages and ranking priorities across the retrofit development stages, providing practical guidance for selecting appropriate retrofit strategies. The key outputs of the research include: (1) an empirically validated HBIM-retrofit framework, (2) a prioritized indicator and ranking system for heritage retrofit decision-making, and (3) a decision-support tool to improve HBIM-retrofit project coordination, data management, and digital readiness in conservation practices. The study also contributes theoretically by integrating HBIM and retrofit concepts within a Task-Technology Fit (TTF)-based model to form a conceptual framework, while methodologically demonstrating the combined application of PLS-SEM and AHP in heritage conservation research. Practically, the framework provides a foundation for evidence-based HBIM-retrofit adoption and future heritage digitalization guidance in Malaysia.

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Finally, this thesis is dedicated to my family and to all who strive to preserve our built heritage for future generations. May it serve as a small contribution to knowledge and a step toward meaningful change.

Insha'Allah.

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LIST OF SYMBOLS

Symbols

A	Alpha Value
β	Beta Value
R^2	Coefficient of Determination
f^2	Effect Size
$>$	Greater Than Sign
$<$	Less Than Sign
≤	Less Than or Equal to Sign
≤	More Than or Equal to Sign
%	Percentage
Q^2	Predictive Relevance

LIST OF ABBREVIATIONS

Abbreviations

AEC	Architecture, Engineering and Construction
AHP	Analytical Hierarchy Process
BIM	Building Information Modelling
BES	Building Energy Simulation
BPS	Building Performance Simulation
BPM	Business Process Management
CAD	Computer Aided-Design
CO2	Carbon Dioxide
CITP	Construction Industry Transformation Plan
CIDB	Construction Industry Development Board
CB-SEM	Covariance Based-Structural Equation Modelling
CVI	Content Validity Index
CMB	Common Method Bias
CI	Consistency Index
DV	Dependent Variables
EUI	Energy Use Intensity
EPC	Energy Performance Certificate
EU	European Union
GBI	Green Building Index

HB	Heritage Buildings
HBIM	Historic Building Information Modelling
HBCG	Historic Building Conservation Guideline
HOC	Higher Order Construct
HCM	Hierarchical Component Model
ICOMOS	International Council of Monuments and Sites
IV	Independent Variables
IR 4.0	Industrial Revolution 4.0
IFC	Industry Foundation Classes
IS	Information Systems
ICT	Information and Communication Technology
JWN	Jabatan Warisan Negara
LOD	Level of Development
LOIN	Level of Information Needs
LOA	Level of Accuracy
LOC	Lower Order Construct
M	Mean
MCDM	Multi-Criteria Decision Making
PLS-SEM	Partial Least Square-Structural Equation Modelling
PWD	Public Works Department
SME	Small Medium Enterprise
SD	Standard Deviation

SPSS	Statistical Package for the Social Sciences
TAM	Technology Acceptance Model
TTF	Task-Technology Fit
TLS	Terrestrial Laser Scanning
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN	United Nations
UK	United Kingdom
US	United States
UAV	Unmanned Aerial Vehicle
VIF	Variance Inflation Factors
VR	Virtual Reality

CHAPTER 1
INTRODUCTION

1.1 Introduction

This chapter discusses the research background and statement of the research problems. The discussion will formulate the research questions, research objectives and research aim, followed by the discussion of the significance and contribution of the research. Next, the methodology applied to achieve the research aims is included. The scope and limitations of the research will then be discussed and lastly, the final section will present the definition of key terms, the organization of the thesis and the summary of this chapter.

1.2 Research Background

Heritage buildings (HB) represent significant cultural, historical, and architectural assets that embody Malaysia's national identity and historical development. These buildings, often referred to interchangeably as historic buildings within the conservation context, are structures recognized for their cultural significance and are subject to preservation and conservation efforts. In Malaysia, a comprehensive survey conducted by the Department of Museums and Antiquities identified over 39,000 heritage buildings constructed between 1800 and 1948 across 235 towns and cities (Syed Zainol Abidin, 1995). More recent estimates indicate that over 20,000 buildings remain historically significant and worthy of conservation (Yusoff & Brahim, 2021). Major heritage cities such as Kuala Lumpur, Georgetown, and Ipoh alone contain more than 7,334 historic buildings within their core zones (PLANMalaysia, 2020; Georgetown, 2021; KLCP, 2020), highlighting the substantial presence of heritage buildings within Malaysia's built environment.

Given their importance, safeguarding these assets has become a national priority, particularly following the recognition of Malacca and Georgetown as United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Sites. This recognition has intensified conservation efforts and increased awareness among stakeholders, including government agencies, professionals, and the public

(Halim & Tambi, 2021; Azizi et al., 2016). Heritage buildings are valued not only for their cultural and historical significance but also for their economic, social, educational, and architectural contributions (Khodeir et al., 2016). Consequently, conservation practices aim to prolong the lifespan of these buildings while maintaining their authenticity and integrity (Harun, 2021; Yoke Mui et al., 2016).

However, despite their significance, heritage buildings in Malaysia face increasing challenges related to deterioration, ageing, functional obsolescence, and declining performance over time. These issues are further exacerbated by environmental factors, including climate change, which accelerate material degradation and affect building usability (Tang, 2019; Khalaf, 2021; Ali et al., 2018a; Van Krugten et al., 2016; Yau & Hasbi, 2017). While many studies have emphasized poor environmental performance such as high energy consumption and carbon emissions in historic buildings (Blavier et al., 2023; Jagarajan et al., 2015), the challenges extend beyond environmental concerns to include a much broader project performance issues such as inefficiencies in decision-making, lack of reliable data, cost overruns, time delays, and coordination difficulties in conservation projects (Rahmat, 2008; Khalil et al., 2021; Rodrigues et al., 2019). These multidimensional performance issues highlight the need for more efficient, comprehensive and integrated approaches in heritage building conservation projects.

In this context, retrofitting has emerged as a strategic intervention to enhance the overall performance of heritage buildings. Retrofitting refers to the process of upgrading, adapting, or modifying existing buildings to improve their functional, technical, and environmental performance while maintaining their cultural significance (Husin et al., 2019; ASHRAE, 2019). Unlike conventional existing building refurbishment or new building construction, retrofitting in heritage buildings presents unique challenges. These buildings often lack accurate documentation, exhibit hidden structural conditions, and require careful interventions to preserve original materials and architectural features (Khodeir et al., 2016; Gigliarelli et al., 2022; McCaig et al., 2018). Moreover, retrofit decisions must balance performance improvement with conservation principles, creating a complex and highly constrained decision-making environment.

In Malaysia, the complexity of heritage retrofit is further intensified by the absence of standardized retrofit guidelines, reliance on traditional conventional methods such as manual measurements and Computer Aided Design (CAD)-based processes, and fragmented multidisciplinary practices (Biagini et al., 2016; Ramli et al., 2021). The lack of accurate and comprehensive building data remains a critical issue, leading to uncertainty, inefficiencies, and unreliable decision-making in conservation projects (Baharuddin et al., 2022; Mansir et al., 2016; Baharuddin et al., 2024). Consequently, heritage building conservation projects frequently experience reduced performance, including project delays, cost escalation, and coordination challenges (Rahmat, 2008; Khalil et al., 2021; Arayici et al., 2017). These challenges underscore the need for more structured and technology-enabled approaches to support retrofit processes.

With the rapid advancement of digital technologies, Information and Communication Technologies (ICT) or Information Systems (IS) have been increasingly recognized as critical enablers for improving the construction project delivery and performance (Lim et al., 2021; Khalil et al., 2021; Baik, 2017). Among these technologies, Building Information Modelling (BIM) has gained prominence as a collaborative platform that facilitates integrated data management, visualization, and communication across project stakeholders (Diara, 2022; Alshawabke et al., 2024). In Malaysia, initiatives such as the Construction Industry Transformation Plan (CITP) and Construction 4.0 Strategic Plan by the Construction Industry Development Board (CIDB) have accelerated BIM adoption, with mandates requiring its implementation from large scale to smaller scale building projects (CIDB, 2015; CIDB, 2020; CIDB, 2021; Allison, 2024). However, these efforts are primarily focused on new construction, with limited emphasis on heritage building conservation projects.

To address the specific needs of heritage buildings, Building Information Modelling (BIM) has evolved into Heritage Building Information Modelling (HBIM), which integrates site, historical, geometrical, and material data into digital models to support conservation processes (Arayici et al., 2017; Baik, 2017; Ali et al., 2018a; López et al., 2018; Selim & Ahmed, 2018). HBIM enhances documentation accuracy, visualization, analysis, multidisciplinary collaboration, and decision-making throughout heritage retrofit projects (Mari et al., 2024). Recent advancements in artificial intelligence (AI), particularly in machine learning, computer vision, semantic segmentation, and automated Scan-to-BIM workflows, have further expanded HBIM capabilities in heritage documentation, intelligent 3D reconstruction, and information extraction from complex geometries (Song et al., 2023; Queruel et al., 2024). These developments reflect a growing shift towards more intelligent and data-driven approaches in heritage building conservation and retrofit practice.

Despite its potential, the application of HBIM in heritage building retrofit remains limited, particularly in the Malaysian context. Existing studies have primarily focused on HBIM for documentation and modelling purposes, with limited exploration of its role in supporting retrofit decision-making and improving project performance (Idris et al., 2024; Lim et al., 2021). Furthermore, there is a lack of structured approaches that integrate HBIM capabilities with the unique characteristics and requirements of heritage retrofit processes. While international studies have demonstrated the benefits of heritage retrofit in improving building performance, including energy efficiency and occupant comfort (Historic Scotland, 2016; Historic Scotland, 2021; Wise et al., 2021; Webb, 2017), there remains a significant gap in understanding how digital tools such as HBIM can be systematically applied to enhance overall project performance in heritage building conservation.

From a theoretical perspective, the application of digital technologies such as HBIM can be explained through the lens of ICT adoption to business process theories, which mainly posits that performance improves when technological capabilities align with task requirements (Goodhue & Thompson, 1995). In the context of heritage retrofit, where tasks are inherently complex, uncertain, and multidisciplinary, HBIM offers the potential to provide the necessary technological support to improve decision-making, coordination, and project outcomes (Chen, 2024; Liu et al., 2024). However, there remains a lack of studies that systematically examine the relationship between HBIM capabilities, retrofit processes, and project performance outcomes, particularly within the Malaysian heritage conservation context.

Therefore, this study addresses the need to develop a structured HBIM-retrofit framework that integrates technological capabilities with retrofit requirements to enhance the performance of heritage building conservation projects in Malaysia.

1.3 Problem Statement

Heritage buildings in Malaysia continue to face increasing performance challenges associated with ageing conditions, environmental pressures, and growing retrofit demands. Despite increasing emphasis on sustainability and conservation (Soares et al., 2019), environmental performance aspect such as energy efficiency, has received considerable attention through green rating assessment like the Green Building Index (GBI) for historic buildings (GBI, 2019), heritage building conservation projects in Malaysia continue to face broader performance challenges that extend beyond environmental considerations (Chehrzad et al., 2016).

Heritage building conservation projects frequently encounter broader issues related to project delays, cost overruns, technical uncertainties, fragmented coordination, and difficulties in maintaining quality and consistency throughout the project lifecycle (Nawi et al., 2020). Furthermore, the lack of accurate and comprehensive building data, fragmented working practices, and unclear evaluation standards continue to complicate conservation processes and decision-making in heritage projects (Ismail et al., 2021; Baharuddin et al., 2024; Shan et al., 2022; Masrom et al., 2017). As a result, improving the efficiency, coordination, decision-making, and overall delivery of heritage building conservation projects has become a critical concern within the Malaysian context.

To address these challenges, retrofitting has increasingly been recognized as a unique and strategic approach to improve the functionality, usability and long-term performance of heritage buildings. However, unlike conventional refurbishment or new construction, heritage building retrofit involves complex and highly constrained processes due to the need to balance performance enhancement with the preservation of authenticity, cultural significance, and material integrity. In addition, retrofit interventions in Malaysia frequently involve incomplete documentation, hidden structural conditions, uncertain information, and complex stakeholder requirements, making retrofit implementation significantly more demanding (Harun, 2011; JWN, 2016; Nawi et al., 2020).

Despite the importance of retrofit interventions, existing conservation guidelines and practices in Malaysia remain primarily focused on preserving physical fabric and authenticity, with limited emphasis on retrofit-specific implementation strategies, performance enhancement, or structured decision-making processes (Jamal et al., 2024; Azis et al., 2022; Khalaf, 2021). Although documents such as the Historic Building Conservation Guideline (HBCG) and Heritage Conservation Need Statement (HCNS) provide procedures for conservation works, they do not sufficiently address the systematic integration of retrofit processes, technical implementation, and performance-oriented interventions (JWN, 2016; PLANMalaysia, 2020; Georgetown, 2021). Consequently, retrofit practices in Malaysia often remain fragmented and highly dependent on individual experience and interpretation, contributing to inefficient interventions, coordination difficulties, and inconsistent project outcomes (Penjor et al., 2024; Che Husin, 2017; Al-Obaidi et al., 2017).

In contrast, international practices have demonstrated significant progress in the development of retrofit framework, and case-based approaches that support systematic decision-making and implementation (Historic England, 2020; British Standards Institution, 2021; ASHRAE, 2019; Historic Scotland, 2021; Troi & Bastian, 2015; May & Griffiths, 2015). However, such structured approaches remain limited within the Malaysian context, particularly in integrating retrofit considerations into heritage conservation practice (Dewiyana et al., 2016; Hamzah et al., 2019; Azis et al., 2022). This highlights the need for more structured and context-specific retrofit approaches within the Malaysian heritage conservation context.

At the same time, advancements in digital technologies such as Building Information Modelling (BIM) have demonstrated significant potential in improving project coordination, visualization, information management, and decision-making within the construction industry (Khoedir, 2016; Arayici et al., 2017). In Malaysia, efforts by the CIDB and Public Works Department (PWD) have promoted BIM adoption in the construction sector (CIDB, 2014; CIDB, 2017; CIDB, 2020; CIDB, 2021; JKR, 2025; CIDB, 2025). However, its application in retrofit practice remains limited, with even slower progress observed in the integration of HBIM within heritage building retrofit projects (Said et al., 2025; Ewart & Zuecco, 2018; Jamal et al., 2019; Yusoff & Brahim, 2021).

Within the heritage context, HBIM has emerged as an extension of BIM to support heritage documentation, digital modelling, and conservation processes. Nevertheless, the application of HBIM in heritage retrofit practice within Malaysia remains limited and is still largely concentrated on documentation and modelling purposes rather than supporting retrofit planning, multidisciplinary coordination, and project performance improvement (Salleh et al., 2022; Mustafa et al., 2020; Idris et al., 2024).

Furthermore, there remains limited guidance on how HBIM functionalities can be systematically integrated with the characteristics and requirements of heritage retrofit processes. Existing studies largely focus on technological adoption, modelling capabilities, and documentation aspects without clearly establishing the appropriate HBIM-retrofit concepts and characteristics suitable for heritage building conservation projects in Malaysia (Wong et al., 2022; Said et al., 2025). Although many international studies have explored HBIM applications in retrofit contexts through case studies and best practices (Gigliarelli et al., 2022; Antonopoulou & Bryan, 2017; Baik, 2017; Megahed, 2015; López et al., 2018), such investigations remain limited within the Malaysian heritage conservation context.

From a theoretical perspective, ICT adoption theories such as Task–Technology Fit (TTF) theory suggests that performance improves when technological capabilities are appropriately aligned with task requirements (Goodhue & Thompson, 1995). In heritage retrofit projects, which are inherently complex and multidisciplinary, HBIM demonstrates strong potential to support retrofit processes and improve project outcomes. However, there remains limited empirical understanding regarding the relationship between HBIM-retrofit characteristics and the perceived performance of heritage building conservation projects. Existing research has yet to systematically examine how HBIM functionalities can be aligned with retrofit requirements to enhance project delivery performance within the Malaysian context (Chen, 2024; Liu et al., 2024).

Therefore, despite the recognized potential of HBIM and the growing need for retrofit interventions, there remains a significant gap in knowledge and practice. Specifically, there is still limited understanding regarding the appropriate HBIM-retrofit concepts and characteristics suitable for heritage building conservation projects in Malaysia. In addition, the relationship between HBIM-retrofit characteristics and project performance remains insufficiently examined. Consequently, there is currently no comprehensive and structured HBIM-retrofit framework that integrates HBIM functionalities with heritage retrofit requirements to enhance project performance within the Malaysian heritage conservation context. This gap highlights the need for a structured HBIM-retrofit framework capable of supporting better decision-making, coordination, and overall project performance in heritage building conservation projects.

Based on the preceding discussion, the problem statement can be synthesized into several key research issues, namely the lack of clear HBIM-retrofit concepts and characteristics for heritage building conservation projects, the limited understanding of the relationship between HBIM-retrofit characteristics and project performance, and the absence of a structured HBIM-retrofit framework within the Malaysian context. These identified issues subsequently form the basis for the formulation of the research questions, objectives, and overall research aim, as summarized in Figure 1.1.

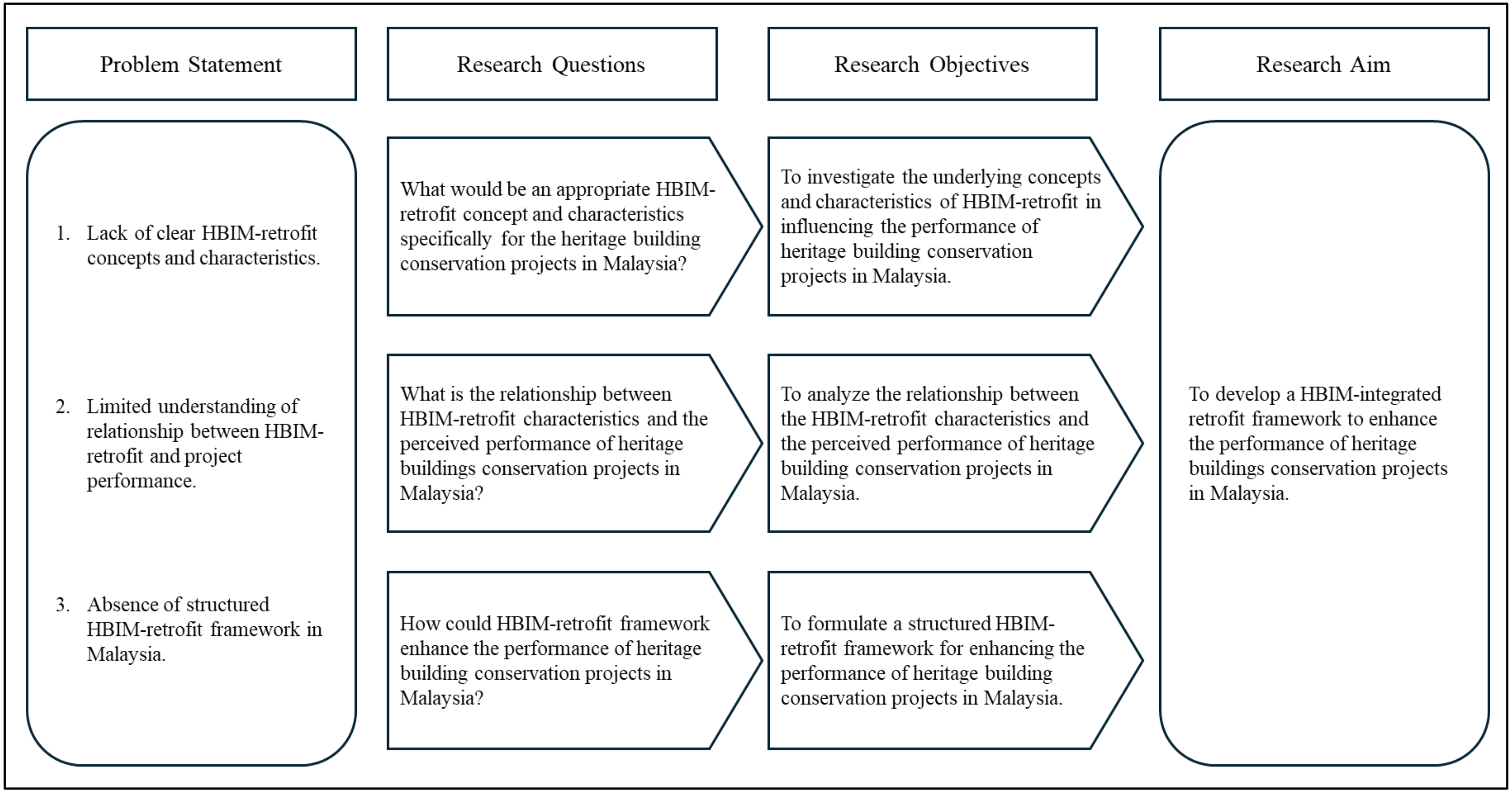

Figure 1.1 Research Relationship Between Problem Statement, Research Question, Objectives and Aim

1.4 Research Questions

i) What would be an appropriate HBIM-retrofit concept and characteristics specifically for the heritage building conservation projects in Malaysia?

ii) What is the relationship between HBIM-retrofit characteristics and the perceived performance of heritage buildings conservation projects in Malaysia?

iii) How could HBIM-retrofit framework enhance the performance of heritage building conservation projects in Malaysia?

1.5 Research Aim and Objectives

The research aim is to "develop a HBIM-integrated retrofit framework to enhance the performance of heritage buildings conservation projects in Malaysia". By having such framework, would further guide and enhance the practice of heritage conservation, whereas practitioners would be able to evaluate and understand the systematic, structured and decision-making process involved in the HBIM-retrofit of heritage buildings conservation projects. Hence, to achieve this aim, the following objectives have been derived.

i) To investigate the underlying concepts and characteristics of HBIM-retrofit in influencing the performance of heritage building conservation projects in Malaysia.

ii) To analyze the relationship between the HBIM-retrofit characteristics and the perceived performance of heritage building conservation projects in Malaysia.

iii) To formulate a structured HBIM-retrofit framework for enhancing the performance of heritage building conservation projects in Malaysia.

1.6 Significance of Study

Within the knowledge context, this research would provide insights into the extensive parameters and characteristics of Historic-Building Information Modelling (HBIM), and its potential value to influence the retrofit process of heritage buildings conservation projects in Malaysia. The study will also uncover the actual HBIM-retrofit definition, classifications and parameters that need to be understood for enhancing the performance of heritage building conservation projects in Malaysia. Moreover, this research will adopt an exploratory study to formulate a HBIM-enabled retrofitting framework, in which it will be tested and evaluated through various research instruments and techniques.

Within the methodology context, this study advances HBIM-retrofit research by employing Partial Least Squares Structural Equation Modelling (PLS-SEM) to rigorously analyse complex relationships and validate the proposed model, offering stronger empirical grounding than descriptive or case-study based approaches. The integration of Analytical Hierarchy Process (AHP) further enhances methodological precision by systematically prioritising the derived HBIM-retrofit criteria and alternatives through expert-driven comparisons. Together, these methods provide a robust, replicable analytical pathway for future research in heritage conservation, retrofitting, and digitalisation.

As for the practicality context, since the framework was developed based on the practical application within the heritage building conservation practice, it could be used by the conservation practitioners, policymakers, implementing agencies as a HBIM integrated retrofit technical and procedural guidance. The framework will provide standardization and outline a systematic process, decision-making aspects and as a result, it will allow for heritage building conservation practitioners to understand and strategically prioritize the various criteria involved in the planning and management of HBIM-enabled retrofit projects. Moreover, the findings presented in this study will convey useful information for future research that will further explore the various benefits and applications of HBIM to other key aspects of the heritage building conservation approaches within its project lifecycle.

1.7 Scope of Research

The main justification of having as research scope is to narrow down the research area and to set the boundaries on what should be investigated. Due to the limitation on resources, time and considering the overall perspective of the research, the field of study will be limited within the context of HBIM and heritage building retrofitting which consequently leads to the development of the framework. Limitation of scope is further discussed as follows:

i. The study focuses on listed and historically significant heritage buildings within the Malaysian heritage-built environment, particularly buildings subjected to conservation and retrofit-related intervention.
ii. The study focuses on conservation-compatible retrofit interventions involving performance improvement works such as energy efficiency, documentation, building performance optimisation, and conservation-supporting digital workflows, excluding full reconstruction and purely commercial refurbishment projects.
iii. Data collection was conducted among the heritage conservation practitioners using purposive and multiple-frame sampling, particularly to experienced conservators registered with JWN and ICOMOS Malaysia, representing expertise relevant to the Malaysian heritage-built environment contexts.
iv. Expert input for framework formulation was obtained from qualified and experienced heritage conservation professionals from recognised organisations involved in national conservation practice.
v. The study focuses on the application of HBIM-retrofit across the historic retrofit process, including pre-retrofit, implementation, and post-retrofit stages, without extending into long-term asset management or digital twin operations.
vi. The research emphasises the performance contribution of HBIM-retrofit, assessed through the Task–Technology Fit (TTF) lens, and does not investigate utilisation behaviour, financial feasibility, or cost modelling.

1.8 Definition of Key Terms

i. Historic Building Information Modelling (HBIM)
HBIM is a digital methodology that integrates geometric, historical, and technical data within BIM to create information-rich 3D models of historic buildings, supporting the management of documentation, analysis, and conservation decision-making across stakeholders throughout the project lifecycle (Dore & Murphy, 2017; Arayici et al. 2017).
ii. Historic Building Retrofit
The interventions beyond routine maintenance that upgrade, adapt, or modify the fabric, systems, or performance of an existing heritage building to meet new

functional, environmental, or regulatory requirements, while maintaining acceptable service levels and respecting its historic and cultural significance (May & Griffiths, 2015).

iii. HBIM-Retrofit Framework

A structured approach that integrates BIM with organizational, technical, and decision-making processes to plan, assess, and manage retrofit interventions in heritage buildings, supporting coordinated stakeholder collaboration, performance evaluation, and conservation outcomes throughout the project lifecycle (Gigliarelli et al. 2022; Hull & Bryan, 2019).

iv. Performance

The extent to which a historic building conservation project achieves its intended economic, environmental, social, and quality-related objectives such as cost efficiency, timely delivery, functional quality, sustainability outcomes, and stakeholder satisfaction, particularly as influenced by the adoption of HBIM-retrofit processes (McGinley et al. 2022).

1.9 Research Methodology

The research methodology for this study outlines a systematic process designed to achieve the research aim and objectives. The approach adopted is structured and well-organised, encompassing stages from the development of research instruments to data analysis. In the first phase, a comprehensive literature review was conducted, aiming to generate knowledge of the existing issues and then ascertain the research problems, research gap, formulation of research questions, research aims and the research objectives.

The objectives that have been delineated also require an extensive and exploratory literature review to be conducted during the first stage of the research. Objective One postulates the need to create knowledge base using document review and content analysis concerning the historic building retrofit characteristics, HBIM-retrofit functionality and HBIM-retrofit performance criteria to enhance heritage building conservation projects in Malaysia, concentrating on investigating the fundamental concepts, characteristics, variables and underpinning theories. A thorough literature review also aims to establish a body of knowledge which further leads to the exploratory identification and thematic development of conceptual framework for this study.

The conceptual framework is necessary to aid the researcher in structuring the hypothesis development and defining strategies for collecting data by highlighting the significant areas that must be identified or examined, as discussed in Chapter Two. The conceptual framework for this study was also developed based on an underpinning theory of Task-Technology Fit (TTF) which corelates with the empirical evidence and gaps that have been identified in Chapter One and Two and is discussed in-depth in Chapter Three of the research.

The conceptual framework incorporates the indicators for each constructed variables, structured both hierarchically and operationally, and will be further discussed in Chapter Three. The independent variables are the established HBIM-retrofit framework keystones which consists of eight (8) independent variables (IV) consists of the heritage aspects, development stages, retrofit design criteria, method of approach, organizational, project lifecycle, technical and informational attributes which has three to seven indicators in the variables respectively.

The conceptual framework incorporates the indicators and higher-order constructs for each variable, structured hierarchically and operationally, as discussed further in Chapter Three. The framework consists of eight independent variables (IV), namely heritage aspects, development stages, retrofit design criteria, method of approach, organizational, project lifecycle, technical, and informational attributes, each comprising three to seven indicators respectively. These attributes postulate direct positive relationships with the dependent variables (DV), represented by seven project performance elements: time, cost, quality, design, environmental, relationship, and communication performance in heritage building conservation projects.

Therefore, the conceptual framework was developed and tested through hypotheses adopting a deductive approach. Furthermore, the operationalization of variables into measurable higher-order constructs through adaptation of the underpinned theory was undertaken to support efficient measurement and analysis of the proposed HBIM-retrofit framework and its influence on project performance enhancement in heritage building conservation projects in Malaysia.

The study adopts a quantitative and deductive research approach centred on questionnaire survey design to support the empirical measurement and validation of the proposed HBIM-retrofit framework. The research approach was developed to align with the application of Partial Least Squares Structural Equation Modelling (PLS-SEM), which is suitable for examining formative constructs, validating complex structural relationships, and establishing the finalized variables and indicators of the HBIM-retrofit framework in enhancing the performance of heritage building conservation projects. Furthermore, the exploratory literature review and operationalization processes conducted during the earlier stages of the research supported the identification and development of the framework constructs, variables, and indicators prior to empirical testing.

Hence, the population size was determined using a non-probability sampling approach, specifically purposive sampling combined with multiple-frame sampling. The respondents consisted of heritage building conservation practitioners possessing relevant experience and knowledge in historic building conservation, retrofitting, and heritage preservation practices. Practitioners registered with the National Heritage Department (JWN) and individual members of ICOMOS Malaysia operating within Malaysia were identified as the primary respondents for the study. The questionnaire survey was developed to align with the research aims, objectives, constructs, and hypotheses of the study. Five-point and seven-point Likert scales were adopted to measure the respondents' degree of agreement and perception towards the identified variables and indicators.

The collected survey data were analyzed using IBM SPSS 27 software for descriptive statistical analysis, where the data were categorized and presented through tabulations, charts, and graphical representations. Subsequently, SmartPLS software was utilized during the phase 2 confirmatory stage of the research for multivariate statistical analysis to assess the measurement model, validate the structural relationships, test the research hypotheses, and establish the finalized indicators and variables of the HBIM-retrofit framework. This phase functions as the empirical confirmatory stage of the study in validating the proposed framework and the causal relationships between the identified constructs.

Following the establishment of the final HBIM-retrofit framework, the Analytical Hierarchy Process (AHP) was subsequently employed during the phase 3 validation and prioritization stage to formulate the framework into a hierarchical structure consisting of clusters, sub-clusters, and alternatives for expert-based evaluation and prioritization. Additional structured questionnaires based on pairwise comparison were distributed to selected experts to support the validation, comparative weighting, and prioritization of the finalized HBIM-retrofit framework components. In this context, AHP functions as a post-confirmatory multi-criteria decision-making (MCDM) technique to determine the relative importance and prioritization of the HBIM-retrofit framework elements from an expert perspective.

As cited by Lucko and Rojas (2010), the importance of administering a structured research process is to ensure that every stage of the research maintains maximum quality standards. Hence, the present study consists of three main stages that collectively describe the overall research process flow, as illustrated in Figure 1.2. Furthermore, a detailed discussion of the research methodology is presented in Chapter Four.

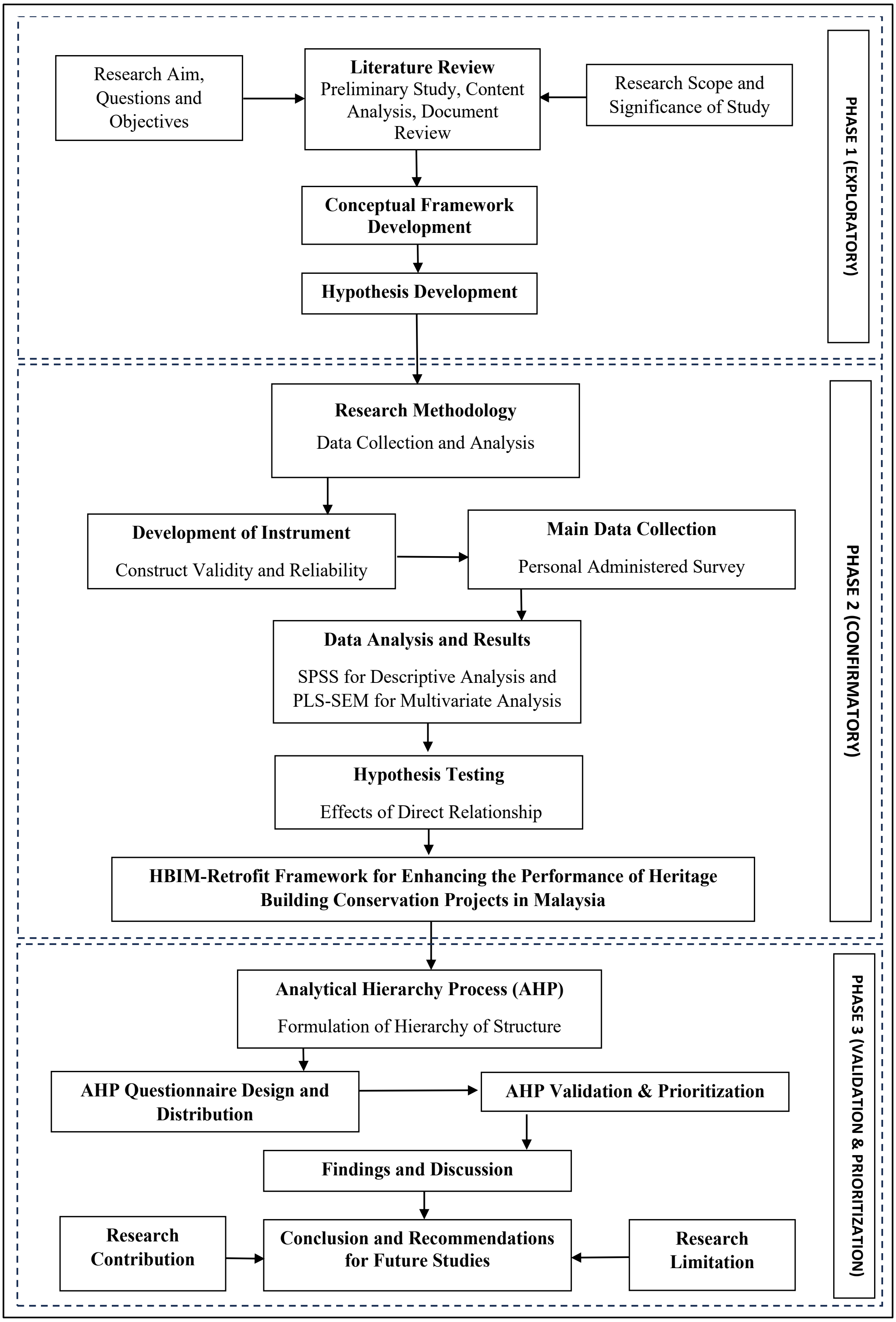

Figure 1.2 Research Process Flow Diagram

1.10 Organisation of Thesis

This thesis is so far comprises of seven (7) chapters in total. Below is a summary of each of the seven chapters.

Chapter 1: This chapter contains a research background followed by discussion of the problem statement, research questions, research objectives, research aim, research scope and limitations, definition of key terms, research methodology, research significance and organization of chapters.

Chapter 2: This chapter reviews the literature particularly in these four areas; the issues and challenges in heritage conservation practice, the historic building retrofit concept and characteristics, the HBIM-retrofitting characteristics, and the performance in adopting HBIM-retrofit framework. At the end of the chapter, the relationship of HBIM-retrofit framework in enhancing the performance of heritage building conservation practice is also explained. Other than this, it deliberates the subject area by gathering information presented by earlier researchers.

Chapter 3: This chapter details a description of the research framework applied with a thorough justification on the underpinning theory that is adapted from the task technology fit theory (TTF), the related variables in the conceptual framework, and hypotheses development of the current study with the target of reaching a complete hold of the prevailing information. This chapter also highlights the relationship between the HBIM-retrofit elements and the performance which leads to a proposal of the conceptual framework for the research which is presented at the end of the chapter.

Chapter 4: This chapter focuses on the research methodology, which discusses and justifies the research philosophies undertaken for this study. In addition, the research instruments used in the study is elaborated, including the data collection techniques and data analysis, which consists of survey formats, survey contents, the measurement of variables, validity, and reliability and lastly the research design is elaborated.

Chapter 5: This chapter discusses data analysis and results. It starts with the preliminary data analysis, followed by a descriptive analysis using IBM SPSS 27 which includes the measurement of frequencies, means and standard deviations and lastly, the multivariate analysis which employs Partial Least Square–Structural Equation

Modelling (PLS-SEM) using SmartPLS software. The data collection and data analysis are reported in detail.

Chapter 6: This chapter presents the findings of the study and provides a detailed discussion of the results aligning to the research objectives. It begins with the discussion of forming the early phase of literature review, conceptual framework development, preliminary data analysis and main data analysis. Furthermore, the Analytical Hierarchy Process (AHP) is applied in conjunction with the outcomes of the PLS-SEM. This is followed by the framework formulation process, which evaluates measurement of weights and pairwise comparisons to ensure robustness and consistency of the developed framework. Finally, the validated framework is ranked and further examined against secondary data, enabling a critical discussion that integrates empirical results with existing knowledge and practice.

Chapter 7: This final chapter presents the conclusion and recommendations for this study. It starts with a recapitulation of the research, the research contributions, research limitations, and several suggestions and recommendations for future research.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to establish a theoretical foundation for the research by reviewing key themes that shape the research questions, objectives, methodology, and design. Three main areas of discussion are outlined.

First, the background of historic building conservation is examined, focusing on challenges of adaptation to historic retrofitting and the role of Information and Communication Technology (ICT) in addressing practical issues. Common challenges such as the fragmented nature of conservation practice, low productivity, cost and time overruns, lack of guidance and the urgent need for heritage buildings to adopt retrofit approaches are reviewed. These are discussed alongside Malaysian government initiatives addressing climate change and environmental concerns.

Second, the literature on historic building retrofit is explored to synthesize knowledge on concepts, classifications, intervention strategies, and technical factors. This includes heritage aspects considerations, development stages, retrofit design criteria, and method of approach. A critical review of thirteen grey documents consists of international guidelines and best practice were conducted, where the elements are classified into themes to establish the attributes of task characteristics in retrofit, ensuring clarity of scope and alignment with the research objectives.

Third, the review considers Historic Building Information Modelling (HBIM) as an enabling tool for historic building retrofit. The discussion highlights its concepts, evolution, organizational, informational, process and technical requirements for HBIM integrated retrofits of historic buildings. A critical review of ten HBIM-retrofit implementation models and elements is also provided, positioning this research within current knowledge and establishing a basis for HBIM-enabled retrofit functionality.

Overall, this chapter provides theoretical and scholarly foundations for developing the body of knowledge, guiding the research enquiry, and supporting the formulation of the conceptual framework and methodological design for the research.

2.2 Background Historic Building Conservation in Malaysia

The concept of heritage building conservation is not new to the Malaysian built environment industry. According to Harun (2021), heritage buildings represent the values of tangible cultural heritage which have their own uniqueness and characters that need to be preserved. Historic buildings are defined by three key features namely age, integrity, and significance (Mazzarella, 2015). To be considered historic, a building must be over 50 years old, maintain its original physical characteristics, and hold importance in terms of evidence, historical, aesthetics, or community value (Webb, 2017; Heritage, 2007).

According to Powell (1994), old buildings are a heritage that holds both implicit and explicit values. There are several importance and contributions of historical buildings in Malaysia, including, among others is to preserve history and belief of a society, maintaining the importance of architectural and culture aspects, psychological aspects and values on historic buildings, providing an image and identity to the city, continuity and stability in built environment, as interpretational elements and tourism image and providing heritage education to the young generation (Harun, 2021).

Historic and traditional buildings represent not only the culturally significant portion of the building stock but also a considerable proportion. Estimates suggest that historic buildings constitute over 5% of the overall building stock, varying by region (Herrera-Avellanosa et al., 2020; Troi, 2011). When considering both historic and traditional buildings together, they comprise between 10% and 40% of the building stock, with the exact percentage dependent on factors such as region and age thresholds (Economidou et al., 2011). As for the heritage building recognition in Malaysia, as of current, there are over 127 registered heritage buildings that is been gazette as National Heritage (JWN, 2024), with many potential future submissions ever since the addition of Georgetown and Malacca to the UNESCO World Heritage List on 7th, July, 2008, which has surge a demand for heritage conservation projects in Malaysia (Harun, 2021).

Through an inventory study undertaken in 1992 and 1993 by the Heritage Trust of Malaysia in conjunction with the National Museum, the Housing and Local Government Ministry and Faculty of Built Environment, Universiti Teknologi Malaysia (UTM), reveals that there are near 39,000 historic buildings built between 1800 and 1948 throughout the country which are considered worthy for preservation and conservation. Buildings built within these periods are classified as ‘pre-war buildings’ due to their year of build, ranging from 1800 to 1948.

Listed in Plate 2.1 is the number of ‘pre-war buildings’ located in 247 cities and towns nationwide. Ali et al. (2018a) highlights the distribution of historical buildings in Malaysia reveals that over 20,000 buildings can be considered as heritage significant and deserving of conservation and preservation. Within established cities such as Kuala Lumpur, Georgetown and Ipoh combined, it is reported in total of over 7334 historic buildings of various categories are recorded within the core areas alone (PLANMalaysia, 2020; Georgetown, 2021, KLCP, 2020). This serves as an important factor to drive the conservation of heritage buildings, as it represents a significant portion of the Malaysian building stocks.

The concentration and extensive distribution of these buildings within major urban areas also indicate increasing conservation pressures associated with ageing building conditions, urban development demands, environmental sustainability requirements, and long-term building performance management. As the number of heritage assets continues to increase, the complexity of managing conservation and retrofit projects also becomes more critical, particularly in aspects related to documentation, multidisciplinary coordination, information management, and decision-making processes (Khalil et al., 2021).

No	States	No of Historical Buildings	Percentage of Historical Buildings
1	Penang	5,057	24.30%
2	Perak	3,351	16.10%
3	Johore	2,323	11.20%
4	Malacca	2,177	10.50%
5	Kuala Lumpur	1,763	8.40%
6	Kedah	1,282	6.12%
7	Selangor	1,166	5.60%
8	Sarawak	1,010	4.90%
9	Negeri Sembilan	999	4.80%
10	Pahang	831	4.00%
11	Terengganu	420	2.00%
12	Kelantan	373	1.80%
13	Perlis	25	0.10%
14	Sabah	10	0.05%
	Total	**20,787**	**100.0%**

Source: Idid (1995).

Plate 2.1 Distribution of Pre-War Urban Buildings (Syed Zainol Abidin, 1995)

The extensive distribution and concentration of historic buildings across Malaysia also indicate the growing demand for more systematic and efficient conservation and retrofit practices (Harun, 2021). As the number of heritage assets increases, the complexity of managing building information, multidisciplinary coordination, documentation accuracy, and decision-making processes in conservation projects becomes more critical (Baharuddin et al., 2024). Consequently, this highlights the importance of structured and technology-enabled approaches such as HBIM-retrofit to support project performance improvement and effective management of heritage building conservation projects in Malaysia (Said et al., 2025).

Consequently, the growing scale and complexity of heritage conservation projects highlight the need for more systematic and technology-enabled approaches to improve project performance in historic building conservation. This further justifies the importance of examining HBIM-retrofit characteristics and developing a structured framework capable of supporting efficient retrofit implementation, coordination, and decision-making processes. The preservation and recognition of buildings and monuments with historical and architectural values require significant attention, supported by strategic planning and effective project implementation. A comprehensive understanding of the concept, definition, and principles of conservation is therefore essential, particularly in guiding decision-making processes for safeguarding heritage (Harun, 2021). Clear comprehension of conservation meaning and its practical applications enables more efficient practices while ensuring adherence to established professional ethics.

Harun (2021) and Carbonara (2017) outline fundamental principles of historic building conservation: minimum intervention, which emphasizes preserving original materials and avoiding unnecessary changes; reversibility, ensuring interventions can be undone where possible; distinguishability, requiring new works to remain identifiable against the original; and compatibility, which demands coherence between old and new materials, design solutions, and historical features. These principles are equally important in energy improvement, where understanding a building's bioclimatic functioning often revealed through its historic technologies is vital to optimizing passive performance. Respect for both material and figurative authenticity remains central to conservation practice (Carbonara, 2017; Harun, 2021). Policies and guidelines thus provide structured frameworks for conservation practitioners, ensuring that interventions are evidence-based and systematically executed (Harun, 2011).

In Malaysia, statutory and policy frameworks establish the foundation for conservation practices. The National Heritage Act 645 2005 (Act, 2005) serves as the principal legislation for protecting and managing heritage buildings, aiming to safeguard cultural assets from inappropriate use, subdivision, or development (Hariry, 2021). Building upon this, practical references such as the Historic Building Conservation Guideline 2016 (HBCG) provide detailed procedures for conservation within the context of government policy. Additional frameworks include guidelines prepared for government-linked projects (JKR, 2018), development control within federal territories (PLANMalaysia, 2023), and local authorities in heritage-rich urban areas such as Kuala Lumpur, Ipoh, Georgetown, and Malacca. Yet, debates persist regarding the Draft Special Area Plans, which raise concerns that valued heritage and character areas may still face threats of demolition (JWN, 2016; PLANMalaysia, 2020; Georgetown, 2021).

Despite this, current guidance remains limited with respect to retrofit practices in heritage buildings. Given the urgency of environmental sustainability, Malaysia lacks comprehensive policies addressing the integration of energy efficiency into conservation efforts. Jahed et al. (2020) argue that effective retrofit requires regulatory frameworks at national or regional level to align energy and conservation priorities. Developing methodological approaches that reflect both limitations and opportunities could provide a pathway for effective practice. Although recent studies have evaluated Malaysia's conservation policies and frameworks (Azis et al., 2022; Zaid et al., 2021), none have adequately addressed the absence of technical and practical guidance for the retrofitting of historic buildings. These increasing conservation demands have consequently introduced multiple sustainability, technical, managerial, and digitalization challenges that continue to affect the efficiency and effectiveness of historic building conservation practices in Malaysia.

2.3 Current Challenges and Context of Historic Building Conservation in Malaysia

This subchapter focusses on identifying the challenges that are discussed further in line with the scope of historic buildings in Malaysia. Many of the limitations preventing the practice of retrofit in historic buildings are neither purely social nor purely technical, but rather the combined result of socio-technical issues (Herrera-Avellanosa, 2020; Buda et al., 2021). Consequently, there are four clusters which are grouped to frame these barriers, as described in the following sub-section and this will then be discussed to frame the gap of the research and to justify its significance to be studied.

2.3.1 Sustainability Challenges and Retrofitting Imperatives for Historic Buildings

At this point it is important to understand that historic buildings are a finite resource that resembles significant values, spirit and identity of country and place. However, as time eventually progressed, such historical assets are under constant pressure and challenges to improve their environmental sustainability performance (Soares et al., 2019). In general, buildings consumed 30% of the total energy use in the world, and 10% of the total energy building use is consumed by historic listed buildings (Kalibatas et al., 2014). The present issues and debate on climate change, natural resource depletion, and global demands for energy security underscore the need for a more sustainable heritage-built environment.

The act of degradation, deterioration, and loss of performance in heritage buildings are caused by a variety of factors, which have resulted in a list of concerns and threats facing heritage buildings in Malaysia. In UNESCO world heritage sites in Malaysia, heritage buildings have been cyclically adapted for new uses over time, one example is the Penaga Hotel building in Penang, which the state of building could be improved to meet the Green Building Index (GBI) criteria (Dewiyana et al., 2016; Harun, 2021). To guarantee their use in the future, these buildings must also be adapted, repaired, rehabilitated and retrofitted to face future environmental challenges and user expectations regarding thermal comfort and energy efficiency.

Developing countries like Malaysia relies mainly on fossil fuels to supply the energy demand, in which brings many negative impacts to the environment (Chan et al., 2022; Moey et al., 2020). Malaysia has a rising energy demand due to the growing development in industrial, transportation and agriculture sectors. The growth demand of electricity in Peninsular Malaysia from 2016 to 2021 is 21,773 MW to 23,344 MW (Malaysia Energy Statistics Handbook, 2021) and is expected to reach peak demands by the end of 2035. According to the Energy Commission Malaysia (2021), the total amount of installed energy capacity in year 2021 is 36,182.8 MW with the biggest contributor to the electricity generation comes from fossil fuel sources 82.1% which comes from sources of coal, gas, diesel and oil (Energy Commission, 2021).

Balaras et al. (2004) highlights, a modern building built after the year 1990 recorded an average Energy Use intensity (EUI) of around 40kWh/m2, while buildings built before the year 1930, which are mostly considered old historical buildings, consumed an average of 170kWh/m2. This is diminished further by the anticipated quick shift in climatic conditions, which might pose further threats to future heritage buildings. Furthermore, according to the United Nations (UN) Office for Disaster Risk Report (UNDRR, 2020), Malaysia is expected to experience up to 10% more annual rainfall owing to climate change, with mean annual surface temperatures rising by approximately 2° Celsius by 2050.

Tang (2019), through projected simulations predicted a temperature rise of less than 4° Celsius till the end of the 21st century and lack of a definitive pattern for rainfall, with increasing rainfall trend. As for historic buildings, Yau & Hasbi (2017), has projected from the baseline of year 2000, the cooling demand is expected to gradually increase by 2.96 percent, 8.08 percent, and 11.7 percent in 2020, 2050, and 2080, respectively. With the maximum cooling load of 297,000 KJ/h generated in the year 2000, the increase is translated up to 330,000 KJ/h by the year 2080. The increase in maximum cooling demand is linked to a projected increase in external temperature, which causes more heat to penetrate spaces through its building fabric.

Several case studies concluded substantial benefits can be gained through the practice of retrofit. For example, in the United Kingdom (UK), energy retrofit is capable to optimize the building thermal value as much as 70% with significant improvement to Band B of the Energy Performance Certificate (Historic Scotland, 2021) and in Turkey, recorded 37% of energy reduction through retrofit plans (Cho et al., 2022). Therefore, this signifies actions need to undertake improvement to the performance and resilience of historic buildings, to become adaptable to the challenges of the 21^{st} century (Dias Pereira et al., 2021), which imposed unpredictable weather behaviour, higher temperatures and increased flood risk as the climate change takes effect.

2.3.2 Policy Context and Challenges in Historic Building Retrofit Practice

In the Malaysian context, the challenges of heritage buildings in the 21st century highlight the importance of understanding the policy environment and initiatives that influence sustainable retrofitting efforts. According to Mokariantabari (2019), building refurbishment and retrofitting are emerging as significant sectors within the construction industry, largely driven by economic recession, deterioration, obsolescence, and the increasing demand for green buildings (Zolkafli et al., 2017; CIDB, 2021). Statistics reflect this trend, with the refurbishment sector contributing 17% of construction activity in 2005 and rising to 22% in 2014, although many projects remain undocumented. Recognizing this growth, the Malaysian government has implemented multiple initiatives aimed at embedding environmental sustainability within the heritage-built environment, aligning with global climate aspirations through technological and innovative approaches.

Green policy frameworks have been central to this development. The National Policy of Climate Change (NPCC, 2010) and the National Green Technology Policy (NGTP, 2009) established explicit directions to promote sustainability in existing buildings. Expectations included retrofitting for efficient cooling, ventilation, and lighting, along with the adoption of energy efficiency features and renewable energy systems (NPCC, 2010; NGTP, 2009). The Low Carbon Cities Framework (LCCF, 2015) further outlined performance criteria aimed at carbon reduction through refurbishment and lifecycle extension, while the 12th Malaysia Plan (2021) reinforced these priorities by setting a target for RE to contribute 31% of installed capacity.

Despite these measures, significant barriers persist. The Green Technology Masterplan Malaysia 2017–2030 (GTMM, 2017) acknowledges retrofitting as crucial for energy and carbon reduction but highlights that regulatory instruments remain inadequate, with certification systems designed primarily for new buildings. Consequently, enforcement is weak, and industry stakeholders often lack awareness of responsible retrofit practices (Dewiyana et al., 2016; Al-Obaidi et al., 2017; 2017; Zaid et al., 2021; Che Husin, 2017; Mansir et al., 2016; Harun, 2011; Sopery, 2023). Implementation has therefore been skewed towards new buildings (Nasid, 2017), creating challenges as Malaysia pursues its ambitious 80% carbon reduction target by 2050 (Sopery, 2023; Ishak et al., 2018).

Historic building conservation policies also play a crucial role in shaping retrofit practices. Conservation practices in Malaysia are guided by statutory frameworks such as the National Heritage Act (Act, 2005) and guidelines including the Garis Panduan Pemuliharaan Bangunan Warisan (JWN, 2016). These policies ensure preservation of heritage value but prioritize authenticity and cultural significance over environmental performance (Zaid et al., 2021). Heritage conservation is typically approached as a reverse engineering process, requiring detailed surveys, documentation, and analyses of as-built conditions before interventions (Lee et al., 2020; Wilkinson, 2011). Such assessments focus on defects, cracks, and material integrity to safeguard originality and authenticity (Azis et al., 2022). However, little consideration is given to address measures and protocols in retrofit projects (Dias Pereira et al., 2021). This disconnect creates a “gap” between conservation outcomes and sustainability expectations (Mohareb et al., 2017). Scholars argue that conservation must integrate updated science and technology to remain relevant (Halim et al., 2012); Bait, 2012).

Recent scholarship suggests that heritage policies should evolve to address global sustainability agendas. (Khalaf, 2021) proposes reinterpreting authenticity within the concept of heritage integrity, emphasizing continuity and adaptability to align with contemporary challenges. This shift is essential given global priorities such as climate adaptation, disaster resilience, and the Sustainable Development Goals (Assembly, 2015; UNDRR, 2020; UN, 2022). Heritage buildings, as a significant portion of Malaysia’s building stock, must therefore be repositioned not only as cultural assets but also as contributors to climate mitigation and resource efficiency.

In summary, this discussion highlights the broader policy and regulatoru context influencing historic building retrofit practices in Malaysia. Although policies and legislation are not directly investigated in this research, the discussion demonstrates the existing gaps in retrofit guidance, sustainability integration, and implementation practices within the heritage sector. These contextual challenges further justify the need for a structured HBIM-retrofit framework to support more systematic, efficient and sustainable heritage building conservation practices in Malaysia.

2.3.3 The Complex Nature of Decision Making in Multidisciplinary Approach in Historic Building Conservation

As previous studies mutually highlighted there are many challenges and issues concerning the needs of retrofit and policies and initiatives of heritage-built practice lifecycle, further issues and complexities faced within the retrofit practice requires identification. Fundamentally, according to Rahmat (2008), the heritage building conservation practice is generally a multidisciplinary practice with involvement of various stakeholders in delivering projects. This includes involvement of different stakeholders such as owners and building professionals in the retrofit process that is driven by different values (e.g., heritage and cultural, affective, aesthetic, architectural) in the decision-making process (Buda et al., 2021).

However, such nature has imposed many complexities in its process, potentially resulting in tensions or even synergies, towards the identification of possible energy-efficient retrofitting solutions (Buda et al., 2021). Furthermore, fragmentation and work in silo culture within the multidisciplinary practice of heritage building conservation with high dependency of traditional approach in the practice was seen as a barrier towards the complexities in coordination of retrofit interventions (Baharuddin et al., 2024). Moreover, in many cases, none of the professionals involved in the historic building retrofit are experts in energy efficiency of historic buildings, introducing a coordination and decisional challenge in retrofit projects (Bertone et al., 2018).

Furthermore, Ismail et al. (2021), highlights the current state of heritage-built practice encountered inaccurate project information (Zhou, 2016), insufficient and missing documentation and the lack of technology adaptation and poor report reliability (Rodrigues et al., 2019). Due to this heritage building conservation project are often under perception of underestimation and faced unforeseen variations from final account (Rahmat, 2008). Hence, this would subsequently cause projects delivery to face issues of uncertainty, inaccuracies and unreliability which often impose challenge to the project team and complicates the design process (Baharuddin et al., 2024; Khalil et al. 2021; Ramli et al., 2021; Arayici et al., 2017).

Through such challenges, has a direct influence towards the practice of heritage conservation to transform the way of delivering projects towards efficient and effective practice by leveraging innovative and integrated solutions in practice (Buda et al., 2021). In a study by Dias Pereira et al. (2021), the authors examined current challenges in retrofitting cultural buildings and highlighted the role of BIM, particularly its integration with energy-efficiency interventions, in establishing a sustainable, multidisciplinary retrofit framework.

2.3.4 The Complexity of Conservation-Compatible Retrofit Solutions in Practice

Furthermore, another study by Khalil (2017) highlights the most deterring obstacle that faces in historic building conservation is the shortage of data in performing optimal decision-making in determining proper conservation approaches (Khalil, 2017). Data collection in heritage building conservation is a prerequisite for any attempt towards a historic building conservation. The data required include accurate as-built drawings, information related to building materials, and their properties (Harun, 2021).

However, previous research highlighted among the obstacle in conservation practice is the limitation on the traditional as-built drawings methods and level of information as to compared to new building works where most of the information are easily available and accessible (Amano & Lou, 2016; Baharuddin et al., 2024). Hence, digital technology has been seen to improve the productivity of heritage-built practice, with the application of integrated project delivery tool and management mechanism that allows collaboration between all stakeholders within the supply chain are needed to overcome such challenges (Said et al., 2025).

The need to systematize solutions deemed suitable for historic buildings is accompanied by that of defining an integrated, adaptable, and consistent evaluation method that supports a whole-building assessment of scenarios, with the objectives of energy saving, environment, indoor quality, economic saving, and conservation (Buda et al., 2021).

2.3.5 Digitalization Challenges and HBIM Adoption in Historic Building Retrofit Practice

Digitalization in the Malaysian heritage sector has increasingly been recognized as an important enabler in improving information management, coordination, and project performance in historic retrofit practice. Meanwhile, in the Construction

Industry Transformation Plan (CITP) has imposed strategic thrust in, in embracing the trends of Industrial Revolution 4.0 (IR 4.0), CIDB through Construction 4.0 Strategic Plan have identified BIM as one of the 12 key technologies that would significantly change the construction industry including 3D laser scanning and photogrammetry, virtualization and cloud real-time collaboration (CIDB, 2015; CIDB, 2020).

In the latest BIM report, the Public Works Department (PWD) has imposed public projects of RM100 million or more have been mandated to use BIM since 2019 (CIDB, 2021). This government mandate makes no distinction between new-build and existing and historical assets therefore it is also applicable to heritage building conservation projects. Further initiatives were made to spearhead the digital revolution in conjunction to IR 4.0 to embrace and utilize future trends in the construction sector. BIM is one of the government's agendas in the 12th National Key Economic Area (NKEA) which is to enhance business growth in the Architecture, Engineering, Construction (AEC) industry.

At the strategic level, in 2021, the Ministry of Works have released the National Construction Policy 2030, where the study has formulated a strategic plan for the holistic adoption of digitalization to enhance the productivity and competitiveness of the construction industry. Meanwhile, the Construction 4.0 Strategic Plan (2021-2025) is the main accelerator towards the industry 4.0 (CIDB, 2020). Despite many initiatives conducted strategically to embrace the benefits of ICT and digitalization, the implementation of digitalization in construction in Malaysia are still relatively low.

Government bodies such as Construction Industry Development Board (CIDB) and Public Works Department (PWD) has introduced series of BIM guidance, standards and manuals to expedite best practice of BIM in public projects, however much of the focus is on the adoption to new constructions rather than interventions towards existing and historical buildings, which dealt with unique complexities and distinctive process (Arayici et al., 2017).

Hence, this is limiting the uptake of HBIM in historic buildings as opposed to international countries such as UK, Italy and which has uncovered comprehensive HBIM-retrofit guidance and funded research projects on different facets of HBIM for heritage buildings (Di Biccari et al., 2022; Othman et al., 2021). These limitations demonstrate the need for a more structured and integrated HBIM-retrofit approach capable of supporting retrofit decision-making, multidisciplinary coordination, and overall project performance in heritage building conservation projects.

Despite the relatively low level of ICT readiness among construction players, recent developments indicates increasing interest towards AI-assisted and data-driven digitalization approaches within the heritage conservation sector, particularly in areas related to photogrammetry, laser scanning, computer vision, semantic segmentation, and automated Scan-to-BIM workflows for 3D heritage modelling (Waqar, 2026). Recent studies have demonstrated that artificial intelligence (AI) and machine learning technologies are increasingly capable of improving the efficiency, automation, accuracy, and semantic interpretation of point cloud processing and HBIM generation processes, particularly for complex and irregular heritage geometries (Queruel et al., 2024; Song et al., 2023).

Emerging AI-driven approaches such as automated object recognition, semantic classification, predictive modelling, and intelligent digital twin generation are also increasingly being integrated into HBIM (Inzerillo et al., 2025) and Scan-to-BIM workflows to support more efficient heritage documentation, retrofit assessment, lifecycle management, and decision-making processes (Alshawabke et al., 2024). Nevertheless, the adoption of HBIM and advanced AI-enabled digital technologies in Malaysian historic retrofit practice remains limited and fragmented. Therefore, to realize the government's digitalization vision and address the conservation challenges discussed previously, there is a growing need for more structured and integrated HBIM-retrofit approaches capable of supporting retrofit assessment, information management, multidisciplinary coordination, and project performance improvement in heritage building conservation projects.

2.3.6 Research Gaps and Need for HBIM-Retrofit Framework

Despite the growing body of literature on heritage building conservation, sustainability, retrofit practices, and digitalization initiatives, several important gaps remain within the existing body of knowledge. Previous studies have extensively discussed issues related to environmental sustainability (Buda et al., 2021), conservation policies, multidisciplinary complexities, and BIM implementation in heritage buildings (Dias Pereira et al., 2021; Arayici et al., 2017). However, much of the existing research remains fragmented, where studies on historic retrofit primarily focus on technical or environmental performance, while HBIM-related studies are largely concentrated on documentation, visualization, and modelling applications (Salleh et al., 2022; Mustafa et al., 2020).

Furthermore, limited studies have systematically examined how HBIM functionalities can be aligned with the characteristics and requirements of historic building retrofit processes to improve project performance outcomes such as coordination, decision-making, information management, and project delivery efficiency (Kermanshahi et al., 2020; Said et al., 2025). Existing international studies have demonstrated the potential of HBIM-enabled retrofit approaches through case studies and conceptual applications (Gigliarelli et al., 2022; Antonopoulou & Bryan, 2017; López et al., 2018), however, such investigations remain limited within the Malaysian heritage conservation context.

In addition, there remains an absence of a structured and integrated framework that holistically connects HBIM capabilities, retrofit characteristics, and heritage project performance considerations within a multidisciplinary conservation environment. This indicates a significant theoretical, practical, and contextual gap in current knowledge. Therefore, the following subchapter further examines the concepts, characteristics, and implementation aspects of historic building retrofit and HBIM-retrofit as the foundation for developing the proposed HBIM-retrofit framework for heritage building conservation projects in Malaysia.

2.4 Historic Building Retrofit

This subchapter discusses related literature reviews regarding historic building retrofit to form the fundamental knowledge area. The literature review was done to satisfy the scope of the research and the achievement of Objective One which is identify the relevant concepts and characteristics of HBIM-retrofit in influencing the performance of heritage building conservation projects in Malaysia.

2.4.1 Definition of Historic Building Retrofit

The current national-level heritage conservation guideline does not include a specific definition of retrofit. However, the process of updating and reusing building components similar to retrofitting, is expressed through several terms, including refurbishment, restoration, rehabilitation, and adaptation. These terms can be confusing as all the approaches can usually be defined similarly with retrofit (Sopery, 2022), thus adding a plethora of terms used to cover retrofit, which is described by Wilkinson (2011), has often exist in a ‘state of pleasant confusion'.

Hence, a distinction between these terms should be identified and defined to establish a clear context for the term retrofitting. The terms retrofit and refurbishment are often used as if they are interchangeable. However, they have different meanings. Fundamentally, the term retrofit, as derived from Douglas' (2006) is defined as "any work to a building above and beyond maintenance to change its capacity, function, or performance," or "any intervention to adjust, reuse, or upgrade a building to suit new conditions or requirements". According to Eames et al. (2014), retrofit means to provide something with a component or accessory not fitted during manufacture or to add something that did not have when first constructed (Eames et al., 2014).

It is frequently related to the installation of new building systems, but it may also refer to the fabric of a building such as retrofitting insulation, walls, or windows. To further extend, May & Griffiths (2015), defined retrofit as the process of improving the energy and environmental performance of buildings through technical interventions, albeit that to achieve benefits, this process often needs to encompass occupants’ lifestyle changes and involves a systematic programme of upgrade, repairs and maintenance.

The key focus of retrofit is to achieve enhanced energy performances while maintaining satisfactory service levels and acceptable indoor thermal comfort suitable for contemporary lifestyles using less energy compared to the energy use values before intervention (Moran et al., 2014; Ma et al., 2012). For instance, in the building fabric, energy efficiency measures can be assessed and applied modifications to building components such as walls, doors, windows, floors and roof, thereby cutting the heating and cooling costs, energy use and carbon emissions (Almeida, 2014).

However, there are other important aspects of interventions of reducing these impacts which includes modification of building systems, including natural daylighting and artificial lighting controls, indoor air quality, energy performance, ventilation and using renewable energy. According to Wilkinson (2011), retrofitting can occur on an entire building or on a portion of a building, such as one or more floors of a building. The definition includes both within-use and across-use retrofits.

The term "retrofit event" refers to any activity involving individual building permits on existing buildings. Retrofit events in buildings can be referred to as alterations and extensions, upgrades, change of use, and renovation; as such, multi-tenanted buildings will experience multiple events in the same building. According to Almeida (2014) and Aikivuori (1996), a historic building should be retrofitted if considered into one of the following categories, (1) failure in the building due to deterioration, (2) change in use; (3) optimization of economic factors by improving energy efficiency, (4) subjective features of the decision maker and (5) change of circumstances.

2.4.2 Historic Building Retrofit Characteristics

The development of an effective procedural framework necessitates a comprehensive understanding of the organizational, process, methods, regulations and technical requirements underpinning a strategic plan for historic building retrofit. This subchapter therefore explores these dimensions in greater detail by discussing the roles of stakeholders, the key phases of retrofit projects, the importance of retrofitting criteria and their associated activities, and the methods and tools used to evaluate historic retrofit performance. Establishing such classifications provides the necessary context for identifying the retrofit attributes that forms the foundation of this research.

To structure this classification, the study examined thirteen (13) grey literature documents comprising historic retrofit guidance from various countries. These documents were selected because they represent a recognized international best practice, frequently referenced in the implementation of historic building retrofit projects. Their inclusion provides a robust comparative basis for developing a framework applicable to the Malaysian context. Given the current absence of formal guidelines for energy retrofitting of historic buildings in Malaysia (Dewiyana et al., 2016; Azis et al., 2022), it was necessary to conduct a comprehensive literature review of international practices.

This review identified several technical guidelines that specify, in detail, the scope, principles, and stages of retrofitting historic buildings. These guidelines not only articulate the theoretical foundations and methodological approaches but also provide practical and regulatory insights, including the role of stakeholders, the sequencing of project stages, and the technical criteria and methods commonly employed in historic building retrofit projects.

By synthesizing these international guidelines, the study establishes a retrofit taxonomy encompassing four major elements: (i) concept and principles, (ii) stakeholder responsibilities, (iii) development stages and (iv) technical methods and evaluative techniques. Collectively, these insights provide the practical, methodological, and regulatory underpinnings required for formulating the proposed HBIM-retrofit framework. Table 2.1 outlines the selected primary guidelines as follows.

Table 2.1
Summary of Guidance on Retrofits for Historic Buildings

Guidelines	Date	Institution/Country of Origin	Main Focus	Reference
PAS 2038:2021 - Retrofitting non-domestic buildings for improved energy efficiency	2021	British Standards Institution (UK)	UK specification for managing retrofits in non-domestic buildings, including historic stock, using a structured whole-building approach.	British Standards Institution (2021)
Energy Guideline for Historic Buildings (Guideline 34)	2019	ASHRAE (US)	Structured retrofit approach in the U.S. context; energy efficiency without compromising heritage values.	ASHRAE (2019)
Guide to Energy Retrofit of Traditional Buildings	2021	Historic Environment Scotland (UK)	Technical guidance for retrofitting Scotland's traditional buildings; practical solutions.	Historic Scotland (2021)
EN 16883 Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings	2017	CEN/TC 346 (EU)	European standards provide step-by-step methodology for decision-making and assessing energy efficiency interventions in historic buildings.	de Normalisation (2017)
Planning Responsible Retrofit of Traditional Buildings	2015	Sustainable Traditional Building Alliance (UK)	Whole-building approach to retrofitting; moisture, risk assessment, and heritage sensitivity	May & Griffiths (2015)
Energy Efficiency and Historic Buildings: How to Improve Energy Efficiency	2018	Historic England (UK)	Technical notes on walls, roofs, floors, windows, services, insulation, and moisture control.	McCaig et al. (2018)
Energy Efficiency Solutions for Historic Buildings: A Handbook	2015	3ENCULT (EU)	Handbook with case studies and technical solutions; integrating energy efficiency with cultural heritage.	Troi & Bastian (2015)

Energy Heritage: A Guide to Improving Energy Efficiency in Traditional and Historic Homes.	2008	Changeworks (UK)	Practical guide on improving energy performance of traditional homes while retaining character; focused on Scottish housing stock.	Changeworks. (2008)
Energy Heritage: A Guide to Improving Energy Efficiency in Traditional and Historic Buildings	2008	English Heritage (UK)	Early consolidated guidance on balancing energy upgrades with conservation needs.	Heritage (2007)
Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage	2011	ICOMOS (International)	International principles underpinning conservation, used as a baseline for retrofit interventions.	ICOMOS (2011)
Planning Energy Retrofits of Historic Buildings: EN 16883 in Practice	2021	IEA-SHC Task 59 (International)	Companion handbook applying EN 16883:2017 through practical examples, case studies, and methodologies.	Leijonhufvud et al. (2021)
The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings.	2013	US National Park Service (US)	U.S. benchmark for rehabilitation; illustrated sustainability guidelines that balance energy efficiency with heritage character.	National Park Service (2013)
EE-HBIM Guidelines for Energy Efficient Retrofit (BEEP Project)	2021	EU ENI CBC Med Project (EU)	Guideline to improve the energy efficiency of historic buildings using an integrated Building Information Modeling (BIM) approach.	Gigliarelli et al. (2022)

Upon investigation of the documents, the literature has classified four important key themes that needed to be explored further, this includes the heritage aspects, development stages, retrofit design criteria and method of approach. Table 2.2 highlights the keystones according to respective authors.

Table 2.2
Selected Historic Retrofit Guidance and the Keystone (Author)

Author/Year	Historic Retrofit Keystones			
	Heritage Aspect	Development Stages	Retrofit Design Criteria	Method of Approach
McCaig et al. (2018)	✓	✓	✓	✓
ASHRAE (2019)	✓	✓		✓
Troi & Bastian (2015)	✓	✓	✓	✓
Historic Scotland (2021)	✓		✓	✓
de Normalisation (2017)	✓	✓	✓	✓
Changeworks (2008)	✓	✓	✓	✓
May & Griffiths (2015)	✓	✓	✓	✓
National Park Service (2013)	✓		✓	✓
Heritage (2007)	✓	✓	✓	✓
ICOMOS (2011)	✓			✓
Leijonhufvud et al. (2021)	✓		✓	✓
British Standards Institution (2021)	✓	✓		✓
Gigliarelli et al. (2022)	✓		✓	✓

The identified retrofit keystones derived from the reviewed international guidelines form the foundational variables for the conceptual framework development presented in Chapter Three. The recurring themes namely heritage aspects, development stages, retrofit design criteria, and methods of approach were consistently emphasized across the literature and were therefore operationalized as the principal dimensions of historic building retrofit characteristics. These dimensions subsequently informed the development of the first-order constructs, indicators, and higher-order constructs within the proposed HBIM-retrofit conceptual framework.

2.4.2.1 Heritage Aspects

The retrofitting of historic buildings requires careful attention to heritage values to ensure the preservation of cultural, architectural, and historical significance. Central to this process is the need for thorough historical research and the application of a whole-building approach, which considers the original design intent and construction context. Such an approach enables the development of balanced solutions that not only improve energy performance but also sustain heritage character while ensuring occupant comfort and health (McCaig et al., 2018).

An equally important dimension is the assessment of heritage significance, which extends beyond architectural features to encompass environmental, cultural, community, and economic values. This holistic evaluation provides the foundation for informed retrofit decisions (Historic Scotland, 2021). The process must also adhere to established conservation principles, which set out the reasoning, methods, and tools for interventions. These principles ensure that any modification respects the authenticity of the building while addressing the demands of change (Troi & Bastian, 2015).

Complementing this is the role of policies and regulations, which formalize heritage conservation through zoning controls, building codes, and preservation standards. Such regulatory frameworks provide structured review and approval processes, offer incentives or funding mechanisms, and mandate public participation, thereby embedding heritage preservation within retrofit projects (McCaig et al., 2018; Troi & Bastian, 2015; May & Griffiths, 2015).

Finally, successful heritage retrofit projects rely on multidisciplinary collaboration. The integration of expertise from architects, engineers, conservators, policymakers, and sustainability specialists allows complex challenges to be addressed comprehensively. This collaborative approach fosters innovative solutions that reconcile conservation goals with technical and functional requirements, leading to sustainable and context-sensitive retrofit outcomes (Heritage, 2007).

2.4.2.2 Development Stages

The development stages of retrofit can be understood as an evolution of earlier models of refurbishment and building adaptation. One of the earliest conceptualizations was the five-phase refurbishment model proposed by Mickaitytė et al. (2008), originally designed for public buildings. This model highlighted the staged nature of decision-making, covering phases of problem identification, option modelling, decision selection, and implementation. While not specific to heritage contexts, it emphasized the importance of phased decision-making and evolving information requirements throughout retrofit processes.

Building upon this foundation, later studies expanded the framework towards energy retrofits and conservation contexts as shown in Figure 2.1. Miran (2020), examined heritage retrofits through a performance-based approach, emphasizing planning and monitoring phases as critical for balancing energy efficiency and conservation ethics. Similarly, Ma et al. (2012) proposed a comprehensive process model for building retrofits that framed retrofitting as a systematic lifecycle of planning, implementation, commissioning, and operation. Lee et al. (2020) further refined these models by integrating post-occupancy evaluation and continuous feedback, stressing that retrofitting is not a one-off intervention but a cyclical process requiring long-term monitoring.

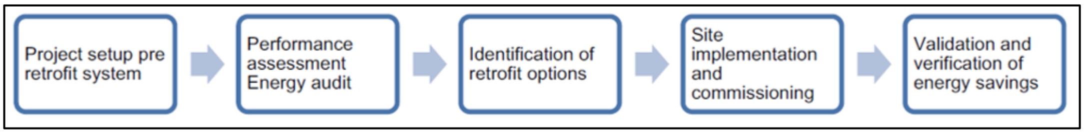

Figure 2.1 Building Retrofit Process (Lee et al., 2020; Miran, 2020; Ma et al., 2012)

The convergence of these contributions led to the articulation of retrofit as a series of development stages, typically synthesized into four categories: pre-design, design stage, implementation, and post-retrofit evaluation. These stages synthesize earlier refurbishment and retrofit theories into a structured lifecycle approach for retrofit implementation. In the heritage context, this approach is particularly important as it provides a structured pathway for reconciling the technical, environmental, and cultural objectives of retrofit projects (Fabbri & Zuppiroli, 2019; Troi & Bastian, 2015).

Within these development stages, HBIM has increasingly been recognized as a supporting technological platform capable of facilitating information management, documentation, multidisciplinary coordination, simulation, and decision-making throughout the retrofit lifecycle (Arayici et al., 2017; Baik, 2017; López et al., 2018). During the pre-design stage, HBIM supports data acquisition and existing condition documentation through Scan-to-BIM processes, while at the design and implementation stages, HBIM enables coordination, visualization, clash detection, and evaluation of retrofit interventions. In the post-retrofit stage, HBIM further supports lifecycle monitoring, maintenance, and long-term heritage asset management. Therefore, the integration of HBIM within the retrofit development stages demonstrates its potential in enhancing project performance and supporting more systematic heritage retrofit processes.

This perspective aligns with project lifecycle management principles, where complex projects are managed through sequential and interdependent phases (PMI, 2017). Within historic retrofit however, lifecycle models are enriched by additional requirements such as the preservation of material authenticity, compliance with conservation regulations, and respect for cultural values (Pocobelli et al., 2018; Historic Scotland, 2021). Volk et al. (2014) further emphasizes the need to integrate performance standards with heritage documentation requirements.

2.4.2.3 Retrofit Design Criteria

The retrofit design criteria is a set of principles and requirements used to guide the planning and design of energy upgrades and interventions in heritage buildings. The emphasis is on specific retrofit solutions, performance targets, and building science considerations that are appropriate for traditional structures. Much of the guidelines often organize content by building elements or systems (walls, roofs, windows, HVAC, etc.) and provide criteria for selecting and installing upgrades that improve efficiency without causing damage. For example, McCaig et al. (2018) delivers detailed technical notes on insulating walls, roofs, floors, windows, improving services, and managing moisture in older buildings. It essentially lists design criteria and solutions for each building component (e.g. recommending ventilation strategies when adding insulation, to prevent moisture issues).

Similarly, Historic Scotland (2021) offers practical technical solutions specific to UK's traditional building stock, addressing common retrofit measures in a heritage-friendly way. European research outputs Troi & Bastian (2015) compile case studies and technical solutions that integrate energy efficiency upgrades with preservation of cultural heritage. At a more introductory level, Changeworks (2008) provides homeowners with practical retrofit tips (e.g. insulation, glazing, draft-proofing) tailored for historic homes, all while retaining the houses' character. There are also illustrated guideline documents, such as National Park Service (2013), which show recommended and inappropriate retrofit practices for historic buildings.

In summary, the retrofit design criteria theme encompasses guidelines that function as catalogues of retrofit measures and best practices, helping practitioners choose and detail interventions that meet energy goals and protect the building's fabric and performance. Therefore, according to McCaig et al. (2018) and Webb (2017), there are five key design criteria that affect energy use and influence retrofitting when implemented in heritage buildings. These are building envelopes, building services and equipment, user behaviour, collections and economics.

2.4.2.4 Methods of Approach

The energy audit process requires employing a combination of techniques and methods to conduct the retrofit design assessment. Studies on historic buildings is often employed based on a whole building analysis or of a single building components to measure and estimate energy performance measures that leads to a feasible a retrofit objectives (McCaig et al., 2018; Lidelöw et al., 2019). Due to sensitivity of historic buildings, it is important that a combination of Non-Destructive Approach (NDT) is conducted during design assessment to avoid risk of damages conducted from field observations and tests (Webb, 2017).

The series of energy assessments for retrofit interventions is conducted using non-destructive methods which consists of combination of either or both environmental and microclimatic observation, in-situ assessment, laboratory testing, building performance simulation, economic analysis, risk assessment and energy performance certificate (EPC) assessment to holistically measure the sustainability performance of historic buildings (Webb, 2017).

Moreover, such an invasive or destructive approach can be considered, however it is an inviable technique and should it be required, it is important to be incorporated with the principles of preservation with reversible effect (Sanhudo et al., 2018). There are no preferred ways of strategizing the assessment and the designers could employ single or multiple methods of approaches by considering the complexity, site and building conditions (McCaig et al., 2018). Moreover, some of these methods have emerged in literature as particularly important or useful for historic buildings and these methods of approaches and their applications are discussed in the following subchapters.

2.4.3 Historic Building Retrofit Elements

Following the identification of four sub-domains, this study undertakes a detailed examination of historic building elements to establish corresponding indicators and their definitions, thereby strengthening the construct of historic building retrofit characteristics. In total, twenty-one elements were identified and are discussed in the subsequent section. The reviewed elements therefore provide the foundational attributes for operationalizing historic building retrofit characteristics within the conceptual framework in Chapter Three.

2.4.3.1 Heritage Building Typology

Historic building typology in retrofit involves identifying and categorizing buildings based on their significance, age, architectural style, and historical context (May & Griffiths, 2015; Harun, 2011). These categories help inform decision-making during the retrofit process by guiding appropriate preservation approaches. In general, there are no specific definition on the categorization of heritage-built in the present guidelines on Heritage Building Conservation by the National Heritage Department (JWN, 2016).

However, guidelines from local authorities have succinctly classified the different categories of heritage buildings in Malaysia, each with its own characteristics, which considers its significant values which includes historical, architectural, cultural and community values, (PLANMalaysia, 2020; KLCP, 2020). Furthermore, the criteria outlined serve as a basis in determining the level of protection and to control scope of interventions for heritage building conservation works.

Buildings designated as listed on heritage registrars, for example, may require more stringent preservation measures compared to those with lesser significance (Webb, 2017). Understanding the categorization of historic buildings informs stakeholders about the level of protection and care needed during retrofitting, ensuring that preservation efforts align with heritage values and regulatory requirements.

Currently, the National Heritage Department carried out a total of 198 conservation initiatives between the year 2016 to year 2021 (JWN, 2025), with 62 projects falling under Category I. Although some have been successfully preserved, many of these structures continue to suffer from defect problems, being abandoned and devalued due to insufficient attention other than minor repairs (Ali et al, 2018b).

2.4.3.2 Values and Significance

Heritage values play a crucial role in historic building retrofit projects, influencing decision-making processes, design considerations, and preservation efforts in historic buildings. As existing historic buildings are in a constant demand to improve its environmental performance, such as meeting energy and green standards, the consideration of heritage values in the retrofit decision is highly important for meeting these standards (Bastian et al., 2014). Moreover, Şahin et al. (2015) defines heritage values as the tangible and intangible significance of historic buildings, including their architectural and aesthetic values, connections with historic communities and events, evidence of technical progression, characteristics of social history. Several guidance emphasizes heritage values as key considerations, which includes evidential, historical, aesthetics and communal values (Heritage, 2007). The importance of considering heritage values in retrofit interventions is crucial due to the role in perpetuating a sense of identity, prestige, and community as well as the needs to address energy-efficiency while navigating the regulatory requirements for alterations (Tokede et al., 2018).

Historic buildings vary greatly in the extent to which they can accommodate change without loss of their special interest. Some are sensitive to even slight alterations, particularly externally, and where they retain important interiors, fixtures, fittings and details, these considerations will influence the extent of change that is appropriate to improve energy efficiency. Furthermore, (Buda et al., 2021), highlights considering heritage values in retrofit decision-making is crucial to find sustainable balance between energy performance and conservation, an thus requires a tailored, case-by-case evaluation of well-balanced solutions (McCaig et al., 2018).

The heritage values consideration in retrofit interventions is emphasized as a complex, context specific process, however in a study by Yarrow (2016), highlights such associated interventions are not adequately captured in general policies, suggesting towards aligning legislation and guidance relating to energy efficiency and heritage values aspects in building conservation could be beneficial.

2.4.3.3 Regulations

Regulatory policy plays a crucial role in guiding and governing historic retrofit projects. They establish preservation standards, zoning regulations, and building codes to ensure that historic retrofits adhere to heritage values while meeting modern requirements (National Park Service, 2011). These regulations provide review and approval processes, ensure compliance with environmental standards, mandate public engagement, and enforce regulations to preserve the cultural heritage significance of historic buildings during the retrofit process (Troi & Bastian, 2015). The retrofit of historic buildings presents a complex challenge due to the need to balance heritage preservation with energy efficiency. Galatioto et al. (2017) and Mazzarella (2015) both highlight the difficulties in implementing energy retrofit actions on historical buildings, including high payback times and restrictions on renewable energy sources combined with the absence of general rules, codes and standards for energy retrofit of historical and architecture valuable buildings, which signifies a limitation in policies directives to the environmental sustainability of historic buildings (Zaid et al., 2021).

Smith (2014), emphasizes the importance of integrating building physics, design, and policy interpretation in sustainable refurbishment projects, while Wise et al. (2021) suggests a more holistic approach that considers user behaviour and non-technical measures. These studies collectively underscore the need for tailored policies and regulations that address the unique characteristics of historic buildings and promote their sustainable retrofit. Furthermore, Conejos et al. (2019) highlights the compliance to regulations, codes and current design requirements are the major challenges encountered in undertaking retrofit projects, hence proposed towards formulating prospective regulations that would address the changing of building use, encourage the integration of modern technologies and best retrofit actions for future global climate protections.

2.4.3.4 Principles of Intervention

Principles in interventions guide the process of retrofitting historic buildings to ensure that preservation efforts are aligned with heritage values and significance. To safeguard its significance, alterations to an historic building are guided by a common set of conservation principles, and any energy retrofits must also adhere to these (Webb, 2017). These principles mutually emphasizes minimal intervention, reversible techniques, and respect for the building's original fabric (McCaig et al., 2018; Heritage, 2007; Troi & Bastian, 2015). By prioritizing the preservation of historic features, materials, and craftsmanship, while accommodating necessary upgrades or adaptations, conservation interventions aim to maintain the building's authenticity and significance (National Park Service, 2011).

Additionally, principles advocate for thorough documentation, stakeholder engagement, and sustainable practices to enhance the long-term viability of historic retrofit projects. A range of studies have explored the principles in conservation intervention in historic retrofit. Ginks & Painter (2017), highlights the importance of conservation principles in retrofit through emphasizing the need to balance energy efficiency improvements with the preservation of aesthetics and structural qualities of historic buildings and the role of conservation professionals in determining the appropriateness of alterations. Ide et al. (2022) further discusses the need to balance energy efficiency with the conservation principles by presenting a methodology and decision-framework for deep energy retrofit analysis that aims to balance trade-off between conservation and sustainability.

2.4.3.5 Multidisciplinary Stakeholders

A multidisciplinary approach to historic building retrofit involves the integration of various disciplines. As historic retrofit is becoming more complex in practice, such multidisciplinary environment can be leveraged by contributing artistically, intellectually and practicality to the process of conservation (Feilden, 2007). Thus, developing innovative solutions that balance preservation goals with practical considerations, community needs, and sustainability objectives (Webb, 2017).

Such practice requires careful attention from building owners, occupiers and the involvement and expertise of various professionals such as town planners, conservation architects, building surveyors, landscape architects, quantity surveyors, specialized engineers, building contractors, archaeologist, art historians and antiquities (Harun, 2021; Almeida, 2014). This approach facilitates holistic decision-making, enhances project outcomes, and ensures the preservation of cultural heritage significance in historic retrofit projects.

Such practice is crucial in the retrofitting of historic buildings, particularly in the evaluation of their structural and energy performance (Ascione et al., 2017). This approach should consider the building's specific use, heritage values and functionality, as well as the potential for occupant behaviour to contribute to energy efficiency (Spigliantini, 2020). The importance of a transdisciplinary approach is further emphasized, particularly in the context of energy efficient retrofitting, to ensure that the building's historical, sociocultural, and architectural values are preserved (Şahin et al., 2015).

These studies collectively highlight the need for a comprehensive, integrated approach that considers the unique characteristics and requirements of historic buildings. The goal of multidisciplinary team is the contribution of each element to understand on one hand the value of the heritage building and, on the other hand, the renovation that the building needs to undergo (Almeida, 2014).

2.4.3.6 Pre-Retrofit Stage

The pre-design stage of retrofit involves the conduct of planning, project setup and survey are the early stage prior to retrofitting involves internal stakeholders such as the building owner, architect, and consultant to determine the scope of work and project objectives by researching budget and available important resources that influence the retrofitting (Lee et al., 2020). According to Edwards (2021), this process would include the risk assessment process during the pre-retrofit survey, the degree of risks correlates with the design and installation requires an analysis of the whole building needs to be undertaken, which includes significance assessment.

Other guidelines emphasize technical and informational investigations. McCaig et al. (2018) and Historic Scotland (2021) direct practitioners to conduct fabric assessments, moisture surveys, and thermal performance evaluations. May & Griffiths (2015) adds a whole-building perspective, highlighting risk assessment of unintended consequences such as condensation and material incompatibility, all of which must be identified in the early stages. Further, de Normalisation (2017) provides a formalized methodology for the pre-design stage, advocating a structured decision-making process that begins with defining objectives, documenting the building, and screening potential measures against cultural and technical constraints.

Its companion, Leijonhufvud et al. (2021) illustrates this through case studies, showing how systematic data collection and evaluation support evidence-based choices. The organizational dimension is also visible in several frameworks. British Standards Institute (2021) and ASHRAE (2019) highlight the need for stakeholder alignment in the early stages, stressing that project teams, owners, and heritage bodies must define shared objectives at the outset. Taking together, these guidelines underscore that the pre-design stage is not merely a preparatory step but a foundation for decision-making that integrates heritage values, technical diagnostics, organizational consensus, and risk assessment. By combining conservation principles with scientific analysis and stakeholder engagement, the pre-design phase ensures that retrofit strategies are context-specific, culturally respectful, and performance-driven, setting the stage for successful outcomes in subsequent design and implementation phases.

2.4.3.7 Design Development Stage

The design stage in the retrofit of historic buildings forms the critical bridge between diagnostic analysis and practical intervention. At this point, retrofit measures are selected and adapted not only to improve energy performance but also to safeguard cultural significance (Pankaduwa, 2024). Unlike conventional BIM-driven retrofits, heritage contexts demand criteria extending beyond technical efficiency to include authenticity, reversibility, and material compatibility (National Park Service, 2013).

Key guidelines emphasize integrating heritage values into technical decision-making. EN 16883:2017 provides a structured methodology for assessing interventions, urging practitioners to screen measures against both conservation and energy goals (de Normalisation, 2017). Its companion volume, Leijonhufvud et al. (2021), illustrates through case studies how design choices must be tailored to individual building contexts. Complementary resources, such as McCaig et al. (2018) and Historic Scotland (2021), highlight fabric-specific considerations, walls, roofs, windows, and services that frame design as balancing technical performance with heritage sensitivity.

Design-phase risks are another recurring concern. Polo López et al., (2021) highlights the importance of risk management during design assessing each design option on technical compatibility, heritage significance, energy performance, indoor environmental quality, economic viability, and outdoor visual impact. May & Griffiths (2015) warns that poorly considered measures can cause moisture or thermal bridging problems, advocating a whole-building approach. Similarly, ASHRAE (2019) promotes performance-based criteria that align energy modelling with preservation principles to ensure safety and comfort without compromising character.

Digital methods are increasingly central in design-phase of retrofit. Gigliarelli et al. (2022) show how integrating survey data, diagnostics, and simulation within HBIM supports scenario testing, while Troi & Bastian (2015) demonstrates the value of iterative and interdisciplinary workflows (Pocobelli et al., 2018). Organizational frameworks also matter. PAS 2038:2021 emphasizes early stakeholder alignment, while advocates participatory design that integrates community values (British Standards Institution, 2021).

2.4.3.8 Implementation Stage

The implementation stage constitutes the transition from planning to physical intervention, representing the most critical phase in retrofitting historic buildings due to the potential for irreversible damage. This stage demands a careful balance between technical performance and conservation responsibility. The National Park Service (2013) emphasizes that interventions must remain minimal, reversible where feasible, and compatible with historic character, cautioning against generic energy upgrades that compromise authenticity. Similarly, Historic Scotland (2021) and McCaig et al. (2018) underscore the importance of workmanship and material compatibility, warning that failures at this stage can undermine both performance and heritage significance. May and Griffiths (2015) further argue that inappropriate materials or poor installation can introduce unintended consequences such as trapped moisture, thermal bridging, and accelerated decay.

The procedural dimension is reflected in de Normalisation (2017), which situates implementation within a structured decision-making pathway, requiring conservation and performance validation during execution. Leijonhufvud et al., (2021) provide empirical evidence that conservation supervision and iterative monitoring enable adaptive adjustments on-site, while Troi & Bastian (2015) demonstrated the value of mock-ups, testing, and stakeholder workshops to reconcile energy goals with cultural values.

Digital innovation has expanded implementation into data-driven practice. Gigliarelli et al. (2022) illustrates how HBIM consolidates diagnostic data, survey outputs, and retrofit scenarios within a single model, enabling precise execution and enhanced communication among conservators, engineers, and contractors. At the organizational level, British Standards Institute (2021) and ASHRAE (2019) highlight project management structures, commissioning protocols, and interdisciplinary coordination as essential mechanisms for accountability. These frameworks recognize that successful implementation extends beyond technical delivery to encompass governance, verification, and stakeholder alignment.

2.4.3.9 Post-Retrofit Stage

The post-retrofit stage is increasingly recognized as a critical phase in ensuring that interventions in historic buildings achieve their intended objectives while safeguarding heritage values over the long term. Unlike new construction, where commissioning often marks completion, retrofitting historic buildings requires continuous evaluation, monitoring, and feedback that extend into occupancy (McCaig et al., 2018). This phase integrates performance assessment with cultural stewardship, ensuring interventions remain effective, reversible where possible, and respectful of heritage significance (National Park Service, 2013).

Several guidelines outline structured approaches. Historic Scotland (2021) and McCaig et al. (2018) recommend systematic post-intervention assessments of thermal comfort, moisture movement, and user satisfaction, emphasizing that outcomes should be measured against both energy targets and conservation benchmarks (Webb, 2017). May & Griffiths (2015) highlight the importance of post-retrofit risk evaluation, particularly regarding moisture dynamics and occupant health, noting that feedback informs future projects. At the European level, EN 16883:2017 requires that selected measures undergo review to confirm long-term performance and compatibility with heritage values. Leijonhufvud et al. (2021) demonstrate how monitoring and iterative feedback loops support adaptive management, while Gigliarelli et al. (2022) demonstrate how sensors, simulation, and HBIM integration provide valuable post-occupancy data.

Beyond monitoring, this stage also includes maintenance planning, operational optimization, and occupant engagement. Activities such as fine-tuning HVAC systems, calibrating HBIM models with as-operated data, and training users in system operation help close performance gaps (Pocobelli et al., 2018; May & Griffiths, 2015). Documentation and knowledge transfer further ensure that lessons learned inform future conservation practice (Webb, 2017).

2.4.3.10 Building Fabric

The building fabric, shell or envelope comprising external walls, floors, roofs, windows and doors forms the primary thermal barrier between indoors and outdoors (IEA, 2013). Its performance is critical for reducing heating, cooling needs and maintaining comfort (Almeida, 2014). In fact, space heating and cooling typically account for over one-third of a building's energy use, rising to over 50% in cold climates (IEA, 2013). Energy losses through the envelope vary with factors like a building's age, construction, orientation and climate.

Poorly insulated or leaky envelopes lead to drafts, overheating, and high energy bills as HVAC systems struggle to maintain temperatures. Figure 2.2 shows the many aspects of interactions of building envelope with the indoor and outdoor environment, such building setting can affect the energy use and the opportunities for improvement towards energy efficiency, occupant comfort and consequently their quality of life (McCaig et al., 2018). Therefore, improving the building fabric is a key retrofit criterion to enhance efficiency, comfort and indoor environmental quality. This includes interventions such as adding insulation and upgrading glazing, which directly reduce heat transfer.

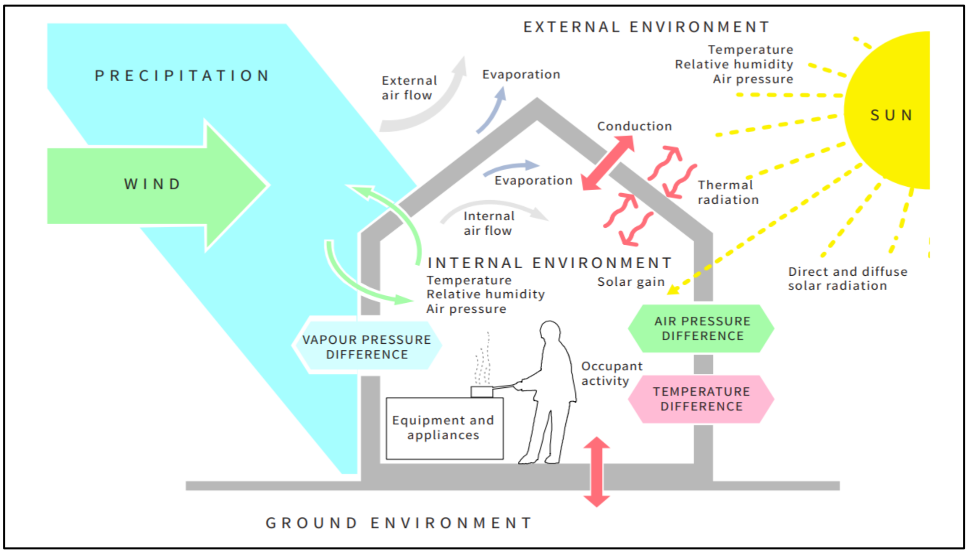

Figure 2.2 Interactions of Building Envelope with the Surrounding Environment (McCaig et al., 2018)

Retrofitting historic buildings' envelopes requires a balanced approach that improves energy performance while respecting heritage characteristics (McCaig et al., 2018). Traditional buildings often have walls with no insulation, leading to significant heat loss and air leakage. For example, unintended air permeability in an old structure can account for tens of thousands of kWh in wasted heat, hence adding insulation is an effective remedy. Li & Tingley (2023) highlights that fabric enhancements are crucial for cutting emissions in pre-1919 buildings. However, external insulation may be infeasible on architecturally significant facades. In such cases, internal wall insulation or thermal plasters can be used, albeit with attention to moisture and space constraints (Annibaldi et al., 2020). Upgrading windows is also vital, replacing single glazing with slim double glazing or installing secondary glazing can reduce window heat losses by 35–73%, markedly improving the envelope's thermal performance (Sevim et al., 2025)

2.4.3.11 Building Services and Equipment

Beyond the building fabric, the performance of systems such as heating, ventilation, air-conditioning (HVAC), lighting, and appliances plays a decisive role in energy efficiency. Electrical and heating systems are often the primary operational energy consumers in historic buildings, where poorly regulated boilers, unzoned heating, and radiators without thermostatic controls lead to disproportionate demand and discomfort (Almeida, 2014).

Retrofitting these systems offers significant opportunities to reduce consumption and improve indoor quality. Simple upgrades, such as energy-saving lighting and low-consumption appliances, can deliver immediate gains with minimal heritage impact (Troi & Bastian, 2015). More complex solutions involve advanced HVAC controls, balanced distribution, and selective integration of renewable sources, though installation often conflicts with conservation restrictions (McCaig et al., 2018).

Best practice emphasizes adaptable systems, including zoned heating with smart sensors, demand-controlled ventilation, and automation, which can achieve 15–60% energy savings across components (de Normalisation, 2017; Azouz & Elariane, 2023). Low-carbon technologies such as air-source heat pumps and biomass boilers have also been explored but require careful heritage-impact evaluation (Gigliarelli et al., 2022). Emerging research highlights data-driven smart maintenance, integrating IoT, cloud and edge computing, and machine learning to enable proactive monitoring, energy optimization, and climate control in heritage buildings (Iwuanyanwu et al., 2024).

2.4.3.12 User Behaviour

The user or occupant behaviour is a critical factor in the energy performance of retrofitted historic buildings. How people use, manage, and even politically or organizationally govern a building can strongly influence energy outcomes (Historic England, 2024; Webb, 2017). Occupancy patterns, user habits, and maintenance practices all shape a building's energy use profile (McCaig et al., 2018). For example, the number of occupants, the comfort levels they expect, and the equipment/services they use have a significant effect on energy consumed in a historic building (McCaig et al., 2018). Furthermore, research shows that modifying user behaviour can yield substantial energy savings in historic buildings.

A case study of a historic housing retrofit found positive occupant behavioural changes contributed an estimated 62–86% of total potential energy savings which have far more impact than the fabric improvements alone (Ben & Steemers, 2014). Conversely, neglecting user behaviour or experiencing rebound effects can offset the gains from physical upgrades. Simple habit changes like opening windows judiciously for ventilation, limiting heating and cooling usage, or lowering thermostats by 1°C can cut heating energy by 10% (Lidelöw et al., 2019). Likewise, in non-domestic historic buildings, scheduling and encouraging such practices such as turning off lights and equipment when not in use and adjusting setpoints can save considerable energy (Ben & Steemers, 2014).

2.4.3.13 Building Structure

The role of building structure in historic building retrofit design criteria is crucial, as it presents unique challenges and opportunities. The need to conduct structural retrofit was mainly to address issues that mainly affects the structural integrity on historic buildings as these building endures slow aging process and exposed to irreversible deterioration of materials, structural damage and vulnerability to natural hazards such as flood-endangered structures and earthquakes (Ercan, 2018; Vicente et al., 2017). Guh & Altoontash (2006), emphasizes the need to preserve the structural safety and integrity of historic buildings, particularly in the context of seismic retrofitting, whereas English et al. (2021), explored innovative foundation techniques for disaster mitigation, looking at flood-risk protection to heritage structures.

Bansal (2018), conducted a case study which overviews the techniques and methods of structural refurbishment which aids for added strength, stability, energy performance, accessibility and safety of the historic buildings. Furthermore, Widström & Mattsson (2011) and Webb (2017) both underscore the importance of considering the multifunctional aspects of building structure in retrofitting strategies, including energy conservation and preservation of cultural artifacts. Kass et al. (2017), further contributes to this discussion by proposing a pre-assessment method that considers the condition of building structures, among other factors, in the selection of retrofit projects. These studies collectively highlight the significance of building structure in the preservation and sustainable use of historic buildings.

2.4.3.14 Collections

The protection of building assets and collections of significant objects and artifacts in historic buildings such as museums, galleries, archives, libraries, and religious spaces is a critical consideration in retrofit (Webb, 2017). According to Michalski (1994), the risks to a collection can be evaluated based on the nine primary agents of deterioration: fire, theft, water, physical forces, pests (insects, mammals, fungi), pollutants, light, incorrect temperature, and incorrect relative humidity and the last three of the factors are directly related to retrofitting.

Guo et al. (2023) conducted a review on the effects of airborne pollutants in collections environments in relation to their common indoor and outdoor sources, furthermore the considerations and target levels specifically for historic building's collections is also provided in ASHRAE (2011). Several approaches in controlling collections through retrofit were identified, Tétreault (2003) explores control strategies include methods that avoid or block pollutant sources, or dilute, filter, or absorb them through a retrofitted mechanical or natural ventilation and filtration.

Pollutant sources and concentrations have been examined in a range of collections buildings, including historic museums, libraries, and religious buildings (Loupa et al., 2010; López-Aparicio et al., 2011), and some of these studies assess the impact of pollutants on human health. Additionally, extensive research has been conducted regarding the influence of temperature and humidity on collections.

Moreover, Pigliautile et al. (2019) delved into pioneering methods for improving microclimate conditions to enhance indoor comfort within historical buildings which are often marked by elevated relative humidity levels and thermal inefficiencies in their envelopes. This leads to necessitating a retrofit strategy for preserving both the buildings and the artworks stored within through the application of innovative thin envelope materials.

2.4.3.15 Economic Factors

Economic factors play a pivotal role in historic building retrofit design criteria, shaping decisions related to project feasibility, funding sources, and cost-effectiveness. They are particularly important for comparing alternative retrofit measures (Ma et al., 2012). Webb (2017) further emphasizes the need to balance energy consumption and heritage conservation with considerations of building fabric, occupants, collections, economics, embodied energy, and climate change.

Despite this importance, several studies highlight the limitations of existing life-cycle costing approaches in retrofitting. Tokede et al. (2018), for instance, revealed that the economic impact of revocability costs could reach as high as 27% in retrofit projects.

The study also outlined a range of economic analysis methods used to evaluate the cost-effectiveness of retrofit solutions, which weigh capital investment against factors such as operational energy costs, maintenance, and replacement costs. Similarly, Cirami et al., (2017) underscores the need for cost-effective retrofit strategies that maintain the historic and architectural value of buildings.

In addition, Tadeu et al. (2015) and Ascione et al. (2017) demonstrate the potential for significant energy savings through cost-optimal efficiency measures in historic buildings. Tadeu et al. (2015) specifically highlights the importance of minimizing both economic and environmental costs. Collectively, these studies stress the necessity of a holistic approach to retrofit design that integrates economic considerations with broader heritage, technical, and sustainability criteria.

2.4.3.16 Environmental Site Monitoring and Analysis

In the case of historical buildings, the monitoring of indoor environmental conditions has primarily been employed mostly to evaluate human thermal comfort (ASHRAE, 2011). These investigations involve gathering continuous or spot measurements of parameters related to thermal comfort, using specific measuring instruments, and then evaluating these measurements to the specified values outlined in the thermal comfort standards (Webb, 2017). In a study by Cardinale et al. (2013), conducted a site monitoring through applying measurement of hygrothermal parameters that characterize the indoor environment such as the air temperature, mean radiant temperature, relative humidity and air velocity including laboratory and in-situ measurement to assess the potential application of HVAC systems in vernacular sites of Sassi and Trulli, Italy.

Gagliano et al. (2014), conducts measurement of thermal behaviour parameters which includes the indoor and outdoor air temperature, inner and outer wall surface temperature, global solar irradiance and wind velocity to analyze the possibility to maintain thermal comfort conditions and avoid overheating of indoor spaces through large surface envelope by exploiting natural ventilation during the nighttime. Similar approach was conducted by Gou et al. (2015), in investigating the climate adaptability of traditional dwellings in Xinye village, China by measuring environmental parameters such as air temperature and relative humidity.

2.4.3.17 In-Situ Measurement

An in-situ approach involves direct measurement of a building component in its original state, such as the U-value of envelope elements, which plays a critical role in energy regulations and ratings (Dias Pereira et al., 2021; Rhee-Duverne & Baker, 2013). Unlike modern buildings where material properties are readily available in databases, historic buildings rely on heterogeneous, locally sourced materials and undocumented alterations, rendering standard values and conventional modelling inadequate (Webb, 2017). In-situ measurement encompasses parameters such as thermal transmittance, air leakage, moisture behaviour, structural response, and indoor environmental quality. Empirical evidence shows measured values often diverge from assumptions. Studies in the UK revealed that solid masonry walls perform thermally better than predicted, with U-values up to 47% lower than default estimates (Historic England, 2023). Similarly, hygrothermal monitoring of internally insulated stone walls demonstrated significant energy savings, though with risks of localized condensation (Blumberga et al., 2023). Beyond thermal and moisture aspects, structural health monitoring with fibre optic sensors has proven valuable in tracking strain and safeguarding heritage fabric (Rossi & Bournas, 2023). Ultimately, in-situ measurement provides evidence-based insights, enabling sustainable interventions that bridge heritage conservation and modern performance goals (Martín-Garín et al., 2020).

2.4.3.18 Laboratory Testing

Laboratory testing represents a cornerstone in the retrofitting of historic buildings, providing both diagnostic insights and validation of proposed interventions. Foundational studies have emphasized the importance of characterizing the mechanical, thermal, and hygrothermal properties of traditional materials to ensure compatibility with retrofit measures. For instance, Posani et al., (2021) examined 20th-century mortars in Lisbon and demonstrated that air-lime mortars exhibited greater porosity and lower strength than cement-based mortars, offering benchmarks for restoration material design.

Likewise, Xu et al. (2023) reported significant variability in the hygrothermal properties of historic bricks within a single wall, underscoring the necessity of site-specific laboratory testing for reliable retrofit risk assessment. Beyond diagnostic characterization, laboratory aging tests such as freeze–thaw cycles, salt crystallization, and high-temperature exposure have been employed to simulate long-term degradation. A systematic review by Lobarinhas et al. (2024), highlighted how fire exposure alters the porosity and mechanical integrity of heritage stones, thereby informing fire-safety strategies in retrofit design.

Recent advances emphasize controlled hygrothermal simulations and laboratory-validated models. Knarud et al. (2023) benchmarked simulations of insulated brick walls against climate chamber experiments, refining predictions of moisture dynamics. Similarly, Dang et al. (2025) demonstrated that capillary-active insulation systems, tested under real climatic exposure, significantly reduced moisture risks compared with vapor-tight alternatives. Laboratory testing has also been extended to innovative retrofit materials. Aerogel-based plasters, reviewed by Del Curto & Cinieri, (2020), offer high thermal efficiency in thin applications, though require standardized laboratory protocols for durability and vapor permeability.

2.4.3.19 Building Performance Analysis and Simulation

The use of building performance optimization methods has surged due to the growing complexity introduced by green building regulations and advancements in computational methods and tools (Seghier et al., 2022). Several tools are used for building energy simulations (BES) in steady-state and dynamic conditions, applying specific algorithms for the calculation and requiring different input and output data. In this direction, the use of HBIM and incorporated with BES has been seen as one the common non-invasive approach in conducting historic retrofit assessment. The application of BES to inform retrofit assessment and intervention have been widely studied in previous literatures. Al Rasbi & Gadi (2021), investigate the thermal performance of new and traditional mosques in Oman using EDSL's Tas Engineering computer simulation software.

The model is also calibrated with monitored data to obtain results close to the experimental data. The outcomes show that traditional constructions are better suited for free-running buildings, while contemporary mosques achieve less cooling load demand per area. These models are also used for defining a compatible retrofit. On hygrothermal evaluation, Martín-Garín et al. (2020) use hygrothermal simulations for assessing different interior insulation systems for walls, without generating damage and moisture problems. They discover that the application of water-repellent impregnation becomes essential to guarantee the integrity of the building envelope.

Furthermore, Cornaro et al. (2016) demonstrates an approach in assessing energy demand in complex historic buildings involves using combination of dynamic simulation tool (IDA ICE 4.5) and on-site measurements. A calibration was made comparing monitored and simulated indoor air temperatures which results in a proposed retrofit solutions with minimal impact on the historical value of the building and achieved an improvement of approximately 40% in the energy demand. In another study by Piselli et al. (2020b), explores innovative integrated modelling and dynamic thermal-energy simulation, consisting of the implementation of Historical Building Information Modelling (HBIM) for the energy retrofit of historical buildings in a medieval complex in Central Italy (Perugia) with renewable geothermal HVAC system. As a result, considerable benefits associated to the implementation of the innovative system in terms of source energy optimization, economic and environmental savings.

2.4.3.20 Energy Performance Certificate (EPC) Assessment

Energy performance certificate (EPC) assessments play a crucial role in the retrofitting of historic buildings, particularly in encouraging user participation and sustainability evaluation in the refurbishment and retrofit process, hence to broadened procedural approach to decision making that will ease the process and improve the outcome of the refurbishment with respect to both energy and heritage aspects (Berg & Donarelli, 2019).

These assessments can help in the early design stage process of environmental sustainability evaluation, leading to the recognition of potential enhancement methods for historic building retrofits (Magrini & Franco, 2016). A multidisciplinary approach to structural and energy diagnosis and performance assessment is essential in evaluating the performance of historical buildings in various forms of traditional constructions (Ascione et al., 2017).

Furthermore, several international retrofit guidance included the aspects of energy performance certificate as an assessment method to evaluate the potential approach and consequences of energy retrofits in European countries has been proposed, which involves categorization of the building stock, identifying targets, and life-cycle cost optimization (Broström et al., 2021; May & Griffiths, 2018; Gigliarelli et al., 2022).

As for the Malaysian context, the Green Building Index (GBI) Non-Residential Existing Building (NREB), is one of the notable green certification tools which sets a sustainability benchmark on historic buildings which includes assessment criteria such energy efficiency, indoor environment quality (IEQ), sustainable conservation management, material and resources, water efficiency and innovations (GBI, 2019).

2.4.3.21 Risk Assessment

Risk assessment plays a crucial role in the retrofit of historic buildings, particularly in the context of energy efficiency improvements. As decision to retrofit a building is challenging due its complexity in many aspects. Hence, a holistic understanding of the whole historic buildings is crucial. McCaig et al. (2018) and May & Griffiths (2015), emphasizes the importance of a risk assessment to appraise practical energy efficiency improvements. This includes evaluating potential risks associated with building fabric, health, heritage and environment and to weight respectively with benefits, costs and technical interventions.

Polo López et al. (2021) emphasize the need for a comprehensive evaluation of potential risks, considering factors such as technical compatibility, heritage significance, and economic viability. Angrisano et al. (2021) further underscores the importance of life cycle assessment in evaluating the environmental impacts of retrofit projects, highlighting the potential of innovative technologies and materials. On the other hand, Wise et al. (2021) adds a behavioural dimension to the discussion, noting the need for a more holistic approach that considers the complex interrelationship between buildings and their users. These studies collectively underscore the need for a thorough risk assessment that considers technical, environmental, and social factors in the retrofit of historic buildings.

2.5 Historic Building Information Modelling (HBIM)

This subchapter discusses related literature reviews regarding Historic Building Information Modelling (HBIM) to form the fundamental knowledge area. The literature review was done to satisfy the scope of the research and the achievement of objective one which is identify the definition, concept, usage of HBIM in the historic retrofit project lifecycle, the design benefits of HBIM and evolution of HBIM implementation models in historic building retrofit practice. The details of the objectives and the scope of the research can be referred to in section 1.3 and 1.6 respectively.

2.5.1 Definition of Building Information Modelling (BIM)

To define HBIM, it is important to understand the fundamental concept behind the terms, and this is rooted from the concept of Building Information Modelling (BIM). According to Aranda-Mena et al. (2009), BIM is an ambiguous term that carries different definitions to different professionals. Confirmed by empirical results from their research, BIM is not only defined in various ways according to particular professions, but some confusion exists at different levels where some professionals define BIM as a low level of software application.

Yet other professionals defined BIM to the level where it is a whole new approach to practice and advancing the Architecture, Engineering and Construction (AEC) profession which requires the implementation of new policies, contracts, relationships amongst the project stakeholders. In addition, current available research, academia and professional bodies also conveyed several views to what constitutes as BIM and HBIM as an extension of BIM. Therefore, to suit the context of this research it is important to define BIM as comprehensively prior to the investigating HBIM as the extension of BIM.

According to the Antonopoulou & Bryan (2017), BIM is defined as "a digital representation of physical and functional characteristic and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its's life cycle". The research, however, needs to set a boundary to differentiate between BIM with other modelling technologies such as 2D/3D vector-based means of creating objects and 3D geometric modelling which is primarily use for the purpose of visualization only.

a) Consist of geometric definition and associated data and rules
b) The geometry is integrated non-redundantly and allows for no inconsistencies. When an object is shown in 3D, the shape cannot be represented internally redundantly, for example as multiple 2D views. All 3-Dimensional and orthographical 2-Dimensional representation of an object must always be consistent. Dimensions cannot be “fudged”.
c) Parametric rules for objects automatically modify associated geometries when inserted into building model or when changes are made to associated objects.
d) Objects can be defined at different levels of aggregation, so the user can define a wall as well as its related components. Object can be defined and managed at any number of hierarchical levels. For example, if the weight of a wall subcomponent changes, the weight of the wall should also be changed.
e) Object rules can identify when a particular change violates object feasibility regarding size, manufacturability etc,
f) Objects possessed the ability to associate, received, broadcast, or export set of attributes, eg, structural materials, thermal properties, acoustic data, energy data, and the like, to other applications and models.

As BIM project has been adopted widely in the AEC industry, BIM has the massive versatility by creating a process integration in the management of different project lifecycle. In the case of new-build projects, BIM offers a robust framework for a multi-disciplinary collaborative process of information production and exchange, resulting in the creation of a reliable, shared, knowledge resource to be used as the basis for decision-making, communication, planning and consultation (Antonopoulou & Bryan, 2017; Eastman, 2011). Kemp (2014), provides a useful summary of the values that is embedded in BIM as a process;

a) BIM converges information production with sound engineering judgement and design.
b) BIM provides wider, faster access to comprehensible and integrated information.

c) BIM fosters instinctive but rigorous collaboration and better decision making.

d) BIM harnesses innovative technologies and harvests intelligence from big data

e) BIM enables reflective, adaptive thinking to incorporate whole life and integrated systems approach within the wider geographic context.

(Antonopoulou & Bryan, 2017; Eastman, 2011)

The benefits of BIM for the architectural, engineering, construction and operation (AECO) industry are well known, but how well it can be applied in the heritage sector is still open to question, partly because of the diversity of projects that involve in historic buildings and sites, such as conservation and refurbishment, adaptive reuse, preventative maintenance, heritage management, interpretation, documentation and research (Antonopoulou & Bryan, 2017).

2.5.2 Historic-Building Information Modelling (HBIM)

BIM has been a wide subject matter within the realm of new construction, with BIM protocols being developed to make the construction process more productive and efficient. Unlike the new-build construction sector, where BIM has been applied widely for several years at an international level, with scores of relevant publications and online content, BIM for heritage assets (historic buildings and sites) is a relatively a new field of academic research and appears as less popular in terms of adoption by the heritage conservation professionals (Antonopoulou & Bryan, 2017). The significant difference between BIM and HBIM are in need to be defined in this research to provide a distinct context in heritage conservation.

Hence, the following subchapter discusses related literature review regarding HBIM to form the fundamental of the research context. The literature review was done to satisfy the scope of the research and the achievement of Objective One, which is to investigate the influence of HBIM towards the sustainable performance of heritage buildings. This is by exploring, appraising and synthesis the definition, concept and use of HBIM in a defined heritage retrofit lifecycle, the design benefits of HBIM and the evolution of HBIM in recent years. The details of the objectives and the scope of the research can be referred to in section 1.3 and 1.4 respectively in Chapter One.

2.5.3 Definition of Historic Building Information Modelling (HBIM)

The term HBIM comes with the adoption and widespread development of 3D laser scanning and photogrammetry technology, in which it has influenced innovative practice in the recording of cultural heritage sites and building. As many benefits can be identified through the adoption of BIM to improve and enhance a certain process within project lifecycle and combined with documentation technology has influenced HBIM to become a well-known platform that aids in the conversation of historic buildings (Khoedir, 2016). According to Arayici et al. (2017), the term Heritage-Building Information Modelling (HBIM) has only begun to be used in latter part of the last decade, since Building Information Modelling (BIM) superseded 3D digital modelling and computer aid design (CAD) as the term was generally used to describe the use of information and communication technology (ICT) for the design, construction, and procurement of the modern built environment.

It is also sometimes defined as HBIM which according to Murphy et al. (2009) is somewhat a narrower term. HBIM is defined as an ecosystem for modelling of historic buildings and their elements using data from laser scanning and photogrammetric technique. According to Arayici et al. (2017), the significant difference of HBIM compared to BIM, is the incorporation of cultural heritage information to add layer in the existing BIM process. This cultural information or elements includes the cultural significance of elements, historic significance analysis, data for authentic replication, particular process, methods for documenting authenticity, recording requirements. Hence, the cultural significance information can be analyzed as a basis of decision-making for conservation interventions.

Unlike BIM for new construction, HBIM relies on a reverse-engineering process in which parametric architectural elements are created and mapped onto laser-scan or photogrammetric data. The workflow typically begins with capturing and processing survey data, followed by identifying historic architectural details, constructing parametric heritage components, and correlating these objects with the scan data to produce accurate measured drawings and documentation (Murphy et al., 2009). The final output is a detailed 3D model that represents the building's geometry, materials, and construction techniques with high fidelity.

2.5.4 Benefits of HBIM in Historic Building Retrofit

As the research is focusing on the scope of the design stage in historic retrofit, it is important that an appraisal of the HBIM benefits within this important stage be identified. Furthermore, the benefits of HBIM need to be discussed to inform the research on the organizational and practical motivation of HBIM implementation in historic retrofit projects, which in turn will affect the level and context of the framework. Previous studies highlight many organizations encountered problems inherited with CAD design complexity and drafting errors. As identified by Kaner (2007) the dependency towards conventional approach in design management such as CAD and paper-based coordination, led to low productivity and low cycle times for design review and assessment.

Thus, trough the understanding of HBIM benefits, the organizational practice could possibly strategize their action plan for HBIM implementation to suit their needs and requirements. As for this research, the advantage of HBIM assists in understanding the justification and the context of HBIM implementation in design assessment of historic retrofit to a practice is essential during the data collection of the case study as this may impose different criteria in the organization's capability to adopt HBIM.

The design stage is an important phase of any nature of projects, this has been shown in the Mcleamy's Curve in Figure 2.3, where the design stages are the highest in terms of the ability to impact cost and functional capabilities to a project (Eastman, 2011). Smith & Tardif (2009) also strengthen the argument by stating that 80% of the cost of a building project is determined within the first 20% of the design process. Hence, by implementing HBIM, according to Elvin (2007), the peak of design effort could be moved back behind the intersection of the cost changes and ability to control cost curves, thus producing better design solutions.

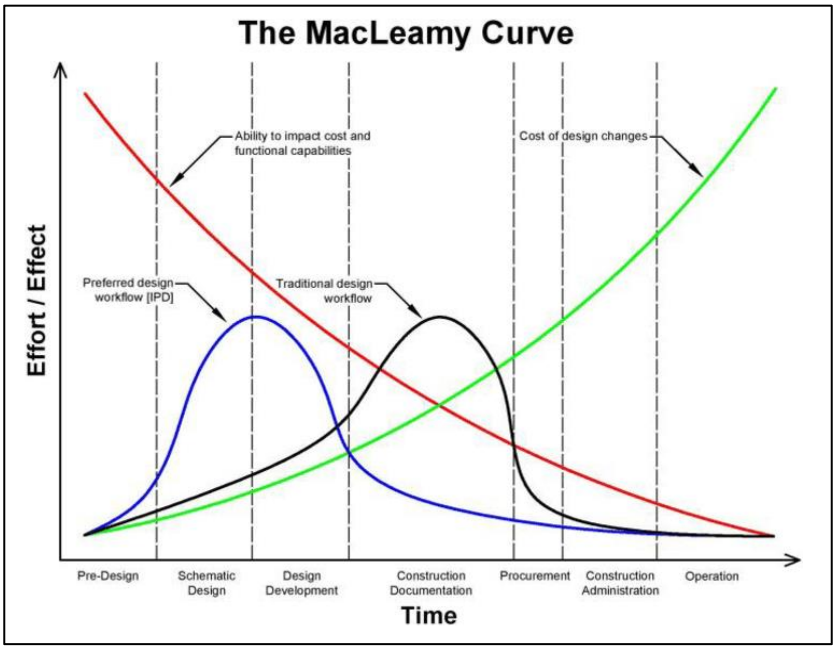

Figure 2.3 McLeamy Curve of Design Effort, the Ability to Control Cost and Cost of Design Change (Eastman, 2011)

Initially, BIM has proved to be a useful, efficient, and practical tool to manage architectural and construction projects in the different phases of design, construction and operation (Carbonari et al. 2015). Its usefulness extends to the existing buildings retrofitting practice and building performance improvement (Habibi, 2017). As conservation, reinforcement and restoration of architectural heritage requires a multi-disciplinary approach (ICOMOS, 2003) and with such approach comes with set of challenges, HBIM allows a "shared digital representation of physical and functional characteristics of any built object which forms a reliable platform basis for decisions" (Jordan-Palomar et al. 2018).

Furthermore, the researcher developed a tool that can comprise different levels of information and a shared medium between different stakeholders. It also helps the integrity of design and visualization, cost estimation, conflict detection, full planning implementation and improved stakeholder collaboration (Volk et al., 2014), something that is needed to improve the productivity of a conservation project which is known to have its challenges and complexity. With the integrated and centralized process of HBIM, project stakeholders would be able to develop reliable as-built information to be used in supporting various conservation efforts of heritage buildings. Although there are limited HBIM case studies presently in the Malaysian context, findings from the literature review have identified several notable HBIM-enabled case studies that have been implemented in heritage conservation.

Many of those studies are from United Kingdom, Italy, Saudi Arabia and Egypt (Baik, 2017; Megahed, 2015; López et al. 2018). In a case study by Rocha et al. (2020), has defined the workflow towards Scan-to-BIM approach involves using 3D laser scanning and photogrammetry technology as a tool to record accurate BIM data acquisition. There are also several studies that have uncovered the parameters of HBIM within the scope of heritage building retrofit, (Selim & Ahmed, 2018, Baik, 2017). Moreover Khodeir (2016), in her case studies has demonstrated how HBIM data could be extended to simulate building energy performance where the outcome leads to the development of HBIM environmental simulation framework for green retrofitting in Egypt.

However, as many evident case studies starting to emerge in the international context, in-depth study of the potential application of HBIM particularly in the process of retrofitting heritage buildings in Malaysia are still relatively scarce (Mansir et al., 2016; Ali 2018). Moreover, the practice of heritage building retrofitting alone was not extensively practiced due to various complexities (Rahmat, 2018; Arayici et al, 2017; Ali et al, 2018). Hence the identified gap can be addressed by investigating in detail the actual parameters through applied case study and which would substantially provide more insights on the applicability of HBIM in historic building retrofitting in Malaysia.

As HBIM tools continue to evolve with improved performance features, workflows, and data exchange formats (Khalil, 2017), there is a need for clearer definitions to ensure these advancements translate into meaningful process improvements. Although HBIM is widely viewed as offering integrated solutions for conservation, its application to environmentally sustainable retrofits of historic buildings remain underexplored and requires further validation. Lim et al. (2021) similarly noted that a detailed taxonomy for interpreting HBIM data to enhance heritage building sustainability is still lacking, especially when compared to the more established use of BIM in new construction.

Thus, the study also suggested several research areas that could further guide researchers in setting the future study in the field of HBIM for sustainable performance and retrofitting of existing heritage buildings in Malaysia, by proposing a clear definition on the actual process and workflow of HBIM towards existing buildings such as to define a specific Level of Development (LOD) for green retrofitting, define data required for various performance and design parameters within the context of existing building retrofit.

2.5.5 The HBIM-Retrofit Functionality

Given the complexity of historic retrofit processes and the extensive informational requirements identified in the preceding discussion on retrofit, digital technologies such as HBIM have increasingly emerged as enabling mechanisms to support retrofit assessment, coordination, and project performance. Consequently, this section examines the functional dimensions and implementation aspects of HBIM-retrofit relevant to heritage building conservation projects.

Ever since the widespread adoption of BIM introduced the early years and the successful adoption and benefits through new construction applications, has influenced its further applications in the existing and historic building context (Arayici et al., 2017). This has further emerged many studies related BIM-retrofit, such as BIM-Building Energy Performance (BIM-BEP), Energy-Efficiency BIM (EE-BIM) and HBIM (Di Bicari, 2022). As BIM systems are complex, the ICT system adoption tend to fail if they are developed too prescriptively narrow to support the full range of practice, because then users must develop and deploy approaches beyond that ICT system scope.

Hence, it is important that a framework for HBIM that is sufficiently embracing the scope of a specific practice, even if not all modules are initially implemented (Counsell & Taylor, 2017). Moreover, the characteristics of HBIM for historic building retrofit has different criteria and unique set of expectations which differs from BIM conventional practice. This requires deeper understanding on the social-environment, technical needs, work process and the careful consideration of information layers, which not just factual, but also includes the site interpretation and the fuzzy qualities of historic places (Littlefield, 2017).

Whilst it is generally agreed that BIM brings together process, technology and policy (Succar, 2009). Dawood & Vukovic (2015), further extend this to add another ‘pillar’ to include people as a critical element in the process. Currently, there are very limited studies on the HBIM associated retrofit model that influences adoption into heritage-built environment. In terms of HBIM guidelines, Hull & Bryan (2019) defines heritage information requirements to guide lifecycle management using HBIM with the primary focus was on developing Asset Information Model (AIM) in line with four pillars discussed. However, the guide indirectly focusses on historic retrofit.

Table 2.3 is a summary of notable HBIM-retrofit research models Across these sources, common trends include an emphasis on information integration and technical workflows addressing the four key elements of HBIM namely organizational, informational, process lifecycle, and technical.

Table 2.3
HBIM-Retrofit Model Elements from Previous Studies

Author/Year	HBIM-Retrofit Functionality Keystones			
	Organizational	Informational	Process Lifecycle	Technical
Khalil et al. (2021)	✓	✓	✓	✓
Khodeir et al. (2016)	✓		✓	✓
Sanhudo (2018)		✓	✓	✓
Khaddaj & Srour (2016)	✓	✓	✓	✓
Khan et al. (2022)		✓	✓	✓
Gigliarelli et al. (2022)	✓	✓	✓	✓
Charlton et al. (2021)	✓	✓	✓	
Salah et al. (2025)		✓		✓
Penjor et al. (2024)	✓	✓		✓
Hull & Bryan (2019)	✓	✓	✓	✓

From the table, Khodeir et al. (2016), identifies in their study the framework of sustainable retrofit to be implemented in retrofitting of historic in Egypt, this can expedite the implementation of HBIM enabled retrofit, however the actual HBIM process was unclear and ambiguous. Khaddaj & Srour (2016), on the other hand, brought further the knowledge and understanding of the criteria of HBIM application in existing buildings, by presenting four key elements of HBIM-retrofit which are the process, organizational, informational and technical needs. This are consistent with many previous studies in BIM, highlighting these factors as a key pillar in BIM implementation (Jamal et al., 2019; Zahrizan et al., 2013; Eastman, 2011; Succar 2009).

Furthermore, Bruno et al. (2018) developed the framework to provide more definition and classification through systematic review which leads towards the proposal of HBIMM performance assessment for diagnosis-aided information modelling and management framework which includes characteristics that defines the involved process, organizational environment, informational framework to build data semantics and provided a process-flow management of knowledge in historic-retrofit.

Charlton et al. (2021) developed a case study highlighting management and coordination challenges in HBIM adoption in facilities management. The study found that defining clear informational standards for historic elements and asset conditions significantly improves cross-disciplinary communication and decision-making, and that new organizational practices with defined roles and protocols are needed to address heritage-specific complexities.

Salah et al. (2025) developed a research framework that balances key specifications on technical like LOD (Level of Detail), LOI (Level of Information), and LOA (Level of Accuracy) combined in HBIM process lifecycle for creating accurate, information-rich models of historic fabric. This study highlights the technical aspects needed in adopting HBIM.

Collectively, these HBIM-retrofit functionalities establish the technological dimensions that support historic building retrofit processes and subsequently form the technology characteristics operationalized within the conceptual framework. Further discussions on the four established HBIM-Retrofit elements are provided in the subsequent sub-sections.

2.5.5.1 Organizational

In the context of Building Information Modelling (BIM), the term "organizational" typically refers to the people involved on the structuring and management of information within the BIM environment (Eastman, 2011). It involves how the data is organized, classified, stored, and accessed within the BIM model by the input stakeholders to ensure effective collaboration, coordination, and decision-making throughout the lifecycle of a building project (Davis et al., 2012).

This may include establishing collaborative standards, protocols, and workflows for data management, as well as defining roles and responsibilities to individuals or teams within an organization to manage and maintain the BIM process and the support ecosystem in developing the human resource aspects such as BIM skills and competencies, training and development is also a key criterion within an organization to adopt BIM (Zahrizan et al., 2013).

Essentially, organizational aspects in BIM focus on the systematic management of information to support efficient project delivery and facility management (Succar, 2009). In an HBIM environment, in which differs from BIM for new building project delivery, requires internal and external organizations (project stakeholders) in a historic building practice to implement strategies and methodologies to adapting with its complexities (Arayici et al., 2017).

This involves looking at the changing of roles, responsibilities, establishing new sets of competencies and protocol instruments in managing BIM projects (Zahrizan et al., 2013). Charlton et al. (2021), in a study to explore the complexities of managing heritage building with BIM highlights the importance of cultural management organizations to understand the processes and the formalities in place for making decisions and implementing changes in historic BIM environment.

The author also emphasized that to address the challenges, a defined role and responsibilities need to be clearly established, this with BIM protocols to define scope of works and understanding the process involved within the multidisciplinary nature of historic building projects (Hull & Bryan, 2019). Moreover, Khaddaj & Srour (2014), in a study to establish a research agenda for BIM retrofitting for the energy efficiency in existing buildings, highlights the importance of training and education of organization human resource to implement technologies for energy-driven refurbishments in existing buildings and understating the collaborative nature required in a BIM process. The definition and of all these aspects will be discussed in the following subchapters.

2.5.5.2 Informational

The informational element pertains to the data-rich nature of the BIM model and its capacity to provide valuable information throughout the lifecycle of a building project. This ‘semantics enrichment’ process adds meaningful domain-specific or application-specific information to a digital building model (Sacks et al., 2017). The building model as a digital representation inputs the set of information about the building from relevant sources (such as a database), and a set of rules that encapsulate expert knowledge of the domain.

This includes data layers related to design, construction, operation, maintenance and other relationships, enabling building project stakeholders to make effective informed decisions to a building project (Eastman, 2011). Moreover, BIM facilitates the integration and management of various types of information within a unified digital model, allowing for improved communication, collaboration, coordination, analysis, and visualization (Davis et al., 2012).

However, the informational aspects in a Historic-BIM environment encompass not only geometrical and spatial data but also non-graphical information such as heritage, historical archives, archaeology and sustainability domain of data for an accurate digital representation of historic building (Arayici et al., 2017). The HBIM documentation process of heritage buildings incorporate a diverse range of information formats and layers that span from quantitative to qualitative and from tangible to intangible elements (Fai et al. 2011; Di Mascio et al. 2013).

Tommasi et al. (2016) discusses the benefit of integrating a range of data sets into a HBIM that supports management and conservation during future adaption work. These rich data sets provide the ability to undertake a more enhanced analysis of the cultural heritage of construction projects (Baik, 2017) and as such the 3D models created can be used for more than just visualization (Dore et al., 2015).

As for the management of HBIM in specific context, the criterion of information is emphasized to allow better understanding of data exchange between heritage building project stakeholders. Khalil et al. (2021) and Brunott et al. (2022), in a study related to the classification of HBIM building data in the digital documentation of heritage buildings, proposed to extend four (4) categories of HBIM information namely the historical, surveying (data capture), building pathology and energy performance. Khan et al. (2022) in a study to develop a novel HBIM framework to facilitate heritage building and restoration planning and facility management (FM), further extends the level of information which includes structural and material data layers.

Furthermore in specific to energy efficiency of historic buildings, Gigliarelli et al. (2022) in a study aim to establish guide for heritage stakeholders to adopt energy and environmental improvement processes (energy retrofit) of a historic public buildings and Kar in a study to investigate energy simulation approaches, data sharing methods, and verification of data availability in BIM, further classifies the environmental data layers as an important criteria in influencing the energy performance data layers in HBIM. Figure 2.4 summarize the informational layers included in the study and this classification data which will be discussed in depth, in the following subchapters.

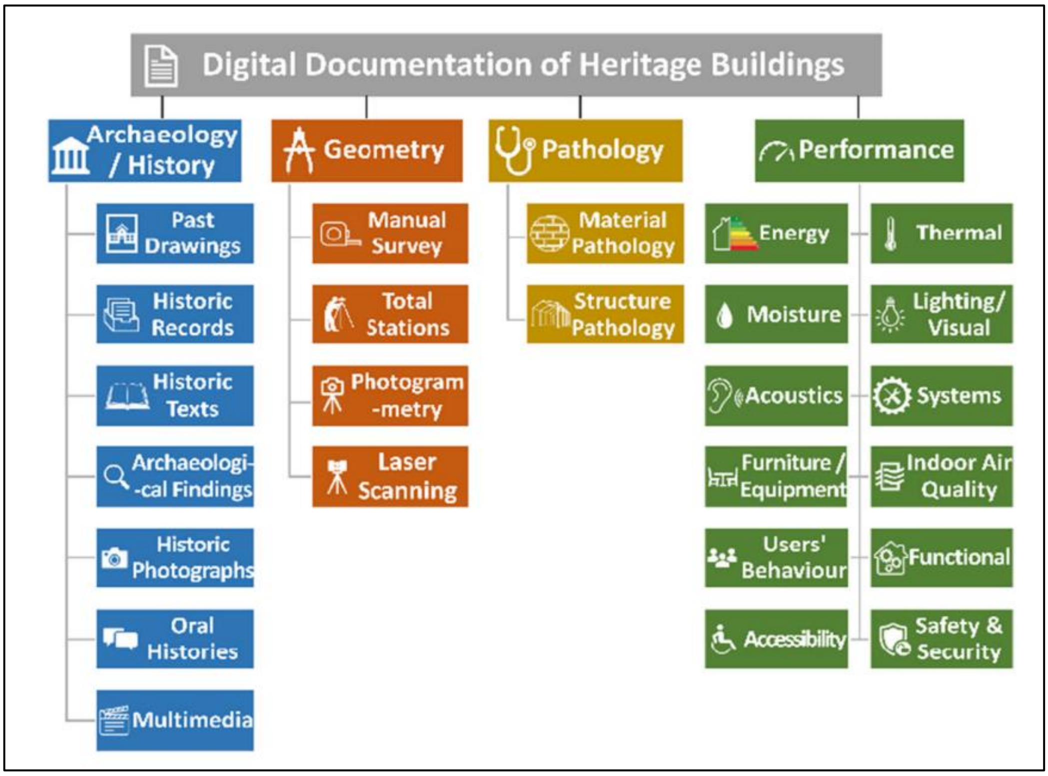

Figure 2.4 Categorization of HBIM Information (Adapted by Author from Khalil et al., 2021; Brunott et al., 2022; Khan et al., 2022; Karlapudi, 2018)

2.5.5.3 Process Lifecycle

The use of BIM in the refurbishment and adaptation of existing heritage buildings has been noted as an approach to capture and digitize historic data which can then be used at all stages of the project lifecycle (Volk et al., 2014). In the context of Historic Building Information Modelling (HBIM), the "lifecycle process" refers to the application of BIM methodologies and technologies throughout the entire lifespan of the historic buildings, including their documentation, conservation, maintenance, and adaptive reuse. This approach involves capturing, managing, and leveraging digital representations of historical structures to support informed decision-making and facilitate the preservation of cultural heritage (Murphy et al., 2009).

The lifecycle process in Historic BIM encompasses several key stages, including data collection or data acquisition, through the use of state-of-the art surveying equipment such as terrestrial laser scanning (TLS), photogrammetry, and archival research; followed by BIM data modelling and analysis to understand the building's existing conditions and performance characteristics; documentation and interpretation of historical features and materials; conservation planning and implementation; and ongoing monitoring and maintenance to ensure the long-term preservation of the building (Khalil et al., 2021). As for the delivery stages of HBIM, Salleh et al. (2022) proposed an implementation with emphasis on the use of scanning and photogrammetry methods which consists of three important stages, namely the Data Capturing, Data Processing and Data Modelling.

However, the study is limited to the first two scopes and requires further definition to capture a holistic HBIM process lifecycle. Khalil et al. (2021) proposed an integrated HBIM process (Figure 2.5), which outlines the application of HBIM across conservation project stages. Similarly, Penjor et al. (2024) classified the HBIM workflow in alignment with conservation stages, namely pre-conservation, construction, and post-conservation. Consequently, the HBIM process lifecycle can be understood as comprising four major steps, as supported by Kamaruzaman et al. (2020) and Khalil et al. (2021). These steps encompass data acquisition of buildings, 3D data authoring and modelling, data simulation and analysis, and design visualization for conservation decision-making.

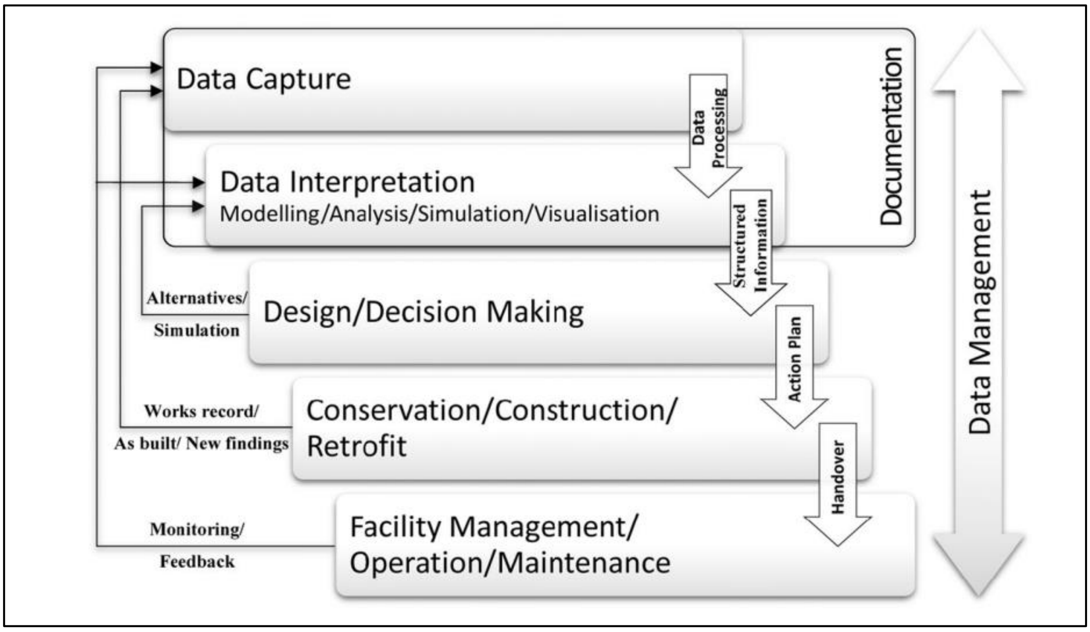

Figure 2.5 Diagram of the Breakdown of the HBIM Documentation Processes within the Historic Building Project Lifecycle (Khalil et al., 2021)

2.5.5.4 Technical

The technical aspects refer to the underlying software and hardware tools, processes, and standards used to create, manage, and exchange BIM data effectively. This encompasses the technical aspects of BIM software applications, interoperability protocols, data formats, and implementation strategies within project workflows (Eastman, 2011). The adoption of BIM relies on various technical components, including 3D modelling software, collaborative platforms, and data exchange formats such as Industry Foundation Classes (IFC) (Davis et al., 2012)

Technical considerations in BIM involve ensuring compatibility between different software tools, establishing data exchange protocols, and implementing industry standards to facilitate seamless communication and interoperability among project stakeholders (Khaddaj & Srour, 2016). Furthermore, technical aspects in BIM encompass the implementation of BIM methodologies and best practices, including training programs, support resources, and quality assurance processes to optimize the use of BIM technology throughout the project lifecycle.

2.5.6 The HBIM Retrofit Elements

The preceding discussion synthesised existing literature to identify the fundamental criteria underpinning HBIM-enabled retrofit practices. This review was undertaken to address the scope of the research, specifically to determine key components, principles, and implementation strategies relevant to integrating HBIM within historic building retrofitting. Di Bicari (2022), provides an extensive synthesis of current grey literature and technical documents, revealing that HBIM-retrofit studies predominantly focus on data exchange (85%), methodologies, and technical issues (70%). The study was particularly useful in outlining best-practice workflows that bridge BIM and Building Performance Simulation (BPS), while also highlighting organisational, informational, and procedural considerations critical to the conservation contexts.

Building on this foundation, seventeen (17) publications were identified as directly contributing guidance on HBIM adoption for heritage building conservation works, with emphasis on historic building retrofit and energy efficiency. These studies were selected based on their methodological relevance and alignment with the aims of the proposed HBIM-retrofit framework. Collectively, they offer classifications, elements, and procedural attributes essential to shaping the theoretical foundation of this research. The extracted HBIM-retrofit elements form an important basis for structuring the conceptual framework, informing the operational definitions, and guiding the development of survey instruments for primary data collection.

Table 2.4 summarises the HBIM-retrofit elements derived from these previous studies, organised according to four major domains namely: Organizational, Informational, Process Lifecycle, and Technical. These domains and their associated elements represent the recurring themes and operational components consistently emphasised across the literature and thus form the core reference points for the HBIM-retrofit framework developed in this research.

Table 2.4
HBIM-Retrofit Elements from Previous Studies

	HBIM-Retrofit Elements	Gigliarelli et al. (2022)	Antonopoulou & Bryan (2017)	Messner et al. (2019)	Reeves (2015)	Ouellette et al. (2022)	Hull & Bryan (2019)	Nieto-Julián, (2021)	Baik (2020)	Banfi (2021)	Quattrini,et al. (2018)	Capone & Lanzara (2019)	Bruno (2018)	Carvalho et al. (2019)	Moyano et al. (2022)	Khaddaj (2016)	Karlapudi (2018)	Stanga et al. (2023)
	Organizational																	
1	Roles and responsibility	✓	✓	✓		✓	✓	✓	✓			✓	✓			✓		
2	Training and education			✓			✓									✓		
3	BIM Protocol	✓	✓	✓		✓	✓		✓	✓			✓			✓		✓
	Informational																	
4	Geometrical	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
5	Historical evidential	✓	✓				✓	✓	✓	✓	✓	✓	✓		✓			✓
6	Pathology						✓											✓
7	Surveying	✓	✓			✓	✓	✓	✓	✓		✓	✓		✓			✓
8	Energy performance	✓	✓		✓	✓	✓						✓	✓			✓	
9	Material	✓			✓	✓	✓							✓	✓		✓	
10	Structural	✓			✓	✓	✓			✓					✓			
	Process Lifecycle																	
11	Data acquisition	✓	✓	✓		✓		✓	✓	✓		✓	✓		✓	✓		✓
12	3D modelling	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
13	Simulation and analysis	✓		✓	✓	✓				✓			✓	✓	✓			
14	Design visualization			✓					✓	✓	✓					✓		✓
	Technical																	
17	Software	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
18	Hardware infrastructure	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓
19	Standards	✓	✓	✓	✓	✓	✓	✓					✓		✓	✓	✓	✓
20	Data exchange						✓	✓		✓	✓		✓		✓	✓	✓	

2.5.6.1 Roles and Responsibilities

HBIM projects involve the use of BIM technology to document, analyze, and manage historic buildings throughout the retrofit process. Hence, understanding the roles and responsibilities in such an environment is crucial for ensuring smooth execution and successful outcomes. As most of historic retrofit projects involving a multidisciplinary collaboration, Gigliarelli et al. (2022) highlights it is important to provide a clear role definition in HBIM-retrofit project as it enhances accountability within project teams, identify potential risks and establish clear protocols for mitigating them (Antonopoulou & Bryan, 2017), this would lead to improved performance and outcomes (Cheng et al., 2015). Succar (2009), emphasized well-defined roles facilitate efficient collaboration among multidisciplinary teams, allowing individuals to understand their contributions to the overall project.

However, the industry is still facing a challenge of establishing clear roles and responsibilities within BIM for existing buildings (Charlton et al., 2021). According to Eastman (2011), design stage involves design activities where major part of the information about a project is produced by various types of project stakeholders. However, most of the information about a project originates with the design consultants, in which according to Brunott et al. (2022) are highly prone to the interest to the architects, engineers and owners as among the key design stakeholders in a conservation project. In general, the stakeholders of heritage assets can be narrowed down to parties who affect or are affected by the decision-making process of heritage asset management.

The level of responsibilities for each stakeholder is not equal, and several parties and departments might have slight to no influence on the management of a BIM historic asset, while some are key to these processes. According to Messner et al. (2019), highlights the need for historic building project stakeholders to have a common understanding, as this is crucial to create a clear strategic plan, which outlines the project mission, vision and goals, protocols, decision-making process involved, and technical needs to ensure the success of BIM implementation project (Messner et al., 2019; Hull & Bryan, 2019).

Moreover, Khalil et al. (2021) have compiled and categorized a list of stakeholders as shown in Plate 2.2, for heritage assets, not all the stakeholders listed are actively involved in the decision-making process of heritage management, which making it vital to identify the new roles, such as BIM Managers, BIM Modellers and BIM Coordinators which would have an influence over the asset and oversee managing the asset information for a project (Gigliarelli et al., 2022). Moreover, according to Nieta-Julian (2021), through a study on collaborative workflow on HBIM application on historic religious building, such adoption demands change of professional relationships and traditional work methodologies, hence more research should be included, considered from several disciplinary perspectives.

Stakeholder	Historic data	Geometry data	Pathology data	Performance data
Owner	●	●	●	●
Listing authority	●		●	
Archaeologist	●	●	●	
Architectural historian	●	○	○	
Museum	●	○		
Public dissemination	●	○		
Architect	●	●	●	●
Structural engineer		●	●	○
Contractor		○	○	○
Conservator	○	○	○	
Energy auditor		○		●
MEP engineer		○		●
Lightning / Acoustic engineer		○		○
Facility / Asset manager		○	○	○
End-user	○	○	○	○

Note:
- ● High interest
- ○ Moderate interest

Plate 2.2 Heritage Conservation Stakeholders and Their Relation to the Various Categories of HBIM Data (Khalil et al. 2021)

2.5.6.2 Training and Education

Training and education play a crucial role in the successful implementation of Historic Building Information Modelling (HBIM) in organizations. Ali et al. (2018a) highlighted the key organizational challenges of HBIM are the insufficient resources and experts to execute the process, with the lack of training and education as one of the factors that hinders application of HBIM-retrofit in Malaysia. Khalil (2017), in a study on HBIM and environmental simulation highlights one of the main differences of BIM to HBIM is due to the complexity of historic buildings itself, which are geometrically complex than other existing buildings and even for new buildings (Khalil, 2017).

Hence, the allocation of training and education on how to implement these technologies, the technical complexities and interventions specifically for energy-driven refurbishments in existing and historic buildings are desperately needed to collaboratively organize the project and achieve optimal results (Khaddaj & Srour, 2016). Facility managers, historic building owners, consultants, and contractors have shown limited adoption of BIM (RICS, 2013), and are not fully integrated into BIM development and implementation processes yet. Consequently, there is a pressing need to improve their integration, as well as to provide enhanced training and education (Volk et al., 2014). This is essential for effectively managing, utilizing, and, if necessary, deconstructing the growing number of complex BIM-constructed and BIM-retrofitted buildings.

2.5.6.3 BIM Protocol

A BIM protocol is a document or set of guidelines that outlines the standards, procedures, and responsibilities for organizations in implementing BIM within a project lifecycle. It serves as a framework for collaboration and information exchange among project participants (Eastman, 2011). As historic buildings have a unique complexity on their own, Hull & Bryan (2019) and Messner et al. (2019) highlight the importance of setting up a BIM execution plan when initiating a HBIM retrofit plan. To data there are several guidance demanded the establishment of a HBIM protocol, which includes various aspects of BIM implementation, including data exchange formats, level of detail (LOD) requirements, ownership, financial and legal consideration (Antonopoulou & Bryan, 2017). As for the context of historic building retrofit, Khaddaj & Srour (2016), highlights the importance of developing legal instruments in the form of contractual agreement order to standardize the model ownership and data responsibility, liabilities, and fees.

This would facilitate BIM implementation in historic buildings, enhance data security and user’s confidence to implement BIM in retrofit. As for the protocol technicalities in historic projects retrofit projects, Gigliarelli et al. (2022), in an EU research funded project, provided a guidance on the forming of protocol specifically for historic building retrofit. The guidance suggests developing a BIM execution plan (BEP) in line with the ISO19650, in which details the strategies on BIM models federation, model uses, naming convention, Level of Development (LOD) and modelling strategy, providing a flexible overall methodology for EE-HBIM.

2.5.6.4 Geometrical

According to Khalil et al. (2021), geometrical information in HBIM is aiming to record, survey and visualize the exact form, shape, and characteristics of the building's fabric on its current state and conditions. Geometrical dataset is an important element for many stakeholders but is the major element in the scope of architects, structural engineers and in general for the construction sector. Geometrical data can be captured and conducted by means of various techniques with a wide range of accuracy, cost efficiency and time constraints.

A common method ranges from manual surveying, photogrammetry to laser scanning approach. These scanned geometries were then authorized in a HBIM modelling environment to further adds information richness to the historic documentation (Dore & Murphy, 2012). Several research on the aspect of geometrical data have been identified. Capone & Lanzara (2019) studies the relationship between the use of survey, HBIM and 3D parametric modelling, using Scan-to-BIM approach that allows to generate 3D geometry of domes using reference from point cloud and analysis of shape grammar, in which new procedural geometric modelling was developed using parametric modelling software such as Dynamo and Grasshopper.

Brumana et al. (2019), proposed a classification on the Level of Geometry (LOG), stating the different categories of parametric information carrying the specific levels of accuracy, complexity and information to define the level of geometry in modelling of historic buildings using HBIM. Furthermore, Yang et al. (2019) explore on how to add richness to the geometric components of a HBIM model, using the datasets from Scan-to-BIM and Mesh-to BIM (parametric model) techniques to represent an ontological and heterogeneous knowledge model that consists of historical, material and structural elements of a historic building documentation.

2.5.6.5 Historical Evidential

Historical evidential data form a core component of the HBIM informational domain, providing the contextual and chronological knowledge needed to understand a building's historical development, cultural significance, and material evolution. Such evidence including archival drawings, photographs, written documentation, maps, surveys, and prior conservation records supports accurate "as-found" modelling and helps distinguish original fabric from later alterations (Brumana et al., 2020).

Within HBIM-retrofit workflows, these datasets enhance diagnostic accuracy and ensure that proposed interventions remain compatible with heritage values (Biagini et al., 2016). Historical evidence also improves interdisciplinary coordination and public interpretation by enabling transparent documentation and virtual reconstructions (Argiolas et al., 2022). Overall, integrating historical evidential information within HBIM strengthens both technical decision-making and the cultural appropriateness of retrofit strategies.

2.5.6.6 Pathology

Pathology involves a process of conducting detailed surveys and assessments to evaluate the current condition of historic buildings. HBIM recognizes the approach to create intelligent three-dimensional models and databases of historic buildings that integrate information and data, attributing to pathologies (Dore et al., 2015).

Furthermore, Jordan-Palomar et al. (2018) proposed an implementation guidance namely BIM-Legacy, emphasis the role of pathological analysis as one of the early interventions in HBIM building registration. This includes a protocol to modelling the current degradation condition of a historic building such as identifying structural deficiencies, material decay, moisture infiltration, and other forms of deterioration that may affect the building's integrity and stability.

Several studies focus on the integration of HBIM methods for condition assessment of historic buildings. Lo Turco et al. (2017) and Zarogianni (2019), proposed a pathology methodology using combination of in-situ measurement, photogrammetry and HBIM platform, to document and classify existing conditions on a historic religious building in Italy and Greece.

The information embedded HBIM includes the historical and pathological elements in structural and non-structural conditions such as the structural decays, materials integrity, cracks and collapsed areas. Which leads to a semantic database and decision-making platforms for multidisciplinary collaborators to conduct pathology design and planning of repair interventions for historic buildings.

2.5.6.7 Surveying Data

The surveying data in HBIM encompasses a range of information gathered through various surveying methods and techniques to document and analyze historic buildings. detailed geometry, materials, and architectural features of historic buildings. This includes capturing intricate ornamentation, decorative elements, and historic fabric with sufficient detail to support conservation.

The characteristics of surveying data in HBIM are crucial for creating accurate digital representations of these structures (Dore et al., 2015). Surveying data in HBIM often relies on non-destructive techniques to minimize impact on the historic fabric of buildings (Arayici et al., 2017). According to Volk et al. (2014), the collection of surveying data for BIM documentation usually consists of a single or multiple combination of non-contact techniques and contact techniques, with the use of image-based techniques (Photogrammetry), range-based techniques (LiDAR, TLS) and manual techniques.

Furthermore, much research focused on capturing geometrical and semantic representations of historic buildings in many aspects. Costantino et al. (2023) explores the methods of capturing and modelling of geometrical elements of a building, using range-based surveying techniques. Carvajal (2019), developed a workflow combining Unmanned Aerial Vehicle (UAV) photogrammetry techniques and range-based survey techniques. The 3D point cloud obtained through scanning was used to develop geometric and non-geometric representation of historic buildings.

Moyano et al. (2022), developed methods and techniques for Scan-to-BIM data processing (Autodesk Recap) using combination of traditional and new data acquisition technologies (TLS, total station, and photogrammetry). Moreover, Quattrini et al. (2017), developed a novel workflow for BIM surveying to modelling, through a process of data enrichment and semantically structured geometric and non-geometric information to produce a knowledge repository for effective management of historic assets. The domain of data enrichment includes building components and elements which are obtained from data acquisition phase.

2.5.6.8 Energy Performance

This factor is aiming to understand, interpret, analyze and evaluate the current status of the building's operability and performance on its various aspects, such as energy performance, thermal performance, users' comfort, building systems' performance, safety and security performance. Performance data is in the core interests of the design phase which involves architects, MEP engineers, lighting and acoustic engineers, energy auditors and other building scientists (Carvalho et al., 2019). Documentation and integration of the building's performance is a major contribution of digital documentation of heritage buildings, which can contribute towards the decision-making process at the design, retrofitting and facility management (Khalil et al., 2021). Monitoring and surveying the status of the building and its performance capacity on various levels is the first step to help in the analysis and determination of any deficiency it could be facing to develop the objectives of any required rehabilitation or retrofitting works.

Khan et al. (2022) suggested the following sub-categories that can capture all possible data sources within the performance data category, which is energy performance, thermal performance, moisture survey, lighting and visual performance, acoustic performance, indoor air quality, systems, furniture and equipment, users' behaviour, functionality, accessibility and safety and security. According to Brunott et al. (2022), as conservation approach can varies depending upon the requirements of the project and asset, hence a collaboration with relevant stakeholders is necessary to develop a network of information related to performance documentation.

Karlapudi (2018) focus on information to produce building energy simulation (BES) which requires the input of four categories of information namely the environmental, geometrical (building data), material data and energy performance data. Furthermore, Seghier et al. (2022), developed a BIM prototype with objectives to minimize OTTV and the retrofit cost to an existing building case study by evaluating the best performing building materials and components. For this, the accuracy of HBIM material composition in building components is crucial for an accurate representation for performance optimization. As an outcome, the developed system provides a valuable design decision support system for cost-oriented retrofitting while optimizing the building envelope thermal performance.

2.5.6.9 Structural Data

BIM structural data is pivotal in conducting assessment and analysis. According to Volk et al. (2014), the building information modelling for existing structures provides crucial insights into the load-bearing capacity, material degradation, and potential structural weaknesses. Bouzas et al. (2022), conducts a case study with the objective to monitor structural health of historic bridge structure. A complex BIM modelling which combines geometrical shape, material composition and structural configuration, in which represents the actual overall physical and mechanical behaviour of the construction.

The collective information is crucial for the analysis of structural integrity and retrofitting. Furthermore, there are several studies of HBIM structural life-cycle data application in the structural condition monitoring such decays and damages in existing timber structures, which requires a complex BIM modelling that includes the structural data for decisions in maintenance and intervention actions (Mol et al., 2020). Furthermore, for historic masonry structure, Valero et al. (2019), combined structural data with geometrical pattern and surveying data to identify deterioration patterns on ashlar masonry load-bearing walls.

2.5.6.10 Data Acquisition

Data acquisition is a critical phase within the HBIM process lifecycle, as it determines the accuracy, completeness, and reliability of the digital representation used for subsequent analysis and retrofit decision-making. Beyond the standardised "Scan-to-BIM" workflow, recent research emphasises the importance of integrating multiple data capture techniques such as terrestrial laser scanning (TLS), photogrammetry, UAV imaging, structured-light scanning, and close-range surveying to document complex geometries and material conditions commonly found in historic buildings (Dore &

Murphy, 2017; Brumana et al., 2020). The combination of these techniques enhances coverage, reduces blind spots, and improves the fidelity of point cloud datasets.

Following acquisition, preprocessing tasks such as noise reduction, point cloud alignment, segmentation, and classification are essential to ensure that the data can be effectively translated into HBIM environments (López et al., 2018). The subsequent modelling stage requires not only geometric reconstruction but also semantic enrichment to embed conservation-relevant attributes. As HBIM matures, integrated acquisition workflows are increasingly recognised as fundamental to producing robust, evidence-based models that support retrofit planning, condition assessment, and heritage documentation.

2.5.6.11 3D Modelling

The 3D modelling phase in HBIM involves the integration of geometrical, alphanumerical, and documentary data within BIM models for the accurate and comprehensive digital representation for the documentation and management of historical buildings throughout the building's lifecycle (Aglietti et al., 2023). The aim of this stage is to further create accurate 3D models of historical buildings by employing modelling process and various data capture techniques such as terrestrial laser scanning and photogrammetry (Liu et al., 2023; Karasaka & Ulutas, 2023). The use of HBIM information, associated software and hardware facilitates the creation of detailed 3D models that can be used for future planning, design, operation, and maintenance processes of historic buildings. However, the modelling of complex and irregular components of historical buildings poses challenges (Dore & Murphy, 2017), requiring the adaptation and reinvention of existing BIM workflows and tools, hence it is critical to identify studies related to modelling approaches in HBIM.

Several authors have proposed novel framework regarding HBIM procedural modelling approaches, which include the creation of complex geometrical and parametric objects for historic building fabrics (Capone & Lanzara, 2019), the geometric modelling and semantic representation approach to structure the heritage documentation in a historic building components, which also covers the workflow to visualize the BIM model through Virtual Reality (VR) (Quattrini et al., 2018), the geometric modelling process which involves applying Non-Uniform Rational B-

Splines (NURBS) techniques for complex shapes and form of historic building fabrics and the implementation of models for sensor data management (Aglietti et al., 2023), and the geometric modelling workflow that integrates with attributes of building performance simulation and analysis (Karlapudi, 2018).

2.5.6.12 Data Analysis and Simulation

The data simulation and analysis phase are to leverage digital models of historic buildings to assess many aspects of building's performance, predict outcomes, and inform decision-making processes in a multidisciplinary environment. Much of the historic retrofit-related studies align the role of building energy simulation (BES) and building performance simulation (BPS) tools as the main attributes towards HBIM analysis (Carvalho et al., 2019). This is due to the capability of HBIM software to perform accurate, detailed and real-time analysis of historic buildings (Gigliarelli et al., 2017; Karlapudi, 2018; Khodeir et al., 2016; Ouellette et al., 2022) and has the capability to benchmark with green and energy assessment standards such as BREEAM and Green Building Index (GBI) (Solla et al., 2022; Ilhan & Yaman, 2016) The techniques to measure performance can be conducted using energy analysis, carbon emissions, acoustic analysis, waste management, lighting analysis, operational energy use, and water use embed in BIM software (Ansah et al., 2019). Several studies related to HBIM-retrofit simulation were identified.

2.5.6.13 Design Visualization

Data visualization in Historic Building Information Modelling (HBIM) retrofit refers to the graphical representation of information related to the existing conditions, proposed interventions, and performance metrics of historic buildings undergoing retrofitting. It involves the use of visual tools and techniques to communicate complex data effectively to various stakeholders involved in the retrofit process (Banfi, 2020). Several numbers of studies have explored the use of HBIM in the data visualization phase particularly the use of augmented and virtual reality (AR/VR) technology in the context of historic building preservation. Barazzetti et al. (2015) and Banfi (2021) both discuss the potential of HBIM point cloud to virtual reality applications, particularly in supporting the condition assessment, analysis and stakeholder's engagement in the context of cultural tourism and archaeological sites.

Stanga et al. (2023), explored the scan-to-HBIM-to-XR process and unmanned aerial vehicle (UAV) photogrammetry to improve the depiction of archaeological ruins, enhancing the representation of building archaeology, thus the approach enabled educational and tourism opportunities through immersive application on ancient structures. Sutcliffe et al. (2019) and Mastrolembo Ventura et al. (2020) provide a more general perspective, with first study focusing on the design process for virtual reality applications and the second study to propose a design review session protocol for the implementation of immersive virtual reality in usability-focused analysis. These studies collectively highlight the potential of augmented and virtual reality in enhancing the user experience and usability of HBIM.

2.5.6.14 Software

The determination of software plays a central role in a BIM processes, enabling the creation, management, visualization, and analysis of digital representations of building projects. Several research highlights the role and use of BIM software in managing the historic building project lifecycle. Reeves et al. (2015), in his research evaluates twelve (12) building performance simulation (BPS) tools, by illustrating the application of three of them (IES VE, Ecotect, Green Building Studio) and developing guidelines for the evaluation, selection and application of BIM-BPS. Rahim et al. (2023), applies 3D laser-scanning software with authoring tools such as Autodesk Revit to generate accurate as-is models that support diagnosis, clash detection and retrofit option testing.

Logothetis et al. (2015), reviews HBIM for cultural heritage stress that the choice of software and the ability to manage point clouds, parametric libraries and semantic data are crucial for reliable documentation and intervention planning. In Malaysia, case studies using BIM/HBIM software to model traditional Malay houses and historic buildings demonstrate improvements in documentation quality, coordination and information accessibility, but also reveal challenges in technical skills, licensing cost and software interoperability (Mustafa et al. 2020; Ismail et al. 2021). Embedding these software capabilities into an HBIM-retrofit framework can therefore enhance project performance by enabling precise diagnostics, accurate simulation of retrofit options, and more informed conservation decisions across all project stages.

2.5.6.15 Hardware Infrastructure

Investment in survey hardware and computational equipment is fundamental to the technical performance of HBIM-retrofit. Advanced capture tools such as terrestrial laser scanning (TLS), UAV photogrammetry, and SLAM-based LiDAR significantly improve data accuracy, enabling precise representation of complex geometries, deformations, and ornamental details in heritage buildings (Volk et al., 2014; Bruno & Roncella, 2019). High-quality data input reduces modelling errors, strengthens retrofit assessments, and minimizes conservation risks (Murphy et al., 2009). Equally important is computational infrastructure. Processing dense point clouds and image sets requires robust workstations with strong CPU/GPU capacity, memory, and storage. Without sufficient hardware, projects face limitations in Level of Detail (LOD) and simulation capabilities, leading to down-sampling and data loss (Volk et al., 2014; Brumana et al., 2019).

Conversely, powerful computing supports efficient registration, parametric modelling, and performance simulations, which are vital for energy analysis, clash detection, and retrofit decision-making (Fai et al., 2011). Investment in hardware also enhances interoperability and collaborative practices. Integrated platforms, including VR/AR environments, allow stakeholders to visualize and evaluate retrofit strategies in real time, improving design coordination and reducing errors (Dore & Murphy, 2017; Brumana et al., 2019). However, studies stress the balance between performance and cost. Premium systems deliver superior outcomes but may exceed the budgets of smaller heritage projects. Low-cost alternatives often compromise accuracy and increase processing demands (Bruno & Roncella, 2019). Therefore, hardware choices must align with heritage significance, project goals, and acceptable tolerance levels

2.5.6.16 Standards

The implementation of HBIM in retrofit projects is fundamentally underpinned by the adoption of various standards that regulate information accuracy, modelling practices, and conservation compliance. Unlike conventional BIM, HBIM-retrofit requires specialized standards to accommodate the irregular geometries, complex fabric, and cultural values of historic buildings (Pocobelli et al., 2018). Without shared protocols, inconsistencies in data modelling and interpretation risk undermining both conservation authenticity and technical interoperability.

A key technical dimension lies in the use of Level of Development (LOD) and Level of Information Need (LOIN). Lie et al. (2023) highlight that retrofit projects demand flexible LOD specifications to balance conservation priorities with analytical requirements, ranging from schematic-level documentation to high-detail component modelling for energy simulation. The introduction of EN 17412 standards on LOIN has further refined this concept by linking information content directly to project purposes, which has been argued by Volk et al. (2014) as particularly beneficial in heritage contexts where over-modelling may distort authenticity.

Equally significant are library and object standards. HBIM libraries are expected not only to represent geometric accuracy but also to embed semantic attributes such as typology, material properties, and historical provenance. Bruno & Roncella (2019) emphasize that the absence of standardized heritage object libraries often leads to fragmented practices, limiting reuse across projects. Furthermore, the adoption of established heritage documentation standards, such as the London Charter (2009) and CIDOC-CRM, has been promoted to ensure consistency and semantic richness in HBIM libraries (Fai & Rafeiro, 2014).

2.5.6.17 Data Exchange

Data exchange and interoperability are critical components of HBIM applications in heritage conservation and retrofit projects. HBIM integrates diverse data sources such as archival documents, laser scanning, photogrammetry and condition assessments into a unified environment that supports coordinated analysis and decision-making. Parente et al. (2020) highlight that HBIM's values lies not only in representing historic geometry but in structuring and exchanging conservation information across the project lifecycle. However, many studies note persistent challenges in interoperability and data fragmentation, which weaken the reliability of HBIM workflows (Baharuddin et al., 2024). Research increasingly points to openBIM standards such as Industry Foundation Classes (IFC) as essential for enabling seamless data transfer between modelling, simulation and documentation tools. Logothetis et al. (2015) demonstrate that IFC-based workflows improve the movement of survey data into HBIM environments, reducing information loss. Similarly, Brumana et al. (2019) show that integrating HBIM with energy simulation tools through interoperable exchanges enhances the accuracy of retrofit performance assessments. In Malaysia, studies by Yusoff & Brahim (2021) identify weak documentation practices and limited digital interoperability as major obstacles in heritage conservation projects. Therefore, embedding robust data-exchange mechanisms within an HBIM-retrofit framework can improve coordination, reduce rework and support more informed planning and evaluation.

2.6 Performance

This section introduces performance as a key consideration in historic building conservation, particularly in the context of HBIM-retrofit adoption. As conservation practices become more digitalized, it is important to understand how a HBIM-retrofit framework aligns with both fundamental performance measures such as; time, cost, and quality and contemporary dimensions such as environmental outcomes, communication, and stakeholder relationships. These expanding criteria reflect the growing complexity of conservation projects and rising sustainability expectations for heritage buildings. The following subsections outline the performance indicators discussed in the literature, establishing their relevance and the factors that influence them. This overview provides the basis for understanding how HBIM-retrofit may enhance project performance within Malaysia's heritage conservation sector.

2.6.1 Performance Criteria for Historic Building Conservation Projects in HBIM-Retrofit Adoption

The use of HBIM-retrofit brings many benefits and impacts to improve the performance of historic conservation projects. This can be related through its high level of automation, ability to associate broad to specific range of information in a digital environment, and this ability would impact in many aspects of project performance.

Furthermore, much of the past research have studied the influence and impact of BIM on performance of new building construction project (Van Tam et al., 2023; Cao & Wang, 2017). Many aspects could be such as the cost factors, (Celoza et al., 2021) evaluated the impact of BIM-related contract practices on project performance which concludes that the BIM association to the process relates to positive project cost outcomes. Hence, this drives the research to further determine the HBIM-retrofit would further influence the performance of heritage building conservation projects in Malaysia.

For many years, many studies categorized the three success criteria corresponding to the Iron Triangle (namely cost, time and quality) and were considered as ideal elements to achieve success in a project. However, through time there is evidence of other research studies that include other aspects of key performance criteria such as safety, environment, and customer satisfaction, relationship and communication (Atkinson, 1999; Suk et al., 2012). In a review paper by McGinley et al. (2022), summarized the key criteria to measure the performance specifically for retrofits of existing domestic buildings, which classified three important criteria namely the economic (cost-based), social and environmental. These performance attributes have started to become a focus to be measured due to the increasing attention and awareness on the sustainability concerns and agendas.

2.6.1.1 Time

It is note even with the vast integrated knowledge areas in project management, delay and cost overrun are the most common issues in construction projects (Samarghandi et al., 2016). Tahir et al. (2017), conducted a review study highlighting the design project coordination is among the leading factors to the cause of delays in design and construction projects, which often emphasized to poor management of design changes, slow decision making, improper planning and design inefficiencies as the main causes of delays in projects (Samarghandi et al., 2016; Shehu et al., 2014). The use of HBIM in historic retrofitting has been shown to have a significant performance impact on the timeliness and efficiency of the process. Li et al. (2014) and Selim & Ahmed (2018) both highlight the importance of BIM in promoting information integration, collaboration, and error reduction in the reconstruction and restoration of historical buildings. In a study by Biagini et al. (2016), significant time savings were gained in several process of HBIM, especially to the measurement of as-built state of historic buildings for restoration. Through the use of terrestrial 3D laser scanning during data acquisition phase is significant due to the speed and accuracy it provides to support the complex modelling BIM geometries, hence increasing design lead time of the project. (Ghosh, 2015) further emphasizes the need for process reengineering to accommodate the new value stream created by BIM, which can potentially improve labour productivity. Gigliarelli et al. (2017) presents an integrated approach using BIM, numerical simulations, and decision support systems to address energy efficiency in historic buildings, which furthers demonstrating the potential time-saving benefits of BIM in this context.

2.6.1.2 Cost

Cost feasibility is being considered as the most important factors that influence the retrofit decisions (Liu et al., 2022b). Typically, the minimization of investment cost is an objective function in the design of retrofit solutions and in pre-retrofit and post-retrofit evaluation studies. The cost estimation exercise involved in a historic retrofit project can varied widely, making it difficult to adequately estimate the total amount of cost that might be involved. This variation is dependent on various factors such as location and type of structure, characteristics of individual buildings, rehabilitation scheme, level of performance desired and other works in the building code triggered by this decision (Egbelakin & Suzanne, 2008).

This is further depreciated with the lack of data and information about existent buildings and the high dependency of conventional methods which are often time-consuming and barely efficient as they are related to exchange of two-dimensional (2D) and paper-based support information in project coordination (Biagini et al., 2016; Sharples et al., 2013; Rodrigues et al., 2019). The use of BIM in design and construction projects has been shown to significantly reduce costs and time, with potential savings ranging from 5 to 52.36% (Sholeh et al., 2020; Lu, 2014; Chelson, 2010; Shin et al., 2018). HBIM provides cost savings performance through the reduction of reworks and idle time due on site, automation aspects of work process including quantity take-off and preparation of estimates (Li, 2014). Thus influence a decreasing turnaround time and assist in controlling errors and inaccuracies, which has a positive effect on the cost performance (Ismail et al., 2015). Furthermore, Egbelakin & Wilkinson (2008) highlights effective teamwork during the design phase of rehabilitation project is crucial in providing impact to the cost reduction as all stakeholders discuss and evaluate cost cutting measures as a team. Thus, the use of HBIM, which highly promotes integrated collaboration and coordination in the early stages of the design process would significantly impact in that aspect (Sacks et al., 2017). A study by Mehndi & Chakraborty (2020) and Chaves et al. (2015), found that the use of HBIM in retrofit can potentially achieve a combined cost and energy efficiency through reduced preliminary building operational cost, including energy consumption reduction, effective capital investment, technical change in emission behaviour, and increased comfort.

2.6.1.3 Quality

Quality in performance refers to the extent to which a design meets functional, cultural, environmental, and user-oriented goals while aligning with stakeholder expectations. In heritage retrofits, this involves safeguarding authenticity and cultural value through minimal and reversible interventions (ICOMOS, 2013; Historic Scotland, 2021), while ensuring structural reliability, energy efficiency, and occupant comfort (Meoni et al., 2022). Through HBIM, design quality is enhanced by accurate documentation, data integration, and collaborative workflows that balance conservation principles with modern performance requirements (Bruno & Roncella, 2019; Piselli et al., 2020b). HBIM-retrofit enhances quality through non-invasive 3D documentation (Bruno & Roncella, 2019), reversible interventions (Piselli et al., 2020b), real-time monitoring (Meoni et al., 2022), and automated conservation standard verification (Žurić et al., 2023).

A case study by Piselli et al. (2020b) showed 70% energy savings, 3,032 kg CO_2 reduction, and Gold Certification in the GBC Historic Building™ protocol, all while preserving architectural integrity. HBIM-retrofit also improves quality through better interdisciplinary interoperability, centralized data management, and integration with conservation practices (Hull & Bryan, 2019). Despite challenges like data management and technical expertise needs, it offers a promising balance between modern performance and heritage preservation (Nieto-Julián et al., 2021).

2.6.1.4 Design

In the context of performance, design refers to the structured process of developing solutions that integrate functionality, efficiency, and cultural significance within project delivery. It extends beyond form-making to embody a systematic approach to decision-making under constraints, aligning with client requirements, regulatory standards, and sustainability goals (Cross, 2021). Within heritage retrofits, design becomes a project management challenge where interventions must ensure authenticity while delivering measurable performance outcomes such as energy savings, comfort, and compliance (ICOMOS, 2013). Thus, design operates as both a process and product, linking creativity with disciplined management to balance heritage values and modern demands.

HBIM-retrofit holds the potential to transform heritage conservation by bridging the gap between preservation principles and modern performance demands. Beyond improving documentation accuracy and energy efficiency, it can support predictive maintenance, real-time monitoring, and certification compliance, ultimately extending the life cycle of historic buildings (Bruno & Roncella, 2019; Meoni et al., 2022). As interoperability and data integration advance, HBIM will further enhance collaborative workflows, reducing fragmentation in heritage projects and ensuring stakeholder alignment (Gigliarelli et al., 2022; Charlton et al., 2021). Its capacity to simulate, test, and verify retrofit interventions before implementation allows designers to balance cultural significance with sustainability, paving the way for evidence-based conservation strategies (Piselli et al., 2020a; Nieto-Julián et al., 2021).

2.6.1.5 Environmental

Much research highlights the role and influence of HBIM on the environmental aspects of performance (Arayici et al., 2017); Karlapudi, 2018; Hull & Bryan, 2019; Gigliarelli et al., 2022). Furthermore, van Eldik et al. (2020), in a study proposed a BIM-based sustainable framework to evaluate potential environmental impact of a building project, hence allowing project team to make effective design priorities in a project environment. The proposed framework has shown that the BIM environment is able to facilitate an automated and integrated environmental impact assessment (EIA) in design projects provided to its accuracy, speed and high level of integration and visualization. BIM can also become a decision-making tool for sustainability metrics, which helps to enable useful decisions in the early project design stage and allows detailed sustainability analysis to be made (van Eldik et al., 2020).

Such approach enables designers to assess various options for sustainable design that promote energy efficiency and resource minimization in relation to project cost (Wong & Zhou, 2015). An aspect of design project performance is the capability of the product to achieve improved environmental performance. Some research has found evidence that environmental benefits and concerns are relevant in the stakeholder's decision to participate in retrofitting (Alberini et al., 2013; Achtnicht & Madlener, 2014), which indirectly has an influence as the key performance indicator of a retrofit project. McGinley et al. (2022), classifies environmental performance in retrofit projects as the ability of the project stakeholders to achieve a significant outcome in elements related to energy and carbon emissions and ability for the project to meet the targeted energy performance certificate (EPC) in which such criteria have been included as the prime indicators for environmental performance in retrofit design decision-making frameworks.

Lizana et al. (2016), adopted a multi-criteria assessment from the perspective of project stakeholders to evaluate the effectiveness of energy retrofit solutions. The assessment emphasized environmental variables, focusing on outcomes such as improvements in energy performance and the reduction of emissions. In line with the growing importance of the green sustainability agenda, the ability to manage and minimize energy consumption and carbon (or GHG) emissions throughout the building lifecycle has become increasingly critical to achieving high standards of performance (Wong & Zhou, 2015).

2.6.1.6 Relationship

Effective relationship performance in historic building conservation projects relies on clear collaboration, efficient communication, and seamless data integration among stakeholders. Several studies highlight these criteria through the role of shared digital environments. Bruno & Roncella (2019) note that incorporating non-geometric information enhances documentation, while García-Valldecabres et al., (2021) and

Thravalou et al., (2023) reported that collaborative platforms and centralized data repositories improve interaction and reduce conflict. HBIM-retrofit tools influence these relationships distinctly. Liu et al. (2023) show that Level of Detail (LoD) guidelines clarify stakeholder priorities and standardize processes. (Jouan & Hallot, 2019) demonstrate that integrating cultural significance into digital models supports informed conservation decision-making.

Moreover, Khan et al. (2022) highlight improved communication through converged building data, and Piselli et al. (2020b) show that user-centric facility management and energy retrofit applications enhance operations. Prizeman et al. (2020) further highlights that HBIM applications facilitate knowledge sharing, supporting cost-efficient and sustainable strategies. Across ten studies, data sharing, stakeholder involvement, and knowledge transfer are consistently emphasized. In practice, HBIM-retrofit supports preventive maintenance, energy upgrades, and asset management, enhancing data integrity and aligning conservation goals. Overall, the evidence confirms that well-implemented HBIM-retrofit solutions significantly improve stakeholder interactions and project performance.

2.6.1.7 Communication

The use of HBIM can significantly influence effective communication within the project team including participating stakeholders of conservation project. Several studies suggest HBIM mechanisms in improving the communicative aspects of projects. Baik (2017) highlights that one of key strengths of HBIM as an effective communication tool is its ability to create a centralized information repository which allow stakeholders to share, access its models simultaneously with up-to-date information which can potentially reducing misunderstandings, discrepancies, fosters a more interactive and cooperative working environment, facilitating better coordination and faster decision-making. Combined with its visual communication through 3D models and digital representations, these visual tools make it easier to communicate complex architectural details, historical contexts, and proposed interventions to both technical and non-technical stakeholders (Fai et al., 2011). Furthermore, HBIM allows the tracking of decisions and changes made throughout the project. This transparency ensures that all team members are aware of the rationale behind decisions, helping to align their efforts and avoid redundant or conflicting actions (Dore & Murphy, 2012). As for HBIM application, Argiolas et al. (2022) examines the integration of HBIM prototype into virtual environments for heritage communication purposes, utilizing AR and VR tools to create immersive experiences where users can navigate and interact with objects. These virtual environments, which replicate real locations or architectural structures, can enhance user's interest, facilitate intangible accessibility, enabling dynamic content presentation and improving comprehension and user engagement.

Studies show that HBIM improves coordination by visualizing structural conditions, material decay, and intervention plans in a shared platform (Baik, 2020). This enhances stakeholder engagement and accelerates approval processes for retrofitting interventions. Moreover, HBIM strengthens public and institutional communication by providing interactive visualizations and simulations of conservation strategies (Bruno & Roncella, 2019). These tools help communicate retrofit impacts to non-technical stakeholders, fostering informed decision-making and greater public support for conservation projects.

2.7 Summary of Chapter

This Chapter has discussed and summarized the key issues, definitions, and classifications that are embedded in the realm of HBIM-retrofit. By analyzing and synthesizing the broader context on the key issues within the relevant field of studies, a much clearer context and background are provided, as result assisting in closing the research gap. The review of previous and current literature highlights key definitions and characteristics that would respond to the first objective, which is to investigate the influence of HBIM-retrofit on performance of heritage buildings conservation projects. An in-depth examination of the definitions and classifications of heritage buildings, HBIM, and retrofit will aid in the researcher in understanding of generic terms that will further determine the method and techniques required in answering the research objectives. All of this will eventually lead to appropriate terms of definition, classification and process to each of the field of study, which will lead towards to the development of the final framework. The proposed research design and methods as well as the intended instruments to collect data for the research will be discussed in the following chapter.

CHAPTER 3
CONCEPTUAL FRAMEWORK DEVELOPMENT

3.1 Introduction

This chapter develops the conceptual framework underpinning this research. Drawing from the literature reviewed in Chapters One and Two, including the characteristics of historic building retrofit and the functionality of HBIM. This chapter also establishes the theoretical foundation and explains how the conceptual framework is constructed. The framework is grounded in the Task–Technology Fit (TTF) theory, which provides the basis for examining how HBIM-enabled retrofit attributes influence performance in heritage building conservation projects in Malaysia. The chapter begins by presenting the underpinning theory, followed by the mapping of research variables to the theoretical constructs. It then introduces the conceptual framework, explains the use of hierarchical component models, and finally outlines the hypotheses tested in this study. A summary concludes with the chapter.

3.2 Relationship Between HBIM Retrofit Framework and Performance

This section explains the relationship between the HBIM-retrofit framework and performance. Much research highlights the substantial roles of HBIM and BIM technology in influencing project performances in construction industry (Van Tam, 2023; Mesároš et al., 2022; Cao & Wang (2017). The high degree of fit between the task (including user and process) and technology contributes to a positive impact to the performance of a project.

This aspect emanates from the fact that an organization's workforce can execute tasks more effectively and efficiently through the utilization of such technology in practice. The cost of executing tasks can also be reduced adequately (Kuo & Lee, 2011). Hence, to know whether a framework that orientates from technology adoption would improve the performance of an entity or not, a study on the relationship between the HBIM-retrofit elements and its perceived impact to the performance is needed.

3.2.1 Underpinning Theory

This section discusses the relevant theory that underpins this study. According to Iyamu (2013), an underpinning theory is the foundation for any philosophical study that supports the researcher in the rigorous pursuit of research and provides guidance from data collection to the data analysis stage. Thus, theory is a foundation upon which the assumptions of the study rest. Underpinning theories posit basic principles and realities that guide a proper understanding of the variables and indicators, and the direction of their relationships (Iyamu, 2013). Hence, it is useful and critically important to underpin a study with one or combination of theories, as such will provide guidance from data collection to empirical data analysis.

As discussed earlier in Chapter Two, it can be said that this study relates in the context of Information System (IS) or Information and Communications Technology (ICT) adoption in a business process management (BPM) of an individual or organization. The adoption of IS or ICT technologies brings significant impact in supporting business units at the decision, design and process level in organizations (Ahmad, 2019). Furthermore, the role of HBIM and BIM as IS/ICT technology has influenced innovation and the change of mindset into the business processes and functions, in the pursuit of transforming organizations to become more lean, efficient, and productive (Jadhav, 2011; Heaton et al., 2019). The IS/ICT discipline in business process is an aspect of technology that continues to involve more of social context in its development and implementation (Avison & Elliot, 2005).

Research on IS/ICT adoption field are carried out primarily to investigate and understand what events happened; why the events happened; how did the events happened; and the impact and influence of phenomenon in the development, implementation, and use of IS/ICT in various environments (Mkhomazi & Iyamu, 2013). Hence, this influenced the emergence of various underpinning theoretical models in the IS/ICT research, formulated to explain the technology-to-performance phenomenon to a business process, among the prominent theories are the Technology Acceptance Model (TAM), Technology to Performance Chain; Task-Technology Fit (TTF), Activity Theory; Diffusion of Innovation (DOI) Theory and Social Cognitive Theory (Mkhomazi & Iyamu, 2013).

These theoretical models provide frameworks for understanding the complex relationship between technology and performance in various organizational contexts (Wu & Chen, 2017). Hence, it is fitting to embrace the selected theory as it strives to define plausible relationships between conditions, actions and outcomes. Furthermore, in line with the given background, a task-technology fit theory (TTF) is considered suitable and adapted as the underpinning theory for this study. The theory was used to develop the conceptual framework for this study, and the relative importance, implementation and limitations of this theory are explained in the next subsection.

3.2.1.1 Underpinning Theory: Task-Technology Fit (TTF) Theory

Theories from the social sciences have long underpinned studies in the application of IS/ICT within business processes (Eze et al., 2017). Through socio-technical perspectives, these studies have contributed theoretically, practically and methodologically to the field of technology adoption. Among the theories commonly used is the Task–Technology Fit (TTF) model, which forms the theoretical foundation of the present research.

In organisational settings, technology is typically introduced with the aim of generating value by supporting individual and collective tasks. However, such adoption requires significant resources for acquisition, implementation, and ongoing use. As a result, organisations frequently question the extent to which a given technology generates tangible value for their business processes (Melville et al., 2004).

Quantifying this value is challenging due to the complex interplay of technology, users, systems, tasks, and processes (Orlikowski, 2000; Goodhue & Thompson, 1995). Consequently, models such as TTF have been proposed as alternative means to assess the impact of technology (Marikyan & Papagiannidis, 2023), which are widely accepted within the Information Systems (IS) domain (Wu & Chen, 2017). TTF has been described as "one of the most important developments in information system theory" (Melchor & Buendía-Carrillo, 2014), offering a structured approach to evaluate a technology's effectiveness within an organisation (Spies et al., 2020; Goodhue et al., 2006). Furneaux (2012) further observed a notable and continuing increase in the use of TTF across a growing range of environments.

The basic TTF model depicted in Figure 3.1, conceptualises how the alignment between technology and task, influences both performance and utilisation (Goodhue & Thompson, 1995; Goodhue et al., 2006; Larsen et al., 2009). Its central premise is that technology creates value when its functionalities adequately support the tasks users must perform.

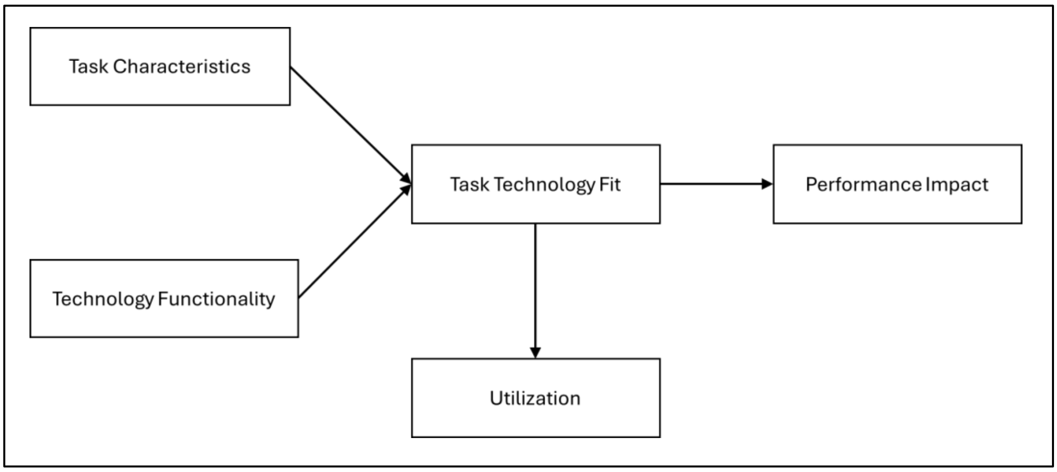

Figure 3.1 Task-Technology Fit Model (Goodhue & Thompson, 1995)

The theory thus provides a basis for evaluating how the alignment between task requirements and technological capabilities affects user outcomes, including utilisation and performance (Spies et al., 2020; Pal & Patra, 2021). It examines the extent to which expected performance results from the alignment among individual abilities, task complexity, and technological functionalities (Marikyan & Papagiannidis, 2023; Larsen et al., 2009). This conceptual logic underpins the present study.

TTF assessments often rely on perceived value as reported by users in their organisational context (Wong et al., 2022). Related studies illustrate this application for instance, Wong et al. (2022) employed TTF to examine facilities management users' behavioural intent toward digital twin technology, while Srećković et al. (2021) adapted TTF and configuration theory to model BIM-Blockchain workflows. These examples reflect the suitability of TTF for developing conceptual models around emerging digital technologies (Spies & Botha, 2020), aligning closely with the nature of HBIM-retrofit research.

Within the TTF framework, task characteristics describe the actions involved in converting inputs into outputs (Goodhue & Thompson, 1995). In this study, the task refers to historic building retrofitting, which possesses distinct technical and procedural requirements. Technology characteristics encompass the functionalities and attributes of the technological system including informational requirement, process, software, hardware, data, user support, training, and accessibility that enable task execution.

For this research, these characteristics are embodied in HBIM, which integrates unique systemic and data-driven processes. Individual characteristics relate to the users' experience, capability, and motivation to adopt the technology. Performance refers to task outcomes such as improvements in efficiency, quality, and decision-making. According to Wong et al. (2022), an increased fit between technology and task leads to positive performance outcomes.

3.2.1.2 Adaptation of TTF for the Current Study

In the Malaysian heritage conservation sector, HBIM adoption remains at an early and inconsistent stage. Recent studies report persistent barriers including limited technical capability, skill shortages, organisational constraints, and the absence of standardised guidelines that restrict widespread HBIM use (Ali et al., 2018a; Ismail et al., 2021; Salleh et al., 2022). More recent regional assessments similarly show that heritage professionals rarely engage with HBIM directly, even though they recognise its potential for improving conservation workflows (Ismail et al., 2021; Said et al., 2025). These studies consistently demonstrate that, utilisation of HBIM is not yet an established or measurable behavioural outcome within the industry.

As a result, including a utilisation construct would produce conceptually weak or biased responses, as respondents cannot reliably evaluate a behaviour they have not performed. This issue aligns with broader technology acceptance literature, which emphasises that pre-adoption evaluations should not rely on actual usage measures but rather on perceived usefulness, perceived fit and expected performance (Davis, 1989; Marikyan & Papagiannidis, 2023).

However, removing the utilisation construct does not conflict with TTF logic; instead, it reflects the methodological flexibility built into the theory. Goodhue and Thompson (1995) explicitly noted that task–technology fit alone is sufficient to predict performance impacts when usage behaviour cannot be meaningfully measured. Accordingly, this research adopts a pre-adoption adaptation of the TTF framework, retaining task characteristics, technology functionalities, task–technology fit, and expected performance impact, which are consistent with approaches used in early-adoption studies (Fuller & Dennis, 2009; Zheng et al., 2024).

Furthermore, literature adapting TTF frequently focuses on the relationship between task and technology characteristics when evaluating how information systems influence user performance (Marikyan & Papagiannidis, 2023; Zheng et al., 2024). This supports the relevance of using TTF to investigate how the HBIM-retrofitting may influence project performance dimensions such as time, cost, quality, design, relationship management, environmental and communication outcomes (Fuller & Dennis, 2009).

Through the TTF lens, this study offers insights into how individuals behave within the complex socio-technical systems, providing a useful predictive model for qualitative and quantitative research (Spies et al., 2020; Eze et al., 2017). In this context, TTF serves as a meta-theory to systematically explain the relevance of HBIM in the retrofit process encompassing task (historic building retrofit), technology (HBIM-retrofit), and individual (heritage conservators) characteristics.

Its application supports identifying impacts, opportunities, and performance implications associated with integrating HBIM into historic building conservation projects. The study thus contributes to the literature by examining the relationship between the HBIM-retrofit framework and its potential to enhance performance within heritage conservation workflows.

3.3 Conceptual Framework Development

A conceptual framework is crafted by researchers from a range of theoretical or conceptual viewpoints. According to Imenda (2014) and Grant & Osanloo, (2014), the objectives of conceptual framework are to:

a) Help the researcher clearly view the core variables and concepts in a specific study.
b) Provide the researcher with a universal approach, methodology, research design, target population and research sample, data collection and analysis.

c) Guide the researcher in the analysis and explanation of the data since there is no prevailing theoretical perspective.
d) Guide forthcoming research, especially where the conceptual framework incorporates literature review and field data, synthesis of relevant aspects.

According to Sekaran & Bougie (2019), conceptual framework represents belief on how certain phenomena (or variables or concepts) are related to each other in form of a model and includes explanation why such variables are associated with each other, forming a collective of theory. Both model and theory flow logically from the documentation of previous study on the problem area. In such case, the conceptual framework is developed based on the critical review of definitions and classifications of the concepts in the three-research domain namely the context of historic building retrofit, HBIM-retrofit and performance. Figure 3.2 shows the HBIM-retrofit influence to performance taxonomy represented in Venn diagram method.

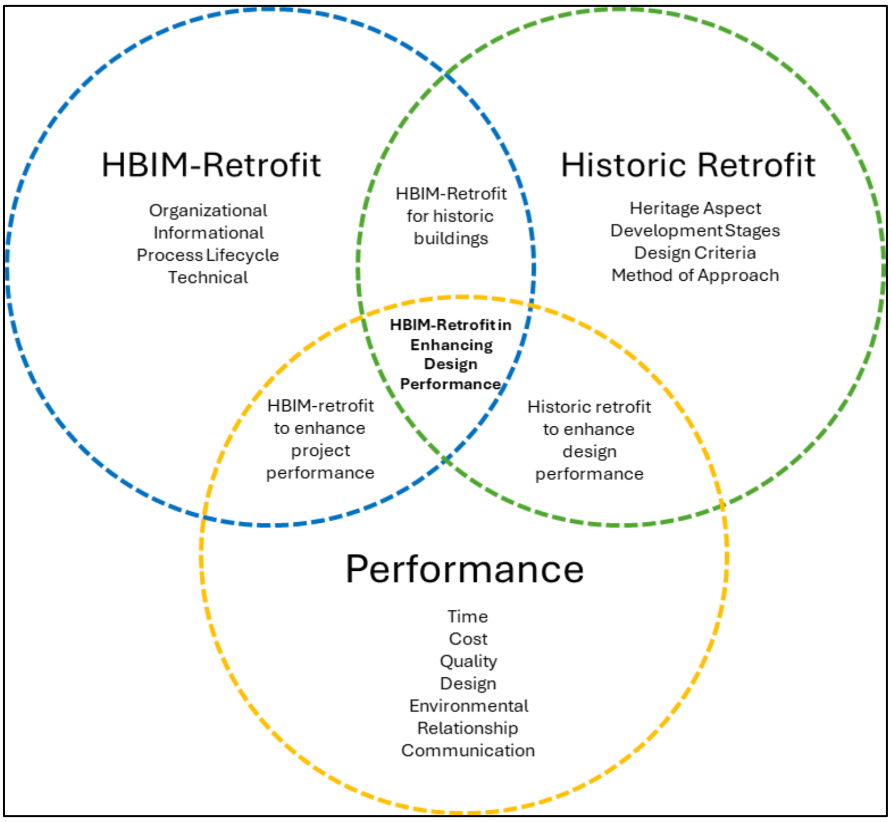

Figure 3.2 The HBIM-Retrofit Influence to Performance Taxonomy Represented in Venn Diagram Method (Developed by the Author)

3.3.1 Mapping of Study Variables to the TTF Construct

The conceptual framework for this study was developed based on Task Technology Fit (TTF) theory and considered empirical evidence identified in Chapter One and Chapter Two. The framework illustrates the relationship of HBIM-retrofit variables on the performance of heritage building conservation projects. Furthermore, previous studies by Van Tam et al. (2023) and Cao and Wang (2017) have examined the direct relationships between BIM implementation factors and construction project performance. Although conducted within the broader construction industry, their findings provide a relevant foundation and further justify the need to investigate similar relationships in the context of HBIM-enabled retrofit for heritage conservation projects in Malaysia.

The variables incorporated into the conceptual framework were systematically derived from the critical synthesis of literature presented in Chapter Two. In particular, the recurring historic building retrofit and HBIM-related themes identified through international retrofit guidelines, HBIM-retrofit implementation studies, and performance in heritage conservation projects literature formed the basis for operationalizing the constructs and indicators used in this study. This approach establishes conceptual continuity between the literature review, underpinning theory, and the development of the proposed HBIM-retrofit framework.

The framework incorporates the indicators or items for each of the variables discussed earlier in Chapter Two. Table 3.1 shows the eight independent variables which are categorized under two overarching domains of HBIM-retrofit: (1) Historic building retrofit characteristics, which includes heritage aspects, development stages, retrofit design criteria, and method of approach; and (2) HBIM-retrofit functionality, which comprises HBIM organizational, HBIM project lifecycle, HBIM technical, and HBIM informational attributes.

Each of these first-order constructs is measured within three to seven indicators. Furthermore, given the complexity of the path model, the domain and construct can also be operationalized at a higher level of abstraction (Sekaran & Bougie, 2019), in which the operationalized definitions that influenced the use of higher-order constructs are discussed in Chapter Four. As a result, grouping them into two higher-order constructs (HOC) which consists of historic building retrofit characteristics and HBIM-retrofit functionality, helps to better reflect their theoretical structure, reduce the number of relationships in the structural model and improves parsimony, consistent with the recommendations of Hair Jr et al. (2019), Hair Jr et al. (2021) and Becker et al. (2012).

Table 3.1
Domain and Construct of Conceptual Framework (Developed by the Author)

Domain	Sub-domain (Variables)	Indicators...
Historic Building Retrofit Characteristic	Heritage Aspects	The heritage aspects in historic retrofit encompass criteria such as historical building categories, values, regulations, principles of intervention and multidisciplinary stakeholders.
	Development Stages	The identification of key activities and decision process in conducting retrofit assessment based on operational perspective such as pre-retrofit, design, implementation and post-retrofit stages.
	Retrofit Design Criteria	The identification of retrofit design criteria influencing retrofit interventions in historic buildings conservation include the building fabric, building systems, structure, user behaviour, collections, and economic factors.
	Method of Approach	The method of approaches in retrofit interventions include techniques such as environmental and microclimatic site analysis, in-situ measurements, laboratory testing, building performance evaluation, EPC assessments, and risk assessments.
HBIM-Retrofit Functionality	Organizational	The identification of the organizational aspects (people) in HBIM adoption for energy retrofit which involves roles and responsibilities, training development and BIM protocol.
	Informational	The identification of the informational requirement for the management of HBIM-retrofit which involves geometrical, historical evidential, pathology, surveying, environmental and structural data.
	Process Lifecycle	The identification of management (process lifecycle) to conduct HBIM-retrofit assessment which includes data acquisition, 3D modelling, analysis and simulation and design visualization.
	Technical	The ICT hardware tools, infrastructure and software to implement HBIM-retrofit assessment, including technical support such as standards and solutions for data exchange.

Furthermore, given that the independent variables represent distinct dimensions of a broader concept, Hair Jr et al. (2019) argues that higher-order constructs are useful in simplifying complex models and enhancing parsimony. Since the research framework is a theory-driven abstraction where the literature describes the overarching concept as a broad domain with subdimensions, omitting the use of higher-order construct would risk a mismatch between theory and measurement.

Becker et al. (2012) similarly emphasize that hierarchical component models (HCM) (i.e., first and second-order constructs) are particularly suitable in such cases. Hair Jr et al. (2021) also highlights it is important to establish HCM on well-established theoretical or conceptual underpinnings, which has been implied to the study by underpinning the TTF theory. Furthermore, the relationship among the indicators forming the independent variables follows a formative-to-formative construct, which will be discussed in detail in Chapter Four.

Accordingly, a conceptual framework for an HBIM-retrofit approach aimed at enhancing the performance of heritage building conservation projects in Malaysia was developed and examined through the hypotheses of this study. The framework, presented in Figure 3.3, illustrates the relationships among the key variables under investigation. Chapter Four further explains the development process, including the construction and operationalized definitions of the independent and dependent variables. The following sub-section elaborates on the relationships among these variables in greater detail.

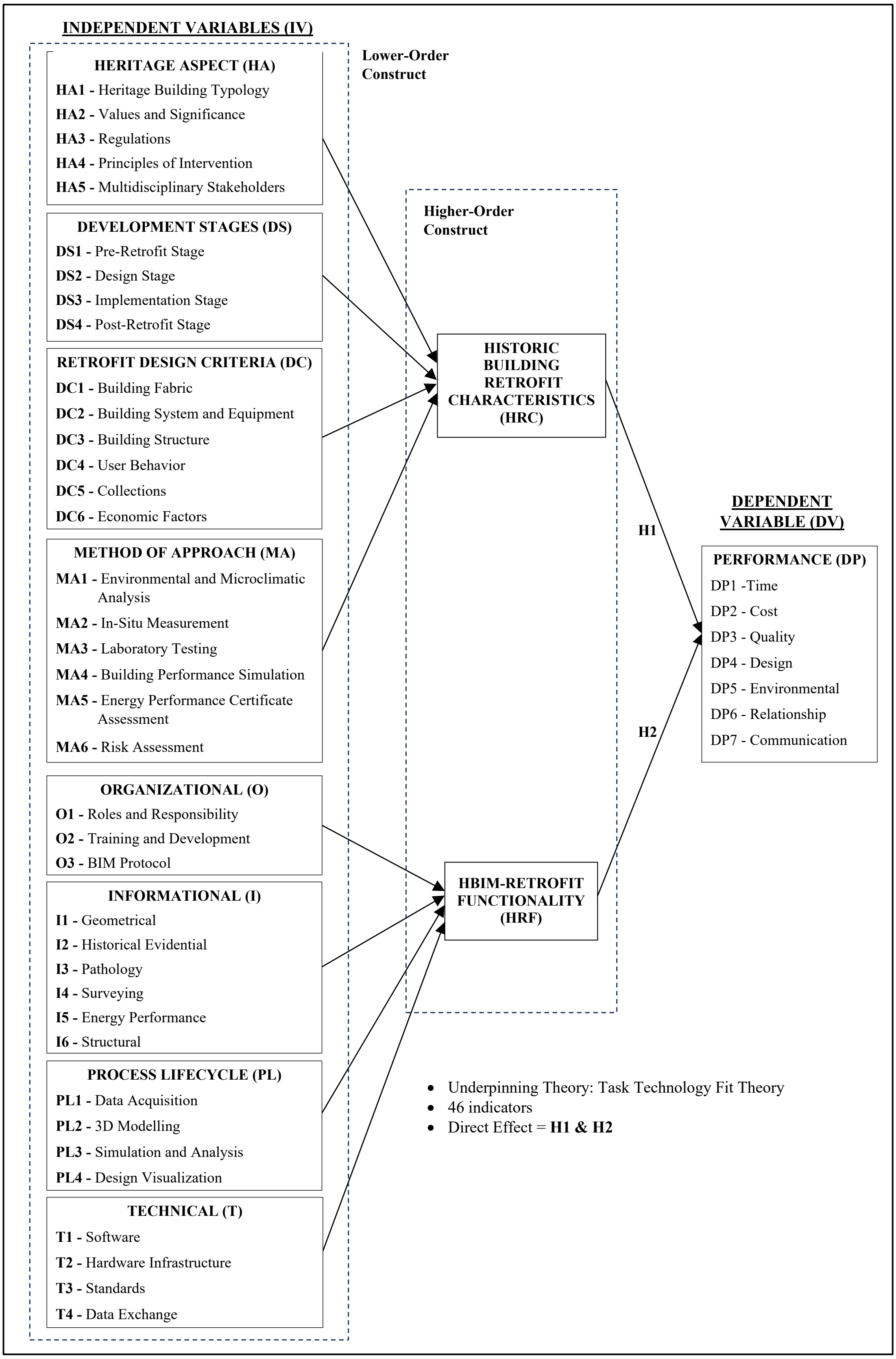

Figure 3.3 The Proposed Conceptual Framework

3.4 Hypotheses Development

Sekaran & Bougie (2019) identified two contrasting relationships between variables within a hypothesis, which may be directional or non-directional. A directional hypothesis specifies the direction of the relationship between variables, particularly between independent and dependent variables, whereas a non-directional hypothesis only indicates the existence of a relationship without specifying its direction. This research adopts the directional hypothesis approach, consistent with the underpinning Task–Technology Fit (TTF) theory and the proposed conceptual framework.

Based on the conceptual framework developed, this study proposes two direct-effect hypotheses to examine how the key elements of the HBIM-retrofit framework influence the performance of heritage building conservation projects in Malaysia. The hypotheses focus on assessing whether historic building retrofit characteristics and HBIM-retrofit functionality contribute positively towards improving project performance.

Historic building retrofit characteristics influence the effectiveness of conservation projects through factors such as heritage aspect, development stages, retrofit design criteria, and methods of approach. Previous studies have emphasized that systematic retrofit planning with appropriate intervention strategies contribute positively towards project delivery, decision-making efficiency and overall conservation project performance (Buda et al., 2021; Troi & Bastian, 2015; McCaig et al., 2018). Within the TTF perspective, these retrofit characteristics represent task-related dimensions that influence the extent to which project requirements can be effectively addressed. Therefore, it is expected that stronger historic building retrofit characteristics positively influence heritage conservation project performance in which:

i. **H1**: There is a significant positive relationship between the historic building retrofit characteristics and the performance of historic building conservation projects in Malaysia.

On the other hand, HBIM-retrofit functionality provides technological capabilities through factors such as organizational, informational, process lifecycle and technical. Previous studies have demonstrated that BIM and HBIM implementation contribute towards improved coordination, communication efficiency, data reliability, and project performance within the heritage conservation environments (Arayici et al., 2017; López et al., 2018; Van Tam et al., 2023). From the TTF perspective, improved alignment between technological functionalities and retrofit requirements enhances performance outcomes. Therefore, it is expected that HBIM-retrofit functionality positively influences the performance of heritage building conservation projects in which:

ii. **H2**: There is a significant positive relationship between the HBIM-retrofit functionality and the performance of historic building conservation projects in Malaysia.

3.5 Summary of Chapter

This chapter discusses the research framework, the underpinning theory and the development of related hypotheses. The research framework for this study was developed based upon a broad review of relevant literature and supporting underpinning theory attained from earlier researchers. Furthermore, the conceptual framework of this study was established based on the task technology fit theory and past research works found in the literature. The exploration of theory allows for better insights, forming a fundamental assumption and motivation to the development of the conceptual framework. In relation to this study, the research conceptual framework was proposed by including the measures of HBIM-retrofit keystones, with eight independent variables which are hierarchically developed into two higher-order constructs comprised of forty-six formative indicators. All of these variables postulate a direct relationship to the dependent variables, namely the performance, which comprised of six indicators to be tested. Finally, two generic hypotheses have been developed to test the relationships among them. The following chapter will discuss the particulars of the chosen research methodology with the target of putting the hypotheses to the test and to be validated.

CHAPTER 4
RESEARCH METHODOLOGY

4.1 Introduction

The purpose of this chapter is to explore and explain the philosophical and methodological context of the research by underlining the research approach, research design which influence the research method, instruments of collecting data and the research process related to the research. This chapter also discusses the underlying idea which leads towards the data collection of primary sources and the factors to take into consideration while defining the study towards the developed framework. According to Fellows & Liu (2021), research methodology refers to the principles and procedures of logical thought process which applied in a scientific investigation. White et al. (2007) further added that research methodology consists of philosophy and science that supports investigation and research consists of careful search and systematic investigation contributing to the sum of knowledge. The research methodology therefore can be considered as an overall strategy used in scientific investigation which consists of the component of philosophy, approach, and techniques.

4.2 Research Methodology Approach

The nature of the shifting surroundings, environment, economic social and human lifestyle results in people inquiring about the phenomena (Tobi, 2013). Burns & Burns (2008) state that research involves the process of thorough and objective identification of the problem, collecting and analyzing relevant data to ascertain the probable aspects causing the problem (Awang, 2012). The term ‘research’ can refer to the development of the latest body of knowledge. Scholars have depicted research as a structured, valid, reliable and systematic effort of creating new and applicable information (Bryman, 2016). This procedure of mixed techniques to discover a particular circumstance or phenomenon is also known as research methodology (Tobi, 2013). Fellows & Liu (2021) point out that research methodology denotes the principles and procedures of logical thought process which are applied to a scientific investigation.

White et al. (2007) also stress that research methodology comprises philosophy and science that support the enquiry. Moreover, as stated by Fellows & Liu (2021), research is made up of comprehensive exploration and a systemic enquiry adding to the sum of knowledge. Hence, research methodology can be regarded as a general strategy used in scientific investigation which includes the elements of philosophy, techniques and approach. To comprehend the elements of research methodology presented by Kagioglou et al. (2001), since it can help in tightening and binding the research philosophy, approach and technique.

In Figure 4.1, the outer ring signifies the unifying research philosophy, guiding and energizing the research approaches and research techniques. Research approach contains the main theory generation and methods of testing while research techniques consist of tools of collecting data. The subsequent section will deliberate every layer of the nested approach in greater detail. Therefore, the subchapter is organized in relation to Figure 4.1, to assist in the discussion. Thus, Figure 4.2 shows the study's general process flow comprising the key stages of the research, the activities and their link in supporting the aims and objectives of the research.

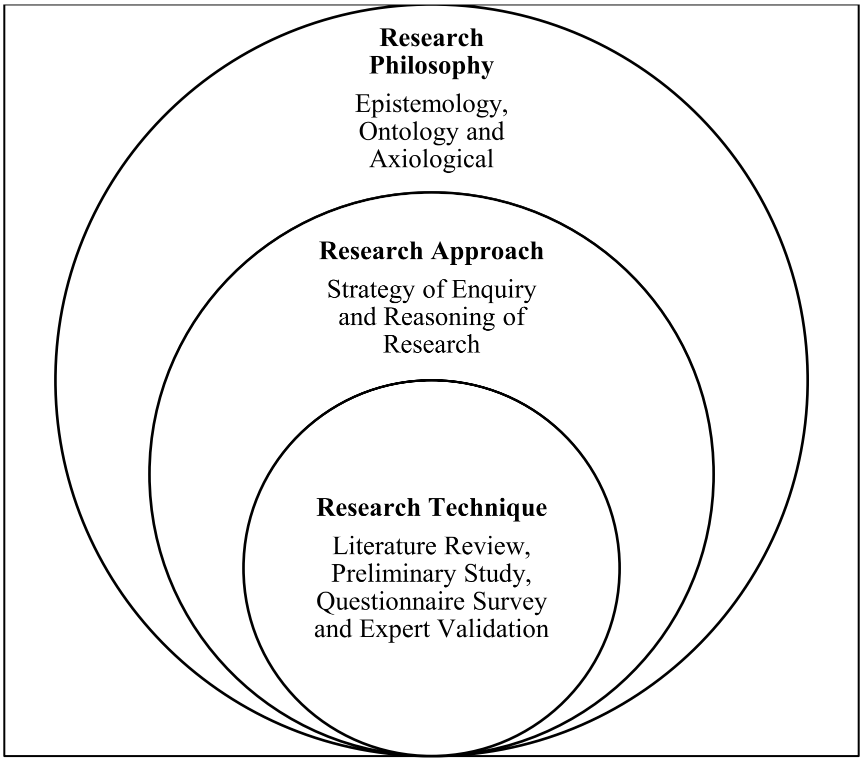

Figure 4.1 Nested Research Methodology Approach (Kagioglou, et al., 2001)

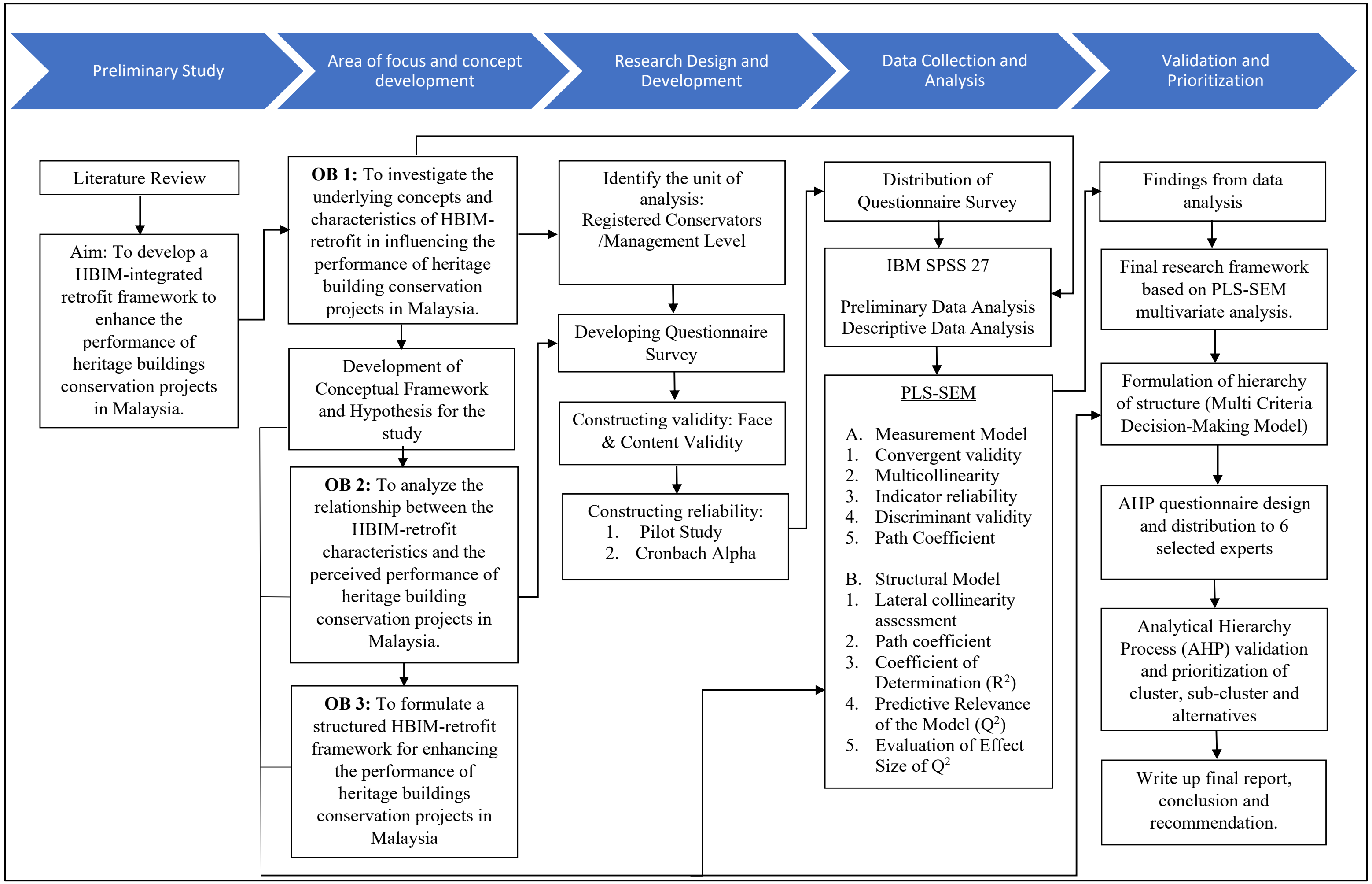

Figure 4.2 Research Process Flow (Author)

4.3 Research Philosophy

According to Saunders et al. (2024), research philosophy contains important assumptions or predictions on the way in which a researcher views the world and defines research. Next, a researcher develops research grounded on specific criteria, beliefs and assumptions concerning the way social reality is comprehended, interpreted and put forward. Thus, the analysis and research interpretation will be clearer if the assumptions made are strong. The beliefs and assumptions in this study are referred to as research philosophy. Some scholars defined research philosophy as a research paradigm (Kuhn, 2012). This study will use the term research philosophy rather than research paradigm. The definition of research philosophy according to (Kuhn, 2012), is the core assumptions and intellectual skeleton whereupon research and development in a field of study is founded on. As pointed out by Patton (2014), research philosophy is the way the complexity of the real world is broken into fragments; by describing how the world works and knowledge is extracted from the world.

Research philosophy is defined by Creswell & Creswell, (2017) as a way of thinking, communicating, perceiving and viewing the world. Research philosophy is an abridged pattern used to demonstrate procedures, processes and theoretical points. It is used to exemplify a conceptual framework with an appropriate model for inspecting problems and looking for solutions. In addition, the research philosophy offers a research path even though varying techniques are used. The research philosophy also affects how the researchers think, write and discuss the findings of the research. Moreover, research philosophy also assists in defining the kinds of questions to be asked and the methodologies to be used in the direction of responding to the research questions. Creswell & Creswell (2017) also categorized research philosophy as shown in Table 4.1 below.

Table 4.1
Philosophical Assumptions

Item	Descriptions
Ontology	The nature of the knowledge under study
Epistemology	Scope of knowledge being researched
Axiological	The philosophical study of value
Methodological	Techniques for solving and investigating the phenomenon

Source: Creswell & Cresswell (2017)

The research philosophy can apply the deductive or inductive approach depending on the way reality is inferred. Social reality can either be interpreted from a subjective or objective angle, regardless of the strategy used in the study; whether it employs the quantitative, qualitative or mixed methodology based on the researcher's philosophical stance such as positivism, critical realism, interpretivism, postmodernism, or pragmatism (Fellows & Liu, 2021; Saunders et al., 2024).

According to Creswell (1994), in general epistemology is the technical term for the theory of knowledge where it describes how a researcher knows about reality and assumptions about how knowledge should be acquired and accepted. It concerns what constitutes acceptable knowledge in the field of study. Within this domain, according to Easterby-Smith et al. (2002), two philosophical paradigms have dominated debate in social science research. They are Positivism which suggest the use of quantitative experimental methods to test hypothetical-deductive generalization and Interpretivism, which suggest the use of qualitative and naturalistic approaches to inductively and holistically understand and explain a phenomenon.

According to Creswell & Creswell (2017), the Interpretivism aim is to increase the general understanding of the subject research in which the research progresses through gathering rich data from which ideas are induced. Additionally, Easterby-Smith et al. (2002), the interpretivist focuses on the ways that people make sense of the world, especially through sharing theories experiences with others via mediums of language. The philosophical approach underlying the present study was positivism, because of its suitability. This can be justified since positivism is connected to the realities that can be observed, and it pursues an understanding of observable meaning and purpose of human behaviour.

In this case, a quantitative analytical method was adopted to address the issues at hand. The positivism quantitative analytical method was most suitable for this study as it allowed the researcher to emphasize quantitative data gathered and analyzed using experiments, surveys and statistics (Sekaran & Bougie, 2019). Also, by considering the philosophy described earlier, the phenomenon that is being explored in this study is the heritage building conservation practice, the influence of HBIM-retrofit framework in relation to project performance (ontology) in the context of the research. Lincoln et al. (2011) further illustrates the description of basic belief in positivism in Table 4.2.

Table 4.2
Research Philosophy of Positivism

Item	Positivism Philosophy
Ontology	Naïve realism – 'real' reality but apprehensible
Epistemology	Dualist / objectivist, finding true
Axiological	Experimental / manipulative, verification of hypotheses, chiefly quantitative methods

(Lincoln et al., 2011)

The positivism philosophy concentrates on a single reality that is seized through a detailed study of suitable methodology adoption. This process includes the collection of data and analysing it to allow theories to be tested and hypotheses to be proven. Surveys and experiments are examples of quantitative methods used. The researcher is not part of the research and has no effect on the research subject. Positivist social science stresses the exploration of causal laws through planned empirical observation and value free research (Guba & Lincoln, 1994; Neuman, 2010; Sarantakos, 2012). Positivism regards reality as an independent existence on the matter that is on research. Therefore, this denotes that the definition of the phenomenon is constant between subjects (Fellows & Liu, 2021; Neuman, 2010).

The ontology of positivism indicates that reality is real and apprehensible whereby the data collection and analysis enable theories to be tested and hypothesis to be proven. The epistemology of positivism regards the researcher as independent from the matter of study and can carry out the study without affecting or being affected by it. The philosophy emphasizes assessing and analyzing causal relationships that are consistent across time and context. It ignores the idea that more than one interpretation of reality may possibly exist (Guba & Lincoln, 1994; Lincoln et al., 2011; Neuman, 2010; Sarantakos, 2012). The positivist paradigm looks for facts or causes of social phenomena without taking the subjective condition of the individual into consideration, as precision and objectivity are favoured over intuition and experience (Fellows & Liu, 2021; Hussey, 1997; Mangan et al., 2004).

Table 4.3
Justification for Choosing Positivist Philosophy in this Research.

Philosophy consideration	Research	Positivist Philosophy
Ontology (What phenomenon or reality?)	HBIM-retrofit framework that relates with performance of the Malaysian heritage building conservation projects.	Reality is real and apprehensible, testing of theories and proving hypotheses.
Epistemology (What knowledge)	Nature of knowledge of HBIM-integrated retrofit for heritage building conservation practitioners.	The researcher is independent, focuses on measuring and analyzing causal relationships that are constant across time and context.
Axiological (What value?)	The significant contribution of HBIM-enabled retrofit framework in enhancing the performance of Malaysian heritage building conservation projects.	Discovery of causal laws through careful empirical observations and value-free research
Methodological	Personal experience of heritage building conservation practitioners in HBIM-enabled retrofit through questionnaire survey	Focuses on a single reality, involves collecting and analyzing data to enable the testing of theories and proving hypotheses through quantitative methods.

Author adapted from Ali (2019)

The justification of selecting positivism philosophy for this study is explained in Table 4.3, therefore, this research focuses on making sense of the role of HBIM-retrofit framework in the heritage building conservation practitioner’s organization (epistemology). The roles and significant contributions of the HBIM-retrofit framework in enhancing the performance of heritage building conservation practitioners (axiology) are applied to better comprehend the social world with regards to developing knowledge through personal experience (methodology).

The selection of positivism as the research philosophy was appropriate as this study focused on examining measurable relationships between the HBIM-retrofit variables and the performance of heritage building conservation projects through objective and quantitative approaches. Positivism supports the testing of theories, validation of constructs, and analysis of causal relationships using empirical observations and statistical techniques (Saunders et al., 2024; Creswell & Creswell, 2017). This aligns with the objectives of the study, which intends to study the causal relationship of HBIM-retrofit framework to the enhanced project performance through quantitative methods including questionnaire surveys, Partial Least Squares Structural Equation Modelling (PLS-SEM), and Analytical Hierarchy Process (AHP).

Furthermore, the study aimed to establish generalizable findings from observable and measurable data obtained from heritage conservation practitioners, which is consistent with the objectivist and deductive nature of positivist research (Fellows & Liu, 2021; Sekaran & Bougie, 2019). Therefore, positivism was considered the most suitable philosophy to support the empirical validation and structured evaluation required for the development of the proposed HBIM-retrofit framework.

4.4 Research Approach

The research approach is an important step to establish the broad assumptions in enquiring the method of data collection, analysis and interpretation. Saunders et al. (2024), argues that in selecting the appropriate strategy of enquiry of a research approach, is to assume that one approach is better than another. Each strategy is better for performing different things and the selection of the more appropriate approaches depends on the research questions that need to be answered. In addition to the research questions, the arguments on the use of each research approach suggest that theories can also be used to determine which methodology will be most appropriate for particular research.

The selection of a research approach establishes the underlying assumptions that guide data collection, analysis, and interpretation. Saunders et al. (2024) emphasize that no single methodological strategy is inherently superior; instead, the suitability of an approach depends on the type of research questions posed and the nature of the inquiry. While qualitative approaches are appropriate when researchers seek to deeply explore unfamiliar phenomena or develop new theoretical insights, the choice of methodology must also consider the role of theory within the study.

Creswell & Creswell (2017) explain that qualitative methods are often used to uncover variables influencing a phenomenon, particularly when existing knowledge is limited. Qualitative research prioritizes rich, detailed perspectives of individuals, whereas quantitative research focuses on measuring variables, identifying patterns, and examining relationships in a systematic and structured manner (Mack et al., 2005). Quantitative approaches are therefore well suited for studies that require empirical testing, validation, and generalization. Sekaran and Bougie (2019) further note that when the researcher seeks to explain, verify, or evaluate established constructs rather than generate new theory, quantitative methods provide a more rigorous pathway.

In the context of this study, the goal is not merely to explore HBIM-retrofit characteristics and elements but to examine measurable constructs, identify significant factors, and empirically test the relationships influencing the performance of heritage building conservation projects in Malaysia. The research aims to operationalize the HBIM-retrofit framework, classify its parameters, and evaluate their effects using structured indicators derived from literature and professional practice. These objectives align with the quantitative tradition, which is suited for addressing "what," "how much," and "to what extent" questions, and for validating theoretical propositions through statistical analysis.

Given that the study seeks to test hypotheses, measure construct relationships, and develop a generalizable HBIM-retrofit framework supported by empirical evidence, a quantitative approach offers a more appropriate methodological foundation. This approach ensures systematic data collection, precise measurement, and analytical robustness necessary for developing and validating a performance-oriented framework for heritage conservation projects.

Although this study adopts a predominantly quantitative and deductive research approach grounded in positivism philosophy, exploratory elements were incorporated during the early stages of the research to support construct identification, framework conceptualization, and variable operationalization. The exploratory component involved extensive literature review, content analysis, expert validation, and instrument refinement processes to systematically establish the relevant HBIM-retrofit constructs, variables, and indicators prior to empirical testing. Therefore, the exploratory activities in this research function primarily as a theory-building and construct refinement process supporting the subsequent quantitative validation stage.

4.5 Strategy of Enquiry

According to Yin (2018), the best research strategy to use depends on the type of research questions, the degree of control the researcher has over the variables, and whether the research is focused on past or current events ie; future events concern predictions or forecasts. Table 4.4 shows different research strategies. Saunders et al. (2024), disputes that while choosing methods of enquiry, one research approach is better than another. Every method has its own strength that each may be better to performing certain tasks, thus choosing which is the most appropriate is subject to the research questions that must be answered. However, Jankowiez (2013) recommends selecting only one type of strategy over another, as it can in due course hinge on the objective of the study. Other than the research questions, the argument for and against the use of each research approach indicate that theories can also be relied on as a factor in deciding the most suitable methodology for a related study.

Table 4.4
Requirements of Different Research Strategies

Strategy	Research Questions	Control Over Variables	Focus on Events
Survey	Who, What, Where, How, Many, How Much?	Not required	Contemporary
Experiment/Quasi Experiment	How, Why?	Require	Contemporary
Archival Analysis	Who, What, Where, How Many, How Much?	Not Required	Contemporary/Past
History	How, Why?	Not Required	Past
Case Study	How, Why?	Not required	Contemporary

Source: Fellows & Liu (2021)

Based on research strategies stated in Table 4.4, generally there are three options in systematically conducting research available. They may be mono-method, mixed-methods or multi-method (Saunders et al., 2024). While the mono-method means a single research approach, mixed methods are the combination of two or more methods of research and normally refers to the application of both qualitative and qualitative methodology. However, the multi-method uses a wider selection of methods (Bryman, 2016). The main contrast between the mixed and the multi-method is that the mixed method includes a combined methodology which constructs a single dataset (Flick, 2011). Hence, Table 4.5 below displays the research choices for mono-method.

Table 4.5
Research Choices for Mono-Method

Characteristic	Quantitative	Qualitative
Assumption	Social facts have an objective reality independent of the knower	Reality is socially constructed and arise out of social action
Purpose	Generalizability	Contextualization

Literature review	Who (how many)? What (how much)?	How? Why?
Paradigm	Positivism Post positivism	Post positivism, Critical theory, Constructivism, Participatory
Methodology	Hypothetical-deductive Focus on description and explanation for example survey or experiment	Inductive / interpretive Focus on understanding and interpretation for example, case study, action research, focus group, interviewing, observation
Researcher's Role	Objective and remote	Up close and personal
Data Collection	Reduction / aggregation of data to numbers	Capture live experience of informants
Nature of Data	Constructs	Words, images, categories
Data Analysis	Falsification of null hypothesis with statistical tests	Identifying recurring themes and patterns in the search of meaning

Source: Ali (2019)

Normally, the researcher hopes to discover mutual patterns in behaviour or belief in quantitative research. Next, a generalization will be made based on the results from the quantitative analysis. Quantitative research is often carried out in strongly controlled situations and is likely to use a confirmatory method, concentrating on hypotheses and theory testing (Saunders et al., 2024). The researcher is detached from the items that are in question. As the philosophy of positivism and deductive approach favours the survey research strategy, the appropriate research selection to study the HBIM-retrofit framework to enhance the performance of heritage building conservation projects is the employment of mono-method using quantitative research.

4.5.1 Reasoning of Research

In lieu of the reasoning of the research, Saunders et al. (2024) mentioned that there are three varying research approaches intended to assist the researchers to emerge with new knowledge. They are deductive, inductive and combination of the two approaches. The discussion will be focused on deductive and inductive approaches. Therefore, it is vital to chart the research philosophy with suitable research approach (Babbie, 2020; Fellows & Liu, 2021; Neuman, 2010; Saunders et al., 2024). To increase the efficiency of the research study, it is important to comprehend these approaches as shown in Table 4.6.

Table 4.6
Deductive and Inductive: From Reason to Research

Characteristic	Deductive	Inductive
Logic	In a deductive inference, when the premises are true, the conclusion must also be true	In an inductive inference known premises are used to generate untested conclusions
Generalizability	Generalizing from the general to the specific	Generalising from the specific to the general
Use of data	Data collection is used to evaluate propositions or hypotheses related to an existing theory	Data collection is used to explore a phenomenon, identify themes and patterns and create a conceptual framework
Theory	Theory falsification or verification	Theory generation and building

Source: Saunders et al. (2024)

Deductive and inductive approaches totally contrast between one another as illustrated in Figure 4.3. The different levels in deductive approach include theory development, hypotheses, observation and confirmation, The deductive approach depends on research instruments like experiments and questionnaire surveys. It is applied in studies whereby the hypothesis raises questions that are generated by theory and required testing. Moreover, the deductive method operates from the more universal to the more explicit whereas inductive reasoning operates from bottom up rather than top down from a theory already developed (Cresswell & Cresswell, 2017; Gill et al., 2010; Saunders et al., 2024).

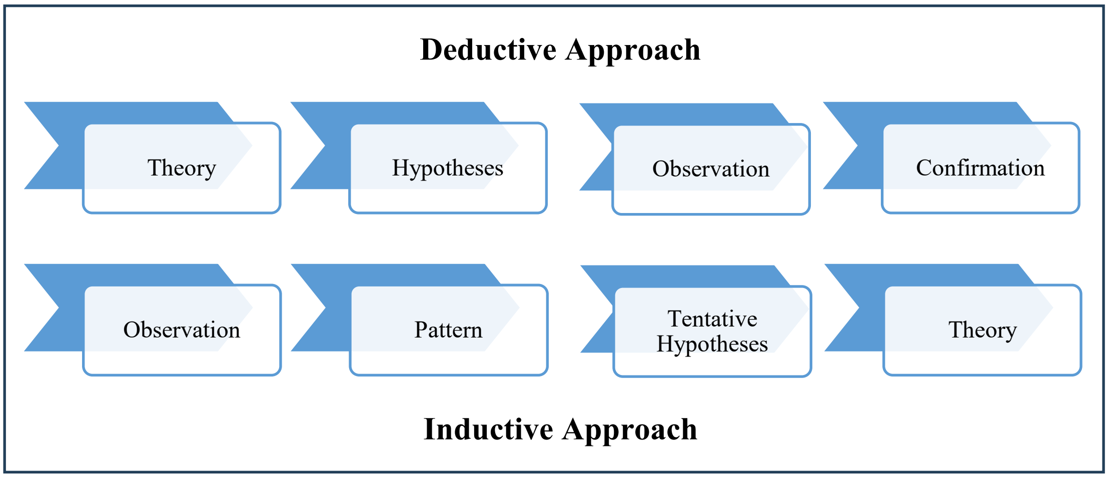

Figure 4.3 Deductive and Inductive Approach (Adapted from Ali, 2019)

According to Snieder & Larner (2009) and Saunders et al., (2024), a deductive research approach is connected to the philosophy of positivism that allows the construction of hypotheses and the statistical testing of anticipated results. On the contrary, an inductive research approach is often linked to the interpretivism philosophy. It is also important to know the two approaches to support the selection of a suitable research philosophy. Hence, a deductive approach will be used in this study since positivism philosophy is appropriately connected to the nature of the study. In adopting the deductive approach, the researcher begins by describing the theoretical proposition (Saunders et al., 2024). Next, the theory will be backed by solid empirical and systematically tested evidence (Cavana et al., 2001; Saunders et al., 2024).

The deductive approach consists of a hypothesis to demonstrate predictions and assumptions. Therefore, it is essential that the researcher is universal in this kind of method. It lets the researcher develop hypotheses by applying a suitable theory in this case the TTF theory adapted in the study. Thus, varying types of data and information are gathered by the researcher to approve or discard the hypotheses to resolve the central issue (Gill, 2010). As a result, the hypothesis suggested in this study which consists of two direct hypotheses as stated in Chapter Three was assessed using the deductive approach which is based on the TTF theory and the relationship of constructs were further tested using multivariate analysis (PLS-SEM). The empirical testing result are supposed to be objective and less prone to bias, as well as generalizing other situations (Holden & Lynch, 2004).

4.5.2 Exploratory Research

According to Sekaran & Bougie (2019), there are three main elements that define the purpose of study in which it is either exploratory, descriptive, and causal in nature. For this research, an exploratory study is deemed appropriate with the aim and objective of the study in which is to explore new areas within the context of the research. In general, exploratory study is undertaken when not much is known about the situation at hand, or no information is available on how similar problems or research issues have been solved in the past. Along these lines, exploratory studies are necessary when some facts are known, but more information is needed in developing a practical theoretical framework (Saunders et al., 2024).

According to Sekaran & Bougie (2019) and Yin (2018), exploratory research often relies on secondary research such as the literature review and quantitative approaches to data gathering such as survey, to more formal approaches such as interviews, focus groups, projective methods, and case studies. The results of the exploratory studies are typically not generalizable to the population and as a rule, exploratory research is flexible in nature (Sekaran & Bougie, 2019). Hence, the exploratory study is considered to be appropriate to support the aim and objectives of the research which is to investigate and define the novelty areas within the context of heritage building conservation projects through HBIM-retrofit model.

Furthermore, as discussed in the earlier sub-chapter, this research is derived from the philosophy of positivism as the fundamental approach to further investigate and measure the relationship between the independent variable (IV) and dependent variable (DV) as presented in the conceptual framework in Chapter Two. Further, in meeting the research objective derived from the problem statement and underlying established hypotheses, the research is developed through an exploratory research strategy. Exploratory research strategy consists of structural models, which are statistical models of linear relationships among latent variables and manifest variables (Sekaran & Bougie, 2019).

In exploratory research, the research objective is to understand the increasing complexity by exploring theoretical extensions of established theories and searching for patterns in the data in case there is no or only little prior knowledge on how the variables are related (Hair et al., 2017; Hair Jr et al., 2021). Therefore, this research measures the relationship between the independent variable (IV) of HBIM-retrofit (historic aspect, development stage, retrofit design criteria. method of approach, organizational, informational, project lifecycle and technical) to which forms an attribute in relationship to the enhanced performance of historic building conservation projects in Malaysia as the dependent variable (DV). Thus, this further justified the relevance of adopting the research techniques which will be discussed in the next sub-chapter.

Importantly in this study, the exploratory component does not constitute a standalone qualitative methodology, but rather supports the preliminary stages of construct identification, theoretical synthesis, framework development, and instrument operationalization. Exploratory procedures may also be incorporated within quantitative and deductive research designs, particularly during the early stages of theory refinement, construct development, and variable specification prior to empirical validation (Hair et al., 2017; Saunders et al., 2024; Sekaran & Bougie, 2019; Creswell & Creswell, 2017). In this context, the exploratory activities were conducted through literature review, content analysis, expert validation, and construct refinement processes aligned with the Task–Technology Fit (TTF) theory. The subsequent stages of the research remain deductive and quantitative, where the identified constructs and hypothesized relationships are empirically tested using multivariate statistical analysis.

4.6 Research Technique

This research engages quantitative research techniques as underlined by the research enquiries discussed in previous subtopics. The secondary data was collected by adopting literature review and subsequently, for the primary data collection, a questionnaire survey is used to further evaluate and validate the proposed generic framework towards completion. The chosen techniques are discussed as follows.

4.6.1 Literature Review

The literature review aims to generate knowledge of the existing issues in the industry and then ascertain the research problems and construction of research questions, aims and objectives. The literature review highlights issues surrounding the historic buildings conservation practice in Malaysia, by framing several contemporary issues that affects the energy and environmental performance of historic buildings, issues regarding the limitations and complexities surrounding current heritage conservation practice, with the unavailability of guidance to guide the best practice of heritage retrofits, and the complexities which hinders the ICT and IS technology such as HBIM in the practice of heritage building conservation.

This has caused the establishment of research aims and the related research objectives, as discussed in Chapter One. The objectives that have been delineated also require a more comprehensive literature review through content analysis to be operated in the first stage of literature review. The requirement is to create knowledge base concerning the historic retrofit, HBIM-retrofit and its relationship to the enhancement in performance of heritage building conservation projects in Malaysia, concentrating on concepts of the theories and fundamentals. A thorough literature review also aims to create a conceptual framework for this study. The function of the conceptual framework is necessary to aid the researcher in organizing the hypothesis and strategies for collecting data by highlighting the significant areas that must be identified or examined, as discussed in Chapter Two.

4.6.2 Questionnaire Survey

This study employed the questionnaire survey as the main method of collecting data. A combination of soft-copy and hardcopy questionnaires were distributed to respondents. As the sample size for the research is relatively small, the mode of data collection employed in this research is primarily using personally administered questionnaires. The main reason for employing such technique as it provides several advantages, for instance it can establish rapport, by having the opportunity to introduce the research topic and motivate the respondents to offer their frank answers. Personally administered questionnaire the ability to clarify any doubts, this is highly important for surveys with complex or technical questions, such as those involving detailed demographic information or specialized terminology in this case the historic building conservation field, personally administering the questionnaire allows researchers to provide assistance and ensure accurate responses.

Another advantage is that such technique often results in higher response rates compared to other methods, such as mail or online surveys (Sekaran & Bougie, 2019). Participants may be more inclined to complete a survey when approached in person, especially if the researcher can provide context and answer questions. However, such a method is time and effort consuming and the explanation to the respondents may introduce a bias to the data collection (Sekaran & Bougie, 2019). As questionnaire survey could introduce a much larger chance of no response and non-response error (Sekaran & Bougie, 2019), thus by directly interacting with participants, researchers will have the ability to monitor and control over the sample and the data collection process to ensure data quality. They can observe participants' responses, identify any errors or inconsistencies, and address them immediately.

4.6.2.1 Questionnaire Format

The aim and specific objectives of the research, as presented in Section 1.5, were considered in constructing the questionnaire survey. The questionnaire adopted Likert-scale formats for all survey items, as this approach is widely applied in quantitative research to measure respondents' perceptions and levels of agreement (Bryman, 2016). For a sequence of statements, respondents identify their level of agreement or disagreement on a symmetric scale, allowing the measurement of the strength of their perceptions and opinions towards a given item (MacDonald & Headlam, 2008).

A 5-point Likert scale was used for the independent variables (IVs), ranging from 1 "strongly disagree" to 5 "strongly agree", as it provides adequate response differentiation while maintaining simplicity and consistency in measuring the HBIM-retrofit constructs. The scale also supports effective distribution of responses and covariance analysis between variables. In contrast, a 7-point Likert scale was applied for the dependent variable (DV) related to project performance measurement, as wider scales provide greater sensitivity, variability, and discriminating power in evaluating performance-related perceptions and outcomes (Bryman, 2016).

Furthermore, the use of different Likert scale formats between the IVs and DV was intentionally adopted as a procedural remedy to reduce the risk of common method bias, as recommended by Podsakoff et al. (2003). Specifically, the 5-point Likert scale was used for the eight construct measures of the IVs, while the 7-point Likert scale was employed for the DV measures. Varying the response formats and scale anchors helps minimise respondents' tendency to provide repetitive or patterned responses across conceptually related constructs, thereby improving the reliability and robustness of the measurement instrument (Bhattacherjee, 2012; Mohamed, 2021).

For better understanding and clarification of the questionnaire survey as a research instrument, a narration of all variables, dimensions, and measurements used in constructing the instrument is presented in the following section

4.6.2.2 Operationalization

The questionnaire for the survey adapted the operationalized definition to establish the measurement of variables. According to Sekaran & Bougie (2019), in tabulating the identified construct (variables) and indicators of a research model, the research must firstly to develop the construct's operational definition. The construct is the main keyword of the research, and the construct is divided into two different variables, including endogenous variables and exogenous variables. The variable measurement table is developed for the indicator's measurement purposes.

Operationalization according to Sekaran & Bougie (2019), is defined as turning an abstract concept into measurable observations and operationalization is a systematic data collection on processes and phenomena that could not be observed directly. Operationalization is essential to remove ambiguity in concepts by specifying the operations by which they are to be measured. In other words, operationalization translates the verbal meaning provided by the theoretical definition into a prescription for measurement. According to Haucke et al. (2024), poor operationalization undermines validity and may lead to misleading conclusions of the study.

Given the high numbers of indicators in the proposed conceptual framework, it has suggested that this complex model can be operationalized at higher levels of abstraction also known as higher-order models or hierarchical model components (Hair et al., 2017). By operationalizing these constructs will allow more parsimony and reducing the research model complexity, complimenting the later stages of multivariate analysis (Hair et al., 2017). Cenfetelli & Bassellier (2009), propose grouping indicators into two or more distinct constructs (operationalized definitions). However, this approach requires the indicator groups to be conceptually aligned and that the grouping makes sense from theoretical and conceptual perspective. The operationalization process also served as an exploratory refinement stage to ensure that the identified constructs, variables, and indicators were conceptually grounded, theoretically aligned with the TTF framework, and contextually relevant to heritage building retrofit practice in Malaysia prior to quantitative measurement and validation.

As discussed in Chapter Three, the operationalized definitions of the constructs were adapted based on the underpinning task-technology fit theory (TTF). Hence, these constructs (historic building retrofit and HBIM-retrofit) are the main keywords of the study in which the task characteristics are defined as historic building retrofit and the technology functionality was represented by the HBIM-retrofit. Furthermore, the constructs expected to directly influence performance of heritage building conservation projects. These characteristics were then constructed as operationalized definitions as shown in Table 4.7. There are several research within the built environment context were identified using similar scheme for the tabulation of operationalized definitions for the measurement of variables and indicators (Lauro et al., 2024; Sonet et al., 2021).

Table 4.7
Operational Definition of the Construct (Author)

Term	Definition of Terms	Reference
Historic Building Retrofit Characteristics (Task Characteristic)	The processes and measures used to improve the energy and environmental performance of historic buildings while preserving their cultural, architectural, and material significance. Retrofit strategies may involve building fabric upgrades, systems improvements, innovative technologies, and passive design interventions. These measures must be selected with careful consideration of the building's unique heritage values, as well as technical, regulatory, and economic constraints. The overarching aim is to achieve an appropriate balance between energy efficiency and the protection of the building's historical integrity.	McCaig et al. (2018); Webb (2017); Troi et al. (2015); May & Griffiths (2015); British Standards Institution (2021)
HBIM-Retrofit Functionality (Technology Characteristic)	The application of Historic Building Information Modelling (HBIM) for the retrofit of historic buildings involves the integration of innovative technologies and modelling techniques to improve energy efficiency while preserving the architectural heritage of the buildings. The use of HBIM allows for the creation and management of comprehensive data (informational) sets related to the retrofit of heritage buildings, across its project lifecycle and involve all relevant stakeholders in the process. The implementation of HBIM in retrofitting projects has been shown to provide significant benefits in terms of energy savings, CO_2 emissions reduction, and operation costs compared to traditional systems.	Gigliarelli et al. (2022); Khaddaj & Srour (2014); Khodeir et al. (2016); Arayici et al. (2017); Antonoupulou (2017); Reeves et al. (2015)

4.6.2.3 Variables and Indicators

This research has identified the construct, variables and indicators of HBIM-retrofit framework for enhancing the performance of heritage building conservation projects in Malaysia. There are two identified constructs, including historic retrofit characteristics and HBIM-retrofit functionality. These constructs were further developed to their variables and indicators with the adaptation from the task technology-fit theory as a fundamental basis in measuring the path model identified from the literature review. Table 4.8 tabulates the variables and indicators related to the details of measurement for the questionnaire survey design in this research.

Table 4.8
Variables and Indicators (Author)

Variables	Construct and Operationalized Definition	Item Measurement	Indicators	Adapted Sources	Level of Measurement	Scale
Heritage Aspects (HA)	Historic Building Retrofit Characteristics	Practitioner's viewpoints on the heritage aspects in HB retrofit	HB Typology Values and Significance Principles of Intervention Regulations Multidisciplinary Stakeholders	May & Griffiths (2015); Harun (2011); JWN (2016); Webb (2017); Ali et al. (2018a); Bastian et al. (2014); Şahin et al. (2015); Heritage, (2007); Tokede et al. (2018); Buda et al. (2021); McCaig et al. (2018); Yarrow (2016); Troi et al. (2015); Galatioto et al. (2017); Mazzarella (2015); Zaid et al. (2021); Smith (2014); Wise et al. (2021); Conejos et al. (2019); British Standards Institution (2021); Historic Scotland (2021); National Park Service (2011); Ginks & Painter (2017); Ide et al. (2022); Feilden (2007); Almeida (2014); Ascione et al. (2017); Spigliantini (2020)	Ordinal Scale	5-point Likert Scale
Development Stage (DS)	Historic Building Retrofit Characteristics	Practitioner's viewpoints on the development stage in HB retrofit	Pre-Retrofit Stage Design Stage Implementation Stage Post-Retrofit Stage	Lee et al. (2020); Edwards (2021); McCaig et al. (2018); Historic Scotland (2021); May & Griffiths (2015); de Normalisation (2017); Leijonhufvud et al. (2021); British Standards Institution (2021); ASHRAE (2019); Pankaduwa (2024), National Park Service (2013); Polo López et al. (2018); Gigliarelli et al. (2022); Troi et al. (2015); Pocobelli et al., (2018); Webb (2017)	Ordinal Scale	5-point Likert Scale

Retrofit Design Criteria (DC)	Historic Building Retrofit Characteristics	Practitioner's viewpoints on the HB retrofit design criteria	Building Fabric Building System and Equipment User Behaviour Collections Economic Factor	IEA, (2013); Almeida (2014); McCaig et al., (2018); Li & Tingley (2023); Annibaldi et al. (2020); Sevim et al. (2025); Troi et al., 2015; de Normalisation (2017); Azouz & Elariane (2023); Gigliarelli et al. (2022); Iwuanyanwu et al. (2024); Historic England (2024); Ben & Steemers (2014); Lidelöw et al. (2019); Ercan (2018); Vicente et al. (2017); Guh & Altoontash (2006); English et al. (2021); Bansal (2018); Widström & Mattsson (2011); Webb (2017); Kass et al. (2017); Michalski (1994); Guo et al. (2023), ASHRAE (2011); Tétreault (2003); Loupa et al. (2010); López-Aparicio et al. (2011); Camuffo et al. (1999); Pigliautile et al. (2019); Ma et al. (2012). Tokede et al. (2018); Cirami et al. (2017); Tadeu et al. (2015); Ascione et al. (2017); Historic Scotland (2021); May & Griffiths (2015)	Ordinal Scale	5-point Likert Scale
Method of Approach (MA)	Historic Building Retrofit Characteristics	Practitioner's viewpoints on the method of approach in HB retrofit	Environmental Monitoring Microclimatic Analysis In-situ Measurement Laboratory Testing Building Performance Simulation Historical Documentation	ASHRAE (2011); Webb (2017); Cardinale et al. (2013); Gagliano et al. (2014); Gou et al. (2015); Posani et al. (2023); Xu et al. (2023); Lobarinhas et al. (2024); Knarud et al. (2023); Dang et al. (2025); Del Curto & Cinieri (2020); Seghier et al. (2022); Al Rasbi & Gadi (2021); Cornaro et al. (2016); Piselli et al. (2020b); Berg & Donarelli (2019); Magrini & Franco, (2016); Ascione et al. (2017); Broström (2021); McCaig et al. (2018); Troi et al. (2015); May & Griffiths (2015); Gigliarelli et al. (2022); GBI (2019). Polo López et al. (2021); Wise et al. (2021); Dias (2021); Rhee-Duverne & Baker (2013); Webb (2017); Organ, 2025; Historic England (2024); Blumberga et al. (2023); Yacub & Salleh (2025); Rossi & Bournas, (2023); Martín-Garín et al. (2020).	Ordinal Scale	5-point Likert Scale

Organizational (O)	HBIM-Retrofit Functionality	Practitioner's viewpoints on the organization aspect of HBIM	Roles and Responsibility Training and Education BIM Protocol	Gigliarelli et al. (2022); Antonopoulou & Bryan, (2017); Cheng, et al., (2014); Succar (2009); Charlton et al. (2021); Eastman, (2011); Brunott et al. (2022); Messner et al. (2019); Khalil et al. (2021); Nieto-Julián (2021); Ali (2018); Khalil (2017); Khaddaj & Srour (2016); Volk et al., (2014); Ouellette et al. (2022); Baik (2020); Capone & Lanzara (2019); Bruno (2018)	Ordinal Scale	5-point Likert Scale
Informational (I)	HBIM-Retrofit Functionality	Practitioner's viewpoints on the informational aspect of HBIM	Geometrical Evidential Pathology Surveying Energy Performance Structural	Khalil et al. (2021); Dore & Murphy (2012); Capone & Lanzara (2019); Brumana et al. (2019); Yang et al. (2019); Khan et al. (2022); Brunott et al. (2022); Dore et al. (2015); Jordan (2018); Lo Turco (2017); Zarogianni (2019); Arayici et al. (2017); Volk et al. (2014); Costantino (2023); Carvajal (2019); Moyano et al. (2022); Quattrini et al. (2017); Karlapudi (2018); Seghier et al. (2022); Bouzas et al. (2022); Mol et al. (2020); Valero et al. (2019)	Ordinal Scale	5-point Likert Scale
Process Lifecycle (PL)	HBIM-Retrofit Functionality	Practitioner's viewpoints on the process lifecycle of HBIM	Data Acquisition 3D Modelling Simulation and Analysis Design Visualization	López et al. (2018); Aglietti et al. (2023); Liu et al. (2023); Karasaka & Ulutas (2023); Dore & Murphy (2017); Capone & Lanzara (2019); Quattrini et al. (2018); Karlapudi (2018); Gigliarelli et al. (2017); Khodeir et al. (2016); Ouellette (2022); Solla et al. (2022); Ilhan & Yaman (2016); Ansah et al. (2019); Banfi (2020); Barazzetti et al. (2015); Banfi (2021); Stanga et al. (2023); Sutcliffe et al. (2019); Mastrolembo Ventura et al. (2020)	Ordinal Scale	5-point Likert Scale

Technical (T)	HBIM-Retrofit Functionality	Practitioner's viewpoints on the technical aspect of HBIM	Software Hardware Infrastructure Standards Data Exchange	Volk et al. (2014); Bruno & Roncella, (2019); Murphy et al. (2009); Brumana et al. (2019); Fai et al. (2011), Dore & Murphy (2017); Pocobelli et al. (2018); Lie et al. (2023); Fai & Rafeiro (2014); Gigliarelli et al. (2022); Antonopoulou & Bryan (2017), Messner et al. (2019); Reeves et al. (2015); Ouellette et al. (2022); Hull & Bryan (2019); Nieto-Julián, (2021); Baik (2020); Banfi (2021); Quattrini et al. (2018); Capone & Lanzara (2019); Bruno et al. (2018); Carvalho et al. (2019); Moyano et al. (2022); Khaddaj & Srour (2016); Karlapudi (2018); Stanga et al. (2023)	Ordinal Scale	5-point Likert Scale
Attributes of HBIM-retrofit model towards the performance of historic building conservation projects in Malaysia	HBIM-Retrofit influence on Performance	Practitioner viewpoint towards the attributes of HBIM-retrofit to influence the performance of historic building projects in Malaysia	Time Cost Quality Design Environmental Relationship Communication	Tahir et al. (2017); Samarghandi et al. (2016); Shehu et al. (2014); Li (2014); Selim & Ahmed (2018); Biagini et al. (2016); Ghosh (2015); Gigliarelli et al. (2017); Liu et al. (2022b); Egbelakin & Wilkinson (2008); Gholami et al. (2013); Rodrigues et al. (2019); Sholeh et al. (2020); Lu (2014); Chelson (2010); Shin et al. (2018); Ismail et al. (2015); Sacks et al. (2017); Mehndi (2020); Chaves et al. (2014); Meoni et al. (2022); Bruno & Roncella, (2019); Piselli et al. (2020a); Piselli et al. (2020b); Žurić et al. (2023); Hull & Bryan (2019); Nieto-Julián et al. (2021); Cross (2021); Gigliarelli et al. (2022); Charlton et al. (2021); Arayici et al. (2017); Karlapudi (2018); van Eldik et al. (2020); Wong & Zhou (2015); Alberini et al. (2013); Achtnicht & Madlener (2014); McGinley et al. (2022); Lizana et al. (2016); Baik (2017); Fai et al. (2011), Dore & Murphy, (2012); Argiolas et al. (2022); Baik (2020)	Ordinal Scale	7-point Likert Scale

Figure 4.4 shows the simple path model of the research. The path model shows the relationship between IV and DV of the research. The eight independent variables (IV) representing the lower order construct comprising the heritage aspect, development stage, retrofit design criteria, method of approach, organizational, informational, project lifecycle and technical and the performance is the dependent variable (DV). There are inner and outer models in the simple path model in the simple path model. The inner model consists of the research variables, and the outer model consists of the variables and indicators.

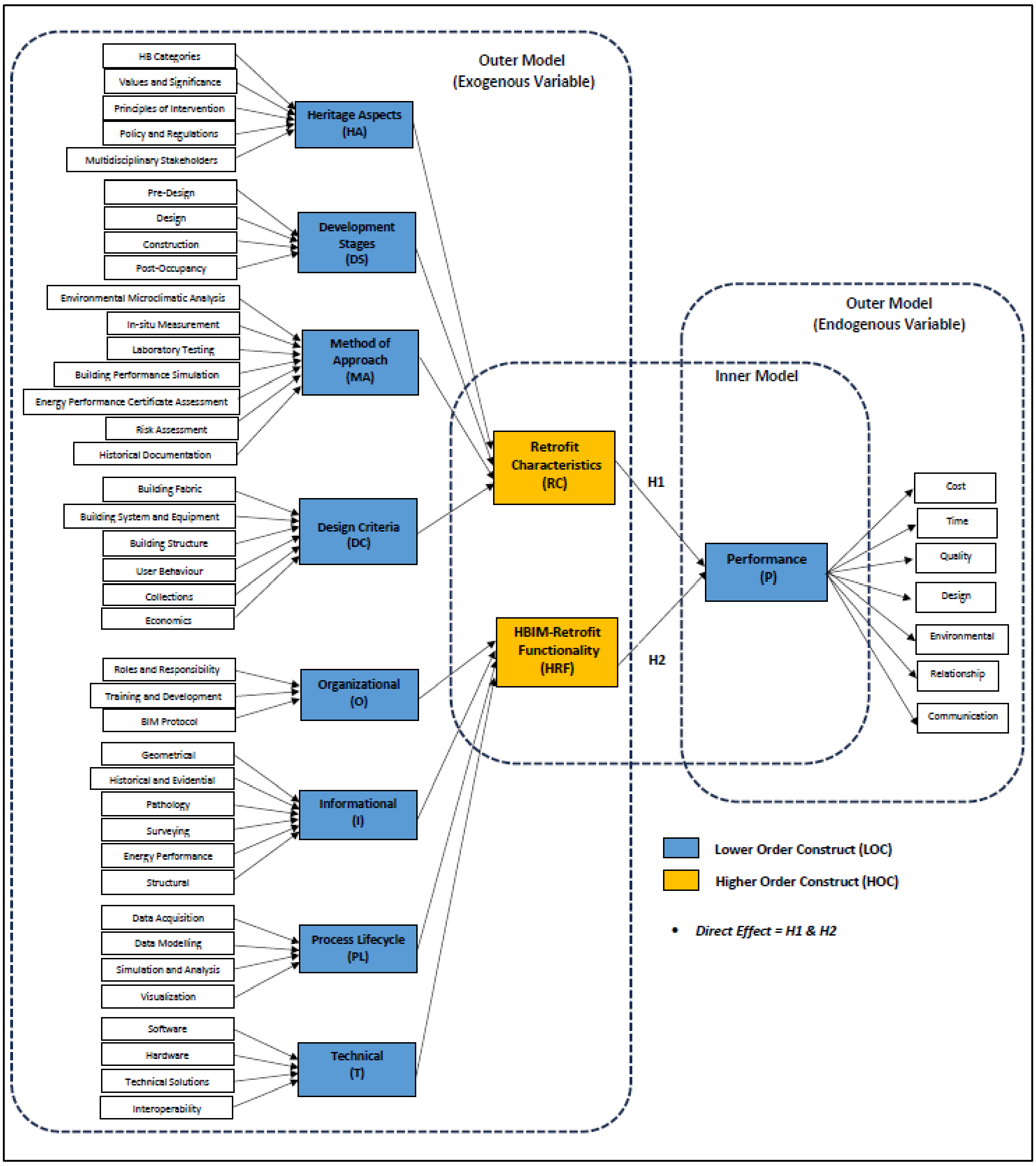

Figure 4.4 The Simple Path Model (Developed by Author)

4.6.2.4 Content

The concluding version of the questionnaire is categorized into five sections as shown in Table 4.9. The sections are as follows.

1) **Section A:** General Information gathered in this section for the purpose of data classification includes respondent's job title, years of experience involved in refurbishment project, general experience and knowledge of BIM, location of the company, and type of business.

2) **Section B:** The Historic Building Retrofit Attributes of Heritage Buildings in Malaysia: This part was designed to rank the scale of agreement on the historic building retrofit characteristics; thus the respondents need to indicate their opinion on the twenty-two indicators that have been grouped into four historic building retrofit construct and operationalized definitions as discussed in earlier section. This aims to forecast the attributes of historic retrofit from the perspective of historic building conservation practitioners.

3) **Section C:** The Historic Building Information Modelling (HBIM)-Retrofit Attributes of Heritage Buildings in Malaysia: This was part was designed to rank the scale of agreement on the HBIM-retrofit functionality, thus respondents need to indicate their opinion on the seventeen indicators that have been group into four categories, as constructed and operationalized in the earlier section.

4) **Section D:** The Project Performance in Historic-Building Information Modelling (HBIM)-Retrofit Adoption: In this section, respondents are required to rate their level of agreement on HBIM-Retrofit relationship in influencing the performance of heritage building conservation projects in Malaysia. It was designed to examine the level of participant contentment, with relation to their personal experience, motivation and viewpoints in delivering heritage building conservation projects. The presentation of performance in adopting HBIM-retrofit framework as discussed in section 2.5.

5) **Section E**: Closing: In this part, participants are permitted to leave an open-ended comment, hence offering qualitative inputs that enhance the richness and depth of the questionnaires.

Table 4.9
Questionnaire Format

Part	Description	Purpose	Number of Questions
A	General Information	Profile of respondents and their organizations	6
B	Historic Building Retrofit Characteristic	To measure the characteristics of historic building retrofit from the viewpoint of heritage building conservation professionals involved in similar retrofit projects.	-
	B1. Heritage Aspects	IV	5
	B2. Development Stages	IV	4
	B3. Retrofit Design Criteria	IV	6
	B4. Method of Approach	IV	7
C	HBIM-Retrofit Functionality	To assess HBIM-retrofit functionalities from the perspective of heritage building conservation professionals involved in historic building retrofit projects.	-
	C1. Organizational	IV	3
	C2. Informational	IV	6
	C3. Process Lifecycle	IV	4
	C4. Technical	IV	4
D	Performance	To investigate the influence of HBIM-retrofit attributes to heritage building conservation practitioners' project performance.	-
	D1. Overall Heritage Building Conservation Practitioners' Performance	DV	7
E	Comments	To provide qualitative inputs	1
	Total		53

4.6.2.5 Measurement of Variables

The measurement of variables consists of fifty three (53) survey items; whereby thirty nine (39) survey items were disseminated across the eight (8) independent variables (IV), and seven (7) survey items across the dependent variables (DV). Furthermore, the independent and dependent variables was categorized. The survey used Likert scales to measure the strength of agreement and disagreement. Moreover, two rating scales were used to measure the items in each variable. The scale used to measure the items in IV was 5 scales and for DV was 7 scales. The reason to use two different Likert scales was to control the common method biases as proposed by Podsakoff et al. (2003). The measurement of variable items were developed as follows:

i. Heritage Aspects (HA)

This survey questions were designed to determine the strength of agreement and disagrement on the indicators of heritage aspects (HA) that can be associated in the retrofitting of heritage building conservation projects in Malaysia.

No.	B1. The HERITAGE ASPECT attributes that should be taken into consideration in the design management of retrofitting historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	HISTORIC BUILDING TYPOLOGY (state or nationally defined classification framework organizing historic buildings by functions, values and characteristics to guide conservation and retrofit)					
2.	HERITAGE VALUES & SIGNIFICANCE (the recognition of tangible and intangible heritage values guiding retrofit decisions of historic buildings)					
3.	REGULATIONS (the compliance with policy, statutory, legal, and regulatory frameworks that govern heritage preservation while promoting sustainable retrofitting)					
4.	PRINCIPLES OF CONSERVATION (the adherence to the key principles in historic building conservation, eg. compatibility, reversibility, respect to authenticity, etc.)					
5.	MULTIDISCIPLINARY STAKEHOLDERS (the integration of diverse expertise to balance heritage values, technical performance, and sustainability in historic building retrofits)					

ii. Development Stages (DS)

This survey questions were designed to determine the strength of agreement and disagrement on the development stages (DS) that can be associated in the retrofitting of heritage buildings conservation projects in Malaysia.

No.	B2. The DEVELOPMENT STAGES attributes essential in the design management of retrofitting in historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	PRE-RETROFIT PHASE (the phase that encompasses preliminary research, surveys, project definition, and planning to guide appropriate retrofit strategies.)					
2.	RETROFIT DESIGN PHASE (which includes retrofit design development and detailed assessment of design objectives)					

3.	IMPLEMENTATION PHASE (which involves executing physical retrofit works, repair, upgrading, and integration aligned with conservation principles, supervision, and design specifications.)					
4.	POST-RETROFIT PHASE (which ongoing monitoring, evaluation, feedback, and maintenance ensuring retrofit effectiveness and heritage preservation.)					

iii. Retrofit Design Criteria (DC)

This survey questions were designed to determine the strength of agreement and disagrement on the significance of the retrofit design criteria (DC) that can be associated in the retrofitting of heritage buildings conservation projects in Malaysia.

No.	B3. The significance of RETROFIT DESIGN CRITERIA that can be associated with the retrofitting of historic buildings in Malaysia.	Strongly Disagree			Strongly Agree	
		1	2	3	4	5
1.	BUILDING FABRIC (retrofit measures on thermal and energy performance of building envelopes including walls, floors, roofs, windows, doors and materials.)					
2.	BUILDING SYSTEMS AND EQUIPMENT (efficiency of HVAC, lighting, and appliances through smart, adaptable, and low-carbon technologies ensuring reduced energy use while preserving heritage integrity)					
3.	BUILDING STRUCTURE (interventions to evaluate structural integrity, safety, and resilience ensuring stability, durability, and adaptability in retrofit strategies)					
4.	USER BEHAVIOUR (assessment of occupants' energy-use patterns, comfort expectations, and management practices influencing retrofit performance in historic building)					
5.	COLLECTIONS (strategies to safeguard valuable objects (eg. artifacts) from environmental risks, pollutants and climatic fluctuations in historic building)					
6.	ECONOMIC FACTORS (evaluates project feasibility, funding, and cost-effectiveness of retrofit measures while sustaining heritage and energy performance)					

iv. Method of Approach (MA)

This survey questions were designed to determine the strength of agreement and disagrement on the significance of the method of approach (MA) that can be associated in the retrofitting of heritage buildings conservation projects in Malaysia.

No.	B5. The METHOD OF APPROACH associated in the assessment for retrofitting historic buildings in Malaysia.	Strongly Disagree			Strongly Agree	
		1	2	3	4	5

1.	ENVIRONMENTAL MONITORING AND ANALYSIS (**p**rovide microclimatic monitoring and assessment of indoor and outdoor conditions of historic buildings)					
2.	IN-SITU MEASUREMENT (**t**he condition measurement and assessment of original and natural state of historic buildings)					
3.	LABORATORY TESTING (**c**ontrolled assessments of historic materials' mechanical, thermal, and hygrothermal properties to validate retrofit compatibility)					
4.	BUILDING PERFORMANCE ANALYSIS (**d**ynamic computational tools to assess energy and hygrothermal performance for optimizing compatible historic retrofit interventions)					
5.	ENERGY PERFORMANCE CERTIFICATE ASSESSMENT (**s**tandardized certification tools assessing energy and environmental performance to guide sustainable historic retrofits (eg. GBI)					
6.	RISK ASSESSMENT (**t**he evaluation of potential impact and benefits associated in the retrofitting of historic buildings)					
7.	HISTORICAL DOCUMENTATION (involving the analysis of records, photos, and drawings to guide accurate and heritage-preserving retrofits)					

v. HBIM Organizational (HO)

This survey questions were designed to determine the strength of agreement and disagreement on the HBIM organizational (O) attributes that can be associated in the HBIM-retrofit framework for heritage buildings conservation projects in Malaysia.

No	C1. The ORGANIZATIONAL attributes to be considered in HBIM-enabled retrofitting of historic buildings in Malaysia	Strongly Disagree			Strongly Agree	
		1	2	3	4	5
1.	ROLES & RESPONSIBILITY (establish clear organizational roles to ensure accountability, coordination, and effective collaboration in multidisciplinary HBIM retrofit projects.)					
2.	TRAINING AND EDUCATION (the development and support of HBIM-retrofit to build capacity of knowledge, skills and competency)					
3.	BIM PROTOCOL (establish standardized frameworks for data integrity, legal clarity and collaboration agreement for HBIM-retrofit)					

vi. HBIM Informational (I)

This survey questions were designed to determine the strength of agreement and disagreement on the HBIM informational (I) attributes that can be associated in the HBIM-retrofit framework for heritage buildings conservation projects in Malaysia.

No	C2. The INFORMATIONAL attributes to be associated in the management of HBIM-enabled retrofitting of historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	GEOMETRICAL DATA (which includes building 2D and 3D data such as shape, size, location, and parametrical information)					
2.	HISTORICAL AND EVIDENTIAL DATA (which includes the historical archives and records, chronologies, ownership, land matters and photos information)					
3.	PATHOLOGY DATA (which includes building's decays, cracks, defects, deterioration, and structural information)					
4.	SURVEYING DATA (which includes existing data capture such as terrestrial 3D laser scanning data, point cloud data and photogrammetry data)					
5.	ENVIRONMENTAL PERFORMANCE DATA (which includes energy, material properties, thermal and environmental performance information)					
6.	STRUCTURAL DATA (which include information related to building structural composition and construction)					

vii. HBIM Process Lifecyle (PL)

This survey questions were designed to determine the strength of agreement and disagrement on the HBIM project lifecycle (PL) attributes that can be associated in the HBIM-retrofit framework of heritage buildings conservation projects in Malaysia.

No.	C3. The PROCESS LIFECYCLE involved in documenting HBIM-enabled retrofitting of historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	DATA ACQUISATION (the HBIM techniques and process of existing site and building capturing for retrofitting of historic buildings)					
2.	3D MODELLING (The techniques and process of geometrical, numerical, parametrical, and documentary modelling of historic buildings)					
3.	DATA SIMULATION AND ANALYSIS (which includes the whole lifecycle building performance evaluation in historic buildings, eg. energy, cost, time, sustainability)					
4.	DESIGN VISUALIZATION (which include the visualization techniques and process such as Augmented Reality (AR), Virtual Reality (VR) and Extended-Reality)					

viii. HBIM Technical (HT)

This survey questions were designed to determine the strength of agreement and disagreement on the HBIM technical attributes (T) that can be associated in the HBIM-retrofit framework of heritage buildings conservation projects in Malaysia.

No.	C4. The TECHNICAL attributes to be associated in the HBIM-enabled retrofitting of historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	SOFTWARE (The initial investment and operational cost of HBIM software and applications)					
2.	HARDWARE AND INFRASTRUCTURES (The initial and operational investment of physical tools and equipment related to HBIM-retrofit such as 3D laser scanners, PC, VR technology)					
3.	STANDARDS (Guide HBIM information accuracy, modelling practices, and semantic consistency through frameworks such as Level of Detail (LOD) and BIM object standards)					
4.	DATA EXCHANGE (which includes technical manual for HBIM-retrofit data compatibility, sharing and interoperability)					

ix. Performance (DP)

This survey questions were designed to determine the strength of agreement and disagreement on the performance (DP) attributes that can be influenced from the adoption of HBIM-retrofit framework for heritage buildings conservation projects in Malaysia.

No.	D1. In adopting HBIM-enabled retrofitting, I believe the design management PERFORMANCE in conserving historic buildings was grounded in..	Strongly Disagree						Strongly Agree
		1	2	3	4	5	6	7
1.	The design project TIME can be significantly reduced.							
2.	The associated COST to the project were substantially reduced.							
3.	The accuracy and QUALITY of the design output was successfully achieved.							
4.	The overall ENVIRONMENTAL impact can be significantly reduced or accomplished.							
5.	The flexibility in historic building retrofit DESIGN can be successfully attained.							
6.	Effective and positive RELATIONSHIP among the project team members/stakeholders can be increasingly satisfied.							
7.	The COMMUNICATION and understanding among the project collaborators were significantly facilitated and enhanced.							

4.6.3 Validity and Reliability of Research Instruments

The validity and reliability of a research instrument are essential to ensure accurate and consistent measurement of constructs. Validity assesses whether the instrument truly captures what it intends to measure, while reliability examines the consistency of results across contexts. In this study, both aspects are evaluated through established statistical tests to confirm that the indicators and constructs are theoretically grounded and empirically dependable.

4.6.3.1 Face Validity of Research Instruments

The face validity of the instruments used in the study was implemented prior to the pilot study. The purpose of applying such method is to identify unclear and ambiguos questions by validating and pre-testing the preliminary questionnaire with selected experts. Babbie (2020), stated that face and content validity means the rate an instrument displays its meaning imbedded in particular concept. Moreover, face and content validity includes getting the opinions of some experts or prospective panels over wordings, clarity and phrases of items in the study (Sekaran & Bougie, 2019). Hence, seven experts were selected and interviewed for this study.

There is no specific criteria in selecting the panellist for face validity unlike content validity (Lawshe, 1975), however according to Creswell & Creswell (2017), the selection of experts, can consists of 5 to 25 individuals to ensure validity. Furthermore, Patel & Desai (2020) suggested a number of 6 to 12 individuals would provide enough and good recommendation for a face and content validity exercise, hence the numbers of experts appointed for this study are sufficient. Table 4.10 illustrates the profile of experts who validated the instrument.

Table 4.10
Expert Validator's Profile

No.	Designation	Organisation	Experience
1	Managing Director	HBIM Consultancy	25 years
2	Chief Executive Officer	HBIM Consultancy	21 years
3	Conservator	Heritage Consultancy	20 years
4	Conservator	Government Agency	12 years
5	Associate Professor	Private University	20 years
6	Associate Professor	Private University	30 years
7	Associate Professor	Public University	13 years

The face and content validity exercise was conducted between 5–17 October 2024. Prior to the meeting session, an email was sent to respective panels explaining the purpose and official invitation to participate the face and content validity session were givem. During the interview session, the questionnaires were handed over in the form of hardcopies to the experts at their respective offices. The process tooks around 30 minutes to 1 hour for the experts to validate the instruments, depending on the time available. The experts were asked to determine whether the questions are clear, relevance and whether the items specified collectively represents the measured elements. Hence in capturing such elements, every experts are required to answer the ten (10) questions below, by evaluating and rate the following questionnaire's face criteria (Patel & Desai. 2020);

- Q1 – Appropriateness of grammar
- Q2 – The clarity and unambiguity of items
- Q3 – The correct spelling of words
- Q4 – The correct structuring of the sentences
- Q5 – Appropriateness of font size and space
- Q6 – Legibility of the printout
- Q7 – Adequacy of instructions on the instrument
- Q8 – Structure of instrument in terms of construction and well-thought out format
- Q9 – Appropriateness of difficulty level of the instrument for the participants
- Q10 – Reasonableness of items in relation to the supposed purpose of instrument.

When conducting the face validity, the selected expert's panel are required to respond by indicating their agreement to each of the questionnaire's face criteria. The criteria for face validity are based on the sets of criteria according to Patel & Desai (2020). The questions to pose the experts are determined to measure the following items. Hence, Table 4.11 illustrates the data collected by the expert's panel and the percentage rate per question agreement.

Table 4.11
Response Compilation from Face Validity

Experts Panels	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Expert A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Expert B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Expert C	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Expert D	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Expert E	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Expert F	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Expert G	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
% of per Question Agreement	100%	86%	100%	100%	86%	100%	86%	100%	100%	100%
Percentage of Overall Agreement (%)								96%		

In determining whether the questionnaire requires any revision, the study follows the interpretation and acceptability of percentage of agreement scale as proposed by Patel & Desai (2020). As shown in Table 4.12, the suggested actions consists whether to retain, redefine or restructure the area covered under per question and entire tool. According to the results in Table 4.11, the percentage of overall agreement is above 90% hence suggeting the questions for entire tool are retained. Furthermore, the questionnaire will be modified along with considering the remark(s) from each rater.

Every experts are encouraged to provide written comments in the remarks section of the face validity form. Once the questionnaire is revised, it should be send back to all rater for their reference. Table 4.13 shows the responses received from the experts on the preliminary questionnaire created. Their feedback was used to reorganize the questionnaire, as there were adjustments in Section A to E of the questionnaire. After that the questionnaire were sent for pilot testing.

Table 4.12
Interpretation and Acceptability of Percentage of Agreement

% of Agreement	Strength of Agreement per question or overall	Action for each Question/ entire tool
< 80	Poor	Restructure
80 – 90	Substantial	Revise
90 - 100	Full	Retain

Table 4.13
Expert's Comments During Face Validity

Expert Panels	Comments (Remarks)	Adjustment made
Expert A	The overall questions are clear and easy to understand.	No amendments made
Expert B	In summary, omitting the section on the level of awareness and usage of HBIM from the questionnaire would result in a significant loss of critical information regarding the awareness, usage, and perception of HBIM among conservation practitioners in Malaysia. This section provides foundational data that informs the current state of HBIM adoption, its benefits and challenges, and the training needs of professionals. Including knowing the level of awareness and usage of HBIM amongst the sampling is essential for a comprehensive assessment of how HBIM can enhance the performance of conservation projects in Malaysia.	The items suggested by the expert panel have been included in the questionnaire
Expert C	To provide definition of retrofitting at the beginning of the survey form. Clearly emphasis on how HBIM can be incorporated in current conservation guidelines, legislation (Act, Enactment or Ordinance) and work method statement. Indicate the importance of HBIM in GBI, UD, SDG and/or data repository. Some terminology in the questionnaire is very technical, suggest rephrasing so for better clarity to the respondents.	The items suggested by the expert panel have been included in the front cover of the questionnaire and discussed in literature review. The questionnaire has been rephrased accordingly.
Expert D	To remove the answer, 'I am not involved' in question 4 as the respondents need to have at least 3 years of experience. Please include the list of definitions of the terms together with the questionnaire so that it will improve the clarity.	The items suggested by the expert panel have been included accordingly in the questionnaire.
Expert E	The overall questions are clear, however there are some comments to address in question 1, to include all the states in Malaysia, to clearly assess the level of familiarity in scale from 'rarely to very well' in question 6 and to add the role of surveying consultants in the list of job title in question 2.	The items suggested by the expert panel have been included accordingly in the questionnaire.
Expert F	To add definition of retrofitting in comparison with other conservation approaches. The indicator item on 'collections' in the retrofit design criteria need to be explained clearly and more specific.	The items suggested by the expert panel have been included accordingly in the questionnaire.
Expert G	I would suggest the researcher includes 'historical documentation' in the method of approach section. The item inclusion is to understand the origins of the design, materials, and past modifications, ensuring structural integrity and authenticity. Historical documentation reveals a building's condition over time, facilitates accurate reconstruction, and balances preservation with modernization.	The items suggested by the panel have been included according to order in the questionnaire.

Hence based on the face validation exercise, one new item were suggested by Expert G. The new item suggested under the method of approach variable and the literature review for the item is discussed below.

i) Historical Documentation

Historical documentation plays a critical role in guiding retrofit interventions for historic buildings by providing evidence of original design, material use, and past modifications. Archival records such as drawings, photographs, and maintenance logs establish a reliable baseline that, when combined with modern survey techniques, enables accurate diagnosis and planning. Recent studies emphasize that retrofits relying on historical documentation are more effective in safeguarding authenticity while addressing performance upgrades. (Chelaru et al., 2024) demonstrated how integrating point clouds, archival records, and condition assessments within HBIM allows for precise correlation of past and present conditions, reducing risks of inappropriate interventions.

Similarly, Lucchi & Agliata (2023) applied HBIM workflows enriched with documentation to design compatible photovoltaic retrofits, ensuring reversibility and visual protection of heritage character. (Gugliermetti et al., 2025) further illustrated how archival evidence informed the HBIM reconstruction of the Casina Cenci Giustiniani in Rome, establishing a decision-support tool for future conservation and retrofit. Beyond design, historical documentation informs risk management and construction phasing, as shown in HBIM emergency applications where archives guided safe stabilization and subsequent retrofit strategies. Moreover, bibliometric reviews (Penjor et al., 2024; Khalil et al. 2021) highlight documentation as a cornerstone of knowledge-centric HBIM, ensuring decisions are traceable and acceptable to regulators.

4.6.3.2 Content Validity of Research Instruments

The content validity of the instruments were also used prior to the pilot study. Content validity is defined as the degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose (Haynes et al., 1995; Cook & Beckman, 2006). The content validity evidence can be represented by the content validity index (CVI) (Davis, 1992; Polit & Beck, 2006; Polit et al., 2007; Lynn, 1986), for instances, several recent studies (Hadie et al., 2017; Marzuki et al., 2018; Lau et al., 2018) established the content validity using CVI to support the validity of an assessment tool.

Based on the evidence, this study describes the best practice to quantify content validity of an assessment tool using CVI. For these, each items in the questionnaire underwent content validation (CVI), in which a total of nine (9) domains namely; heritage aspects, development stages, retrofit design criteria, method of approach, organizational, informational, process lifecycle, technical and performance, were assessed for its relevance and representativeness by the selected panel of expert. Moreover, the expert panels were required to rate each items in the measured domain based on a Likert scale ranging from 0 (i.e., not relevant or not represent) to 4 (i.e., highly relevant or highly represent).

The selection of individual to review and critique an assessment tool is usually based on the individual expertise with the topic to be studied, as shown earlier in Table 4.10. Ozair et al. (2017), recommended that every questions items were tested using the content validation index (CVI), in which the CVI needs to above the acceptable values in ensuring content validity of research instrument. Table 4.14 summarises the recommended number of experts with its implication on the acceptable cut-off score of CVI, hence for test that include seven (7) experts, the acceptable CVI values must be at least 0.83 (Polit et al., 2007; Lynn, 1986).

Table 4.14
The Number of Experts and its Implication on the Acceptable Cut-off Score of CVI

Number of Experts	Acceptable CVI Values	Source of Recommendations
Two experts	At least 0.80	Davis (1992)
Three to five experts	Should be 1	Polit & Beck (2006), Polit et al. (2007)
At least six experts	At least 0.83	Polit & Beck (2006), Polit et al. (2007)
Six to eight experts	At least 0.83	Lynn (1986)
At least nine experts	At least 0.78	Lynn (1986)

The collected raw data were inserted in Microsoft Excel and calculation were made to estimate the item-level content validity index (I-CVI); scale-level content validity index (S-CVI); scale-level content validity index, universal agreement calculation method (S-CVI/UA); and scale-level content validity index, averaging calculation method (S-CVI/Ave). Polit et al. (2007) recommended that each item rated as 3 or 4 were converted to valid ('1') and item rated as 0, 1 or 2 were converted to non valid ('0'). Individual item assessment (I-CVI) and average (S-CVI/UA) of each item will be taken into consideration during the data calculation. The additional universal agreement (S-CVIA/UA) would facilitate the assessment of inter-rater reliability. The summary of ratings and S-CVI (Ave) and S-CVI (UA) score are shown in Table 4.15 below.

Table 4.15
The Relevance Ratings on Domain Scale by Experts

No.	Domain/Construct	Variable	Number of Items Measures	S-CVI (Ave)	S-CVI (UA)
1	Heritage Aspect	IV	5	1.00	1.00
2	Development Stages	IV	4	1.00	1.00
3	Retrofit Design Criteria	IV	6	0.98	0.83
4	Method of Approach	IV	7	0.98	0.86
5	Organizational	IV	3	1.00	1.00
6	Informational	IV	6	1.00	1.00
7	Process Lifecycle	IV	4	1.00	1.00
8	Technical	IV	4	1.00	1.00
9	Performance	DV	7	0.98	0.86

Based on the above calculation, none of the I-CVI, S-CVI/Ave and S-CVI/UA are below the acceptable CVI values (0.83), hence the study can conclude that all the items in each of domains meet the satisfactory level, and thus the scale of questionnaire items has achieved satisfactory level of content validity.

4.6.3.3 Reliability of Research Instruments

According to Cronbach (1951), the foremost essential element for researcher is to attain a satisfactory level of reliability in the research instrument. To obtain the level of reliability, a pilot study was conducted for this research. Bryman (2016) stated that it is preferable to conduct a pilot study before managing a self-completion of questionnaire. This is parallel to the views of Siniscaco & Aurit (2015), who believes that the benefit of running a pilot study includes providing a trial run for the questionnaire. Other than obtaining respondent's feedback, the pilot test also offers the ability to view each question's reliability rate.

Significantly, Bryman (2016) recommends that every question's internal reliability be tested using the Cronbach's Alpha' method. In Cronbach's Alpha's, reliability is measured from 0 (no internal reliability) to 1 (perfect internal reliability). Normal reliability reading is rated 0.9 below. Cronbach (1951) points out that the reading of 0.6 to be minimum level of reliability, while 0.7 being an acceptable level and 0.8 a good standard to be achieved. The suggested Cronbach's Alpha value and internal consistency employed in this study is in line with Cronbach (1951) and the summary is shown in the Table 4.16.

Table 4.16
Cronbach's Alpha Rule of Thumb

Cronbach's Alpha	Internal Consistency
$\alpha \geq 0.9$	Excellent
$0.8 \leq \alpha < 0.9$	Good
$0.7 \leq \alpha < 0.8$	Acceptable
$0.6 \leq \alpha < 0.7$	Questionable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

A pilot study was conducted from 9 December 2024 – 14 January 2025 and is covering 30 randomly selected respondents. This is in line with the suggestion by Johanson & Brooks (2010), which mentioned that 30 participants representing the population is a realistic minimum number suggested for a pilot study. The function of the pilot study was to conduct an initial survey or scale development to ascertain vague questions and offer quick test of the method of collection. The pilot survey was distributed to 40 practitioners of heritage building conservation. When returned questionnaires reached 30 units, the analysis was conducted to test its reliablity. According to the minimum endorsement suggested by Johanson & Brooks (2010), the Cronbach's Alpha reliability test was used. The results of the reliability test can be viewed in Table 4.17.

Table 4.17
Results of Reliability Test Based on Pilot Survey

No.	Construct	Variable	Number of Items Measures	Cronbach's Alpha
1	Heritage Aspect	IV	5	0.874
2	Development Stages	IV	4	0.780
3	Retrofit Design Criteria	IV	6	0.773
4	Method of Approach	IV	7	0.770
5	Organizational	IV	3	0.879
6	Informational	IV	6	0.897
7	Process Lifecycle	IV	4	0.880
8	Technical	IV	4	0.936
9	Performance	DV	7	0.906

The pilot survey contains thirty nine questions (measured items) for independent variables (IV) and seven questions for the dependent variables (DV). Every questions is categorized according to the construct in Chapter Two. This indicates that the reliability of all the questions are in the category of acceptable, good and excellent, as stated by (Cronbach, 1951). The feedback was very useful and specified that the survey instrument can probably work as intended. However, the results obtained from the actual respondents might be unlike the pilot test. Accordingly, this research still observes the belief that real research follows the suggested process and anything that might possibly come out about beyond anticipation may be regarded as a discovery from an opposing viewpoint. After the pilot study, minor alterations were made on the wording of questions to ensure clarity of the research instrument.

4.6.4 Sampling Technique

Two methods were used in determining the sample size for this study namely the use of G-power analysis and Raosoft sample size calculator. The following are the detailed discussions on the two methods applied in the study to acertain the size of sample for this study.

4.6.4.1 Power Analysis using G-power Statistical Analysis

Determining an appropriate sample size requires careful consideration. An insufficient sample may fail to detect significant effects that truly exist in the underlying population, thereby increasing the risk of committing a Type I error, where a valid hypothesis is falsely rejected (Sekaran & Bougie, 2019; Hair et al., 2017). Sekaran & Bougie (2019), mentioned that studies must avoid sample sizes that are too large so that they can be free from the chances of Type II error, implying the acceptance of a particular hypothesis while it ought to be declined in the first place.

Therefore defining a careful and feasible sample size from the total number of research sample entails an outstanding method like the statistical power test, among the most practical instruments in determining sample size. Chin (2013), points out that the power of a statistical test denotes the prospect of eliminating an invalid hypothesis or declining a particular descriptive size of a specific sample size at a certain primary level. Hence, the assessment is able to ascertain variances in a broader population, in case it exists. Ramalu (2010), argues that when alternative methods are taken on to define the size of a research sample, it is similarly advisable to apply power analysis in order to identify the effects of varying sample sizes. Specifically, Hair et al. (2017) suggested for a multiple regression models where the idea is to measure the linear relationship between one dependent and two or more independent variables, the required sample size should be determined by means of power analyses based on the part of the model with the largest number of predictors (Kock & Hadaya, 2018).

As a result, a priori power analysis was carried out utilizing the G*Power 3.1 software to determine the sample size of the study, where sample size (N) was figured as a role in the pre-requisite power level (1-β), the pre-decided rate of significance α, and the effect size of the population which will be decided with probability 1-β. In a priori test, statistical power is proficiently organized prior to the implementation of the real research (Faul et al., 2007). Furthemore, the priori power analyis applied with the aid of G*Power 3.1 software package (Faul et al., 2007) adopts Cohen's (2013) standards in this research to gauge the size of sample. Cohen (2013), provides a detailed guidance on how to use these variables to choose a minimum necessary sample size for multiple regression users aiming to achieve a given level of statistical power. This comprises: effect size (f^2= 0.15); significance alpha level (α= 0.05); anticipated statistical power (1-β = 0.80); and a sum of 2 predictors (historic building retrofit characteristics and HBIM-retrofit functionality).

Gefen et al. (2011) noted that, within the social sciences, a statistical power of at least 80% is conventionally regarded as the minimum acceptable threshold, thereby justifying the anticipated power level for this research. By referring to Figure 4.4, the test outcome data showed that for this study to reach a data analysis of linear multiple regression with a minimum sample of n= 68 is required.

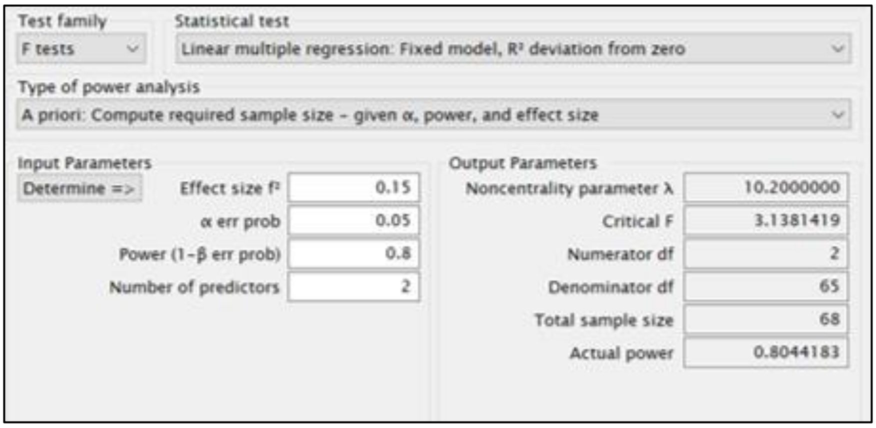

Figure 4.5 Power Analysis for Medium Effect

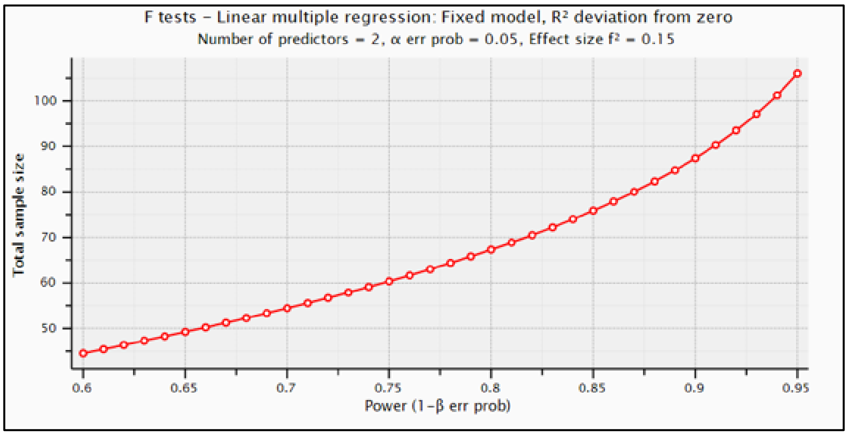

Figure 4.6 X-Y lot for Medium Effect Power Analysis

4.6.4.2 Raosoft© Sample Size Calculator

Moreover, a comprehensive scientific parameter to determine the sample size from a particular population is conducted. Apart from power analysis, determining a sample size that includes considerations of the total population was employed. The determination of a sample size includes making decisions on the total of observations to be included in a sample by applying suitable method of sampling (Awang, 2012).

Methods of sampling are generally categorized into two groups which is probability and non-probability sampling techniques (Kumar et al., 2011).

The probability sampling technique reflects a procedure wherein every element within a targetted population to have an identified, equal and fixed chance of being selected as a sample for the study (Sekaran & Bougie, 2019). On the other side, the non-probability technique refers to a procedure where the selection of a sample depends on the researcher's judgement and not on random selection. For this study, This study utilises a non-probability sampling approach. Due to the specialised nature of the research, respondents were selected based on their professional expertise and involvement in heritage building conservation practice.

Furthermore, purposive, convenience, snowball, quota, self-selection, and theoretical sampling are among the most commonly referenced non-probability sampling techniques (Creswell & Creswell, 2017; Saunders et al., 2024). After considering the characteristics of the target respondents, purposive sampling was deemed the most appropriate method for this study. To ensure that the collected data were both reliable and adequate, it was essential to select a population with the necessary professional experience and domain-specific knowledge in heritage conservation and retrofit practice. Hence, a representative profile of industry practitioners was also required.

Accordingly, the study adopted a multiple-frame sampling approach (Metcalf & Scott, 2009; Hartley, 1974), by combining several organisations into one population frame: (i) registered conservators listed in the National Heritage Department (NHD) registry and (ii) individual members of ICOMOS Malaysia. The most recent NHD registry for 2024–2026 includes 65 conservators, while ICOMOS Malaysia lists 75 individual professionals with at least three years of experience in heritage building conservation works. Membership lists from these organisations were combined to form the sampling frame with a total population size (N) of 140 for this research.

The population was selected primarily due to their specialized knowledge, skills, experience, and regulatory compliance in the field of historic building conservation. These professionals possess expertise in assessing and maintaining historic buildings using various tools and methods, making them invaluable for studying HBIM technologies' application in retrofit. Their practical insights into historic building's complexities and engagement with various project stakeholders ensure a comprehensive representation of perspectives and interests. Additionally, involving registered conservators addresses the ethical considerations inherent in heritage preservation research and facilitates the development of practical, implementable solutions in the development of research.

Furthermore, a sample size determination using Raosoft® sample size calculator was also explored to further strengthen the determination of sample size with the inclusion of margin of error, confidence level, total population size and response distribution. As shown in 4.7, the recommended sample size is 93.

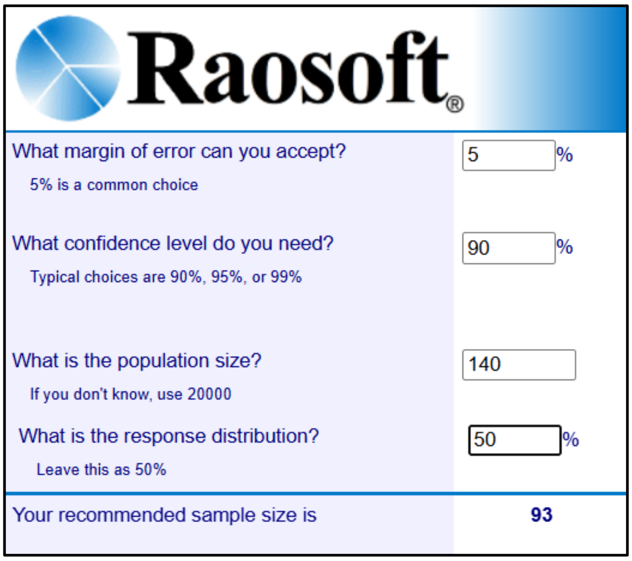

Figure 4.7 Raosoft® Sample Size Calculator

Table 4.18
Population and Recommended Sample Size

Individual	Population (N)	Required Sample (n)	Percentage (%)
Heritage Building Conservation Professionals in Malaysia	140	93	66%

4.6.4.3 Unit of Analysis

The unit of analysis concerns the subjects considered in a certain study. In management, units of analysis are separated into individual, organization and group (Cresswell & Clark, 2017; Kassim et al., 2012). According to Sekaran & Bougie (2019), sampling subjects should be selected based on their proficiency in the field and familiarity with the research problems, questions and objectives. In relation to the present study, the unit of analysis consists of professionals who are specialized and experienced in heritage building conservation works and are registered with relevant heritage conservation bodies as stated previously.

The unit of analysis comprises individuals from various professional and organizational roles, including Directors, Project Managers, Architects, Engineers, BIM Managers, and conservation practitioners holding both specialized and managerial responsibilities. The selected individuals must possess experience in historic building preservation, retrofit interventions, or related conservation activities such as adaptive reuse, refurbishment, and rehabilitation works. Although not all respondents are direct HBIM specialists, the selected professionals possess relevant expertise and practical exposure in heritage conservation, retrofit implementation, multidisciplinary coordination, project management, and digital information processes associated with historic building projects.

This consideration is important as the proposed HBIM-retrofit framework extends beyond software application alone and encompasses broader historic retrofit characteristics, informational requirements, technical coordination, and project performance dimensions within heritage conservation practice. Therefore, professionals involved in heritage retrofit and conservation projects are considered appropriate and relevant units of analysis for evaluating the proposed HBIM-retrofit framework in enhancing the performance of heritage building conservation projects in Malaysia.

4.6.5 Data Collection Procedure

Further to the pilot survey discussed earlier, this study concentrates on the data collection method used for the actual final survey. The research problem generally determines the choice of data collection method (Sekaran & Bougie, 2019). However, limitations of resources, restricted access to respondents and information, as well as the scope and depth of the study also play important roles in determining the appropriate data collection approach (Mohamed et al., 2012). This study employed two sources of data collection, namely primary and secondary data. The primary data were gathered through a structured questionnaire survey distributed among the potential respondents of the study.

The questionnaire instrument comprised four components, namely the subject information sheet, cover letter, consent form, and questionnaire form, which were prepared in both English and Bahasa Malaysia. The questionnaire distribution was conducted through a combination of face-to-face sessions and online platforms via email for respondents who were unavailable for physical meetings. During the face-to-face sessions, the researcher introduced himself as a PhD researcher from Universiti Teknologi MARA and briefly explained the purpose and objectives of the study.

In ensuring ethical research practice, respondents were first requested to read the subject information sheet before voluntarily agreeing to participate in the study by signing the consent form. The information sheet clearly explained the purpose of the research, the voluntary nature of participation, confidentiality of the responses, anonymity of respondents, and the respondents' right to withdraw from the study at any stage without any consequences. Respondents were also informed that the collected data would be used solely for academic and research purposes.

The researcher ensured that respondents participated willingly and without coercion throughout the data collection process. Respondents were allowed to seek clarification regarding any part of the questionnaire before responding. The researcher also remained sensitive to the respondents' verbal and non-verbal reactions during the survey session. Any indication of discomfort, unwillingness, or hostile response resulted in the immediate and respectful termination of the interaction without recording any personal identification or response information.

Upon completion, all returned questionnaires were reviewed for completeness, and only completed responses were coded and keyed into IBM SPSS 27 software for data analysis purposes. All collected data were securely stored and handled confidentially to ensure compliance with research ethics and data protection practices.

4.6.6 Method of Data Analysis

The analysis for this research follows the methods of descriptive analysis, and multivariate analysis. The statistical package for social science (SPSS version 27) was chosen for the data collected to be analysed and processed since it was established as the best available tool that can meet the first research objective, with the subsequent procedures of statitstic analysis. In addition, for the second objective, the multivariate analysis using PLS-SEM (Smart-PLS version 4.1.1) was chosen to project the relationship of the variables and construct. Furthermore, for the third objective, an expert's validation of the findings were carried out throught obtaining feedbacks with regards to suitability, content, acceptance and feasibility in Malaysia.

As the development of the final framework is also considered as a decision-making tool used to prioritize and evaluate alternatives in complex decision scenarios, the Analytical Hierarchy Process (AHP) is applied as another expert validation tool of in order to help systematically assess the framework's components or criteria based on the expertise and judgment of relevant stakeholders. A detailed discussion on the method of data analysis are stated below.

4.6.6.1 Preliminary Data Screening and Preparation

Prior to conducting the main statistical analyses, preliminary data screening and preparation procedures were performed to ensure the quality, consistency, and suitability of the dataset for multivariate analysis. Preliminary analysis is important in PLS-SEM studies as it assists in identifying potential data issues that may affect the validity and robustness of the findings (Hair et al., 2019; Kline, 2023). Therefore, several screening procedures were conducted using IBM SPSS Statistics Version 27 before proceeding to the descriptive analysis, formative measurement model assessment, structural model evaluation, and framework validation stages.

The dataset was first assessed for missing data, suspicious response patterns, and outliers to ensure completeness and reliability of the responses. Cases identified as incomplete or exhibiting abnormal response behaviour were excluded from further analysis. The distributional characteristics of the data were subsequently examined using graphical inspection, Kolmogorov-Smirnov test, and skewness and kurtosis statistics. Although PLS-SEM is robust towards non-normal data distribution, assessment of normality remains important to evaluate the suitability of the dataset prior to multivariate analysis (Hair et al., 2019; Byrne, 2016).

In addition, common method bias (CMB) assessment was conducted through both procedural and statistical approaches to minimise potential measurement bias associated with self-administered questionnaire surveys (Podsakoff et al., 2003; Kock, 2015). These preliminary screening procedures established the suitability of the dataset prior to conducting the descriptive analysis, PLS-SEM analysis, and subsequent AHP validation and prioritization stages.

4.6.6.2 Descriptive Analysis

Descriptive analysis refers to the process of transforming raw data into meaningful information that helps define a set of factors under specific conditions (Sekaran & Bougie, 2019). Before conducting further analysis, the data is first examined for multivariate normality, as PLS-SEM is highly sensitive to data distribution (Hair et al., 2013). In this study, descriptive statistics were also applied to check for potential errors in the data, to describe the characteristics of the sample, and to verify whether the variables met the assumptions underlying the statistical techniques used to answer the research questions. Percentages, frequencies, means, and standard deviations were employed to summarize the key characteristics of the dataset, as they provide clear and straightforward insights into both the sample and the measures (Field, 2018). These tests were supplemented with simple graphical and chart analyses, which form the foundation of most quantitative data analysis.

4.6.6.3 Partial Least Square-Structural Equation Modelling (PLS-SEM)

This study employed partial least square-structural equation modelling (PLS-SEM), a variance-based SEM technique, as required for the analysis of the collected data. Prior to such method, the Covariance-based SEM (CB-SEM) is one of the best-known within the SEM method (Chin, 2010). The analysis of this technique could be implemented using software programs such as LISREL, AMOS, CALIS, EQS, and SEPATH. However, in certain types of research, a number of limitations might exist, which using covariance-based SEM (CB-SEM) analysis is inappropriate. For instance, to apply covariance-based SEM (CB-SEM) requires large sample size and normality. In addition, this type of analysis technique requires reflective constructs where a latent variable is designated as a reflective construct, and if the items are influenced by the construct, then it's assumed to be correlate (Gefen et al., 2011).

The PLS-SEM method was developed by Wold (1975) for studies where data could not meet the limiting rules of CB-SEM techniques. It was used to estimate the parameters of measurement and structural model. The analysis of this technique could be implemented using software such as LVPLS 1.6 and 1.8, PLS-Graph 3.0, WarpPLS 3.0, and SmartPLS 2.0 and 3.0. In this study, SmartPLS Version 4.0 (Ringle et al., 2012) was used to analyse the data. The PLS-SEM technique is most suited for studies that are exploratory and prediction-oriented in nature of research. According to Hair Jr et al., (2019) researcher should select PLS-SEM for the research as follows:

- When the analysis is concerned with testing a theoretical framework from a prediction perspective
- When the structural model is complex and includes many constructs, indicators and or model relationships
- When the research objective is to better understand increasing complexity by exploring theoretical extensions of established theories (exploratory research for theory development)
- When the path model includes one or more formatively measured constructs
- When the research consists of financial ratios or similar types of data artefacts
- When the research is based on secondary/archival data, which may lack a comprehensive substantiation on the grounds of measurement theory
- When the small population restricts the sample size
- When distribution issues are a concern, such as lack of normality
- When the research requires latent variable scores for follow-up analyses

The PLS-SEM technique has several advantages over CB-SEM. For instance, in PLS-SEM, a construct is perceived as a formative construct in case the concerned items cause the latent variable, where the items are not expected to be correlated (Chin, 2010). PLS-SEM is also able to estimate a complex model that comprises a large number of items or constructs. Moreover, if the data of a study does not meet the normality criteria, PLS-SEM can still effectively be used for a large number of indicators (Chin, 2010; Hair et al., 2017). Furthermore, this type of analysis technique does not require a large sample size to generate significant p-values and stable path coefficients. Furthermore, the PLS-SEM analysis method does not have identification, which means that latent variables do not need to have the least of three items required by CB-SEM techniques. In the present study, PLS-SEM technique is primarily adopted to examine the paths in the structural model and SmartPLS Version 3.0.3 (Ringle et al., 2012), also known as SmartPLS 3.0 is used to analyse the data.

Rationally, due to its relevance to the current study and popularity in recent research, the adoption of PLS-SEM is justified, as PLS-SEM in recent years has been getting more interest due to its capacity for modelling latent variables under non-normalised and small number samples, for examining the measurement path and explaining the regression estimation of structural path (Henseler et al., 2009). For this study, the main key argument for employing PLS-SEM relates to the use of formatively measured constructs as part of the structural models since PLS-SEM readily handles both reflective and formative measures. Technically and implicitly, researchers accept the underlying assumptions of the PLS-SEM method (e.g., predictor specification), which allow for the possibility of formative and reflective measurement models (Hair et al., 2011).

Secondly, a large number of items and constructs in the model of this study also supports the use of PLS-SEM, which is able to estimate a complex model comprising a large number of items or constructs (Hair Jr et al., 2017). Thirdly, the ability of PLS-SEM to handle small sample size when the data does not meet the normality criteria further compliments the requirements of the present study (Ringle et al., 2012), Forthly, the research strategy is to use latent variable scores in subsequent analyses to test relationships and hypothesis establishes PLS-SEM as a suitable statistical tool to achieve the Objective Two for this study. Furthermore, the complex nature of research as a result from the high amount of indicators and constructs ammongst the two variables, and explanation offered by past research in the same field of research methodology justifies the use of PLS-SEM method for this study.

4.6.7 The Measurement Model

The PLS-SEM technique of data analysis comprises of two phases, namely the measurement model and the structural model (Hair et al. 2017). In the first phase, the measurement model measures the relationships between the latent variables (unobserved variables) and indicators (observed variables). According to Hair et al. (2017), the measurement model assesses how appropriately the newly established latent variables are linked together and whether or not they are connected adequately to their indicator. Chin (2010) argued that there exists no reason to perform a structural model measurement when the results of the measurement model (reliability and validity) are doubtful. Therefore, before proceeding with the structural model, the measurement model is employed to measure the validity and reliability of the constructs as discussed in the following sub-sections.

There are two types of measurement models in PLS-SEM, namely the reflective and formative measurement models. Whereas reflective indicators are essentially interchangeable (and therefore, the removal of an item does not change the essential nature of the underlying construct), with formative indicators omitting an indicator is omitting a part of the construct (Diamantopoulos & Winklhofer, 2001). The reflective measurement approach focuses on maximising the overlap between interchangeable indicators, while the formative measurement approach generally minimises the overlap between complementary indicators (Hair et al., 2017). For the reflective measurement models, the indicators must be highly correlated to the construct, while in the formative measurement model, the indicators can have positive, negative or no correlation to the construct (Hulland, 1999).

Reflective measures dictate that all indicator items are caused by the same construct, and indicators associated with a particular construct should be highly correlated with each other (Hair et al., 2017). In contrast, formative measurement models are based on the assumption that causal indicators form the construct by means of linear combinations (Hair et al., 2017). Furthermore, there are two types of indicators in the context of formative measurement, which are composite and causal indicators (Hair et al., 2017).

4.6.7.1 Formative Measurement Model

Based on the guideline provided by Hair et al. (2017), the measurement model of this research adopted the formative measurement model evaluation. This is justified by the causal priority between the indicators, and the construct is from the indicators to the construct, the construct is the combination of the indicators (Coltman et al., 2008; Fornell & Bookstein, 1982), and the indicators are not interchangeable because each indicator contributes a specific meaning to the construct (Coltman et al., 2008; Jarvis et al., 2003) therefore, it is explained that any deletion of indicators on the specific variable, will have an effect on the construct.

The independent variables (IVs) that constitute the formative, lower-order constructs of the HBIM-retrofit model include heritage aspects (HA), development stages (DS), retrofit design criteria (DC), method of approach (MA), HBIM organizational (O), HBIM informational (I), HBIM process lifecycle (PL), and HBIM technical (T). These variables are structured hierarchically into two higher-order constructs: historic building retrofit characteristics and HBIM-retrofit functionality. Each constructs has formative to reflective relatiohship with the performance (DP) as the dependent variable. Importantly, each IV and its indicators play a unique role in the framework; thus, removing any of them would compromise the integrity of the overall model, as the constructs are not interchangeable. Furthermore, according to Hair et al. (2017), the formative measurement model evaluation includes (1) convergent validity, (2) multicollinearity (VIF) and (3) significance and relevance of the formative indicators (outer weights) as shown in Figure 4.8 below.

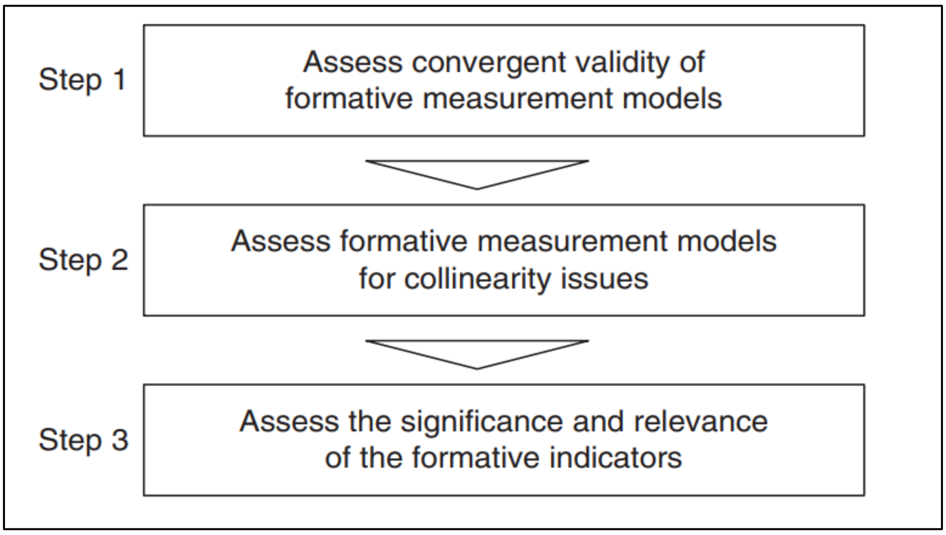

Figure 4.8 Formative Measurement Models Assessment Procedure (Hair et al., 2017)

Furthrmore, when deciding whether to remove the formative indicators based on statistical outcomes, researchers need to be cautious for the following reasons. First, formative indicator weights are a function of the number of indicators used to measure a construct and the greater the number of indicators, the lower their average weight. Second, indicators should seldom be removed from formative measurement models, as the formative measurement theory requires the indicators to fully capture the entire domain of a construct, as defined by the researcher in the conceptualization stage (Hair et al., 2019b).

After assessing the statistical significance of the indicator weights, the researchers examined each indicator's relevance before eliminating the potential indicators as per results (Hair et al., 2019b). The indicator weights are standardised to values between -1 and +1, but, in rare cases, can also take values lower or higher than this, which indicates an abnormal result (e.g. due to collinearity issues and/or small sample sizes). Weight close to zero (0) indicates a weak relationship, whereas weights close to +1 (or -1) indicate strong positive (or negative) relationships (Hair et al., 2019b).

4.6.7.2 Convergent Validity

The first assessment conducted in the formative measurement model is the convergent validity of the variables in the model path. Validity refers to the degree to which an empirical measure adequately reflects the real meaning of the concept under consideration (Barbie et al., 2007). Validity reflects the degree to which a scale or set of scales correctly represents the study's concept, i.e. the extent to which the measure is free from any systematic or unsystematic non-random error. However, accuracy does not ensure validity (Zikmund et al., 2013).

There are possibilities that the scales could have defined what is to be measured but still have an invalid measure of the concept when the supposed appropriate questions in the scale are not being asked (Zikmund et al., 2013). The scales of this study could be deemed valid, as they have been adopted with slight modifications to suit present context from established scales in existing literature, developed by well-known researchers in the field of the present study (Sekaran & Bougie, 2016).

To ensure the validity of the scales used, the variables in this study were measured by multi-item scales adopted from well-established studies of HBIM-retrofit. For formatively measured constructs, convergent validity is assessed by the correlation of the construct with an alternative measure of the same concept (Hair et al., 2019b; Hair Jr et al., 2021). According to Chin (1998), the procedure is referred to as redundancy analysis.

To execute this procedure, the researcher examined the relationship between the multi-item formative construct and the reflective measure of the same construct using correlation or regression (Hair Jr et al., 2020). Hence, in using PLS-SEM, when evaluating formative measurement models for the convergent validity assessment, the researcher examined the correlation relationship between the formatively measured construct with a reflective measure of the same construct (Hair et al., 2017).

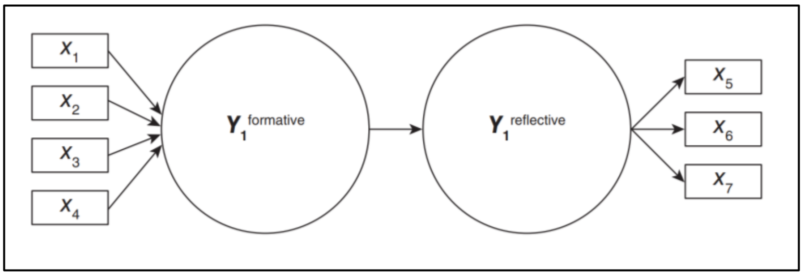

Figure 4.9 Redudancy Analysis for Convergent Validity (Hair Jr et al. 2019)

Figure 4.9 shows the model path for convergent validity assessment for the formative measurement model (Hair et al. 2017). An independent model path for each of the variables is prepared to establish the individual variables' convergent validity through the formatively measured construct to the reflective measure of the same construct. According to Hair Jr et al. (2019), ideally the path coefficient linking both formative to reflective construct should be ideally above 0.70 which translates into R^2 values of at least 0.50. If the analysis lacks convergent validity (eg. R^2 value < 0.50) then the formative construct do not contribute at a sufficient degree to its intended content.

4.6.7.3 Multicollinearity

When the convergent validity is established, the following assessment conducted is the multicollinearity assessment. Multicollinearity is the situation where items for a construct is correlate highly with each other (Gaur & Gaur, 2006). Variance Inflation Factor (VIF) is utilised to assess the degree of multicollinearity among the indicators (Fornell & Bookstein, 1982). The term VIF is derived from the fact that its square root is the degree to which the standard error has been increased due to multicollinearity.

Gotz et al., (2010) stated that the VIF should not exceed a value of 10. However, Hair et al. (2011), mentioned that the VIF value less than 5 shows no issue of multicollinearity. VIF level of 5 indicates that 80% of its variance is accounted for by the remaining formative indicators associated with the same construct (Hair et al., 2017). Another important criterion for evaluating the contribution of a formative indicator, and thereby its relevance, is the outer weight value (Hair et al., 2017).

The outer weight is the result of multiple regression with the latent variables scores as the dependent variable scores as the dependent variable and the formative indicators as the independent variables (Hair et al., 2017). Nonsignificant indicator weights should not automatically be interpreted as indicative of poor measurement model quality (Hair et al., 2017). Figure 4.10 shows the process model explaining when an indicator's outer weight is nonsignificant, but its outer loading is high (above 0.50), the indicator should be interpreted as absolutely important but not as relatively important, and the indicator would generally be retained (Hair et al., 2017).

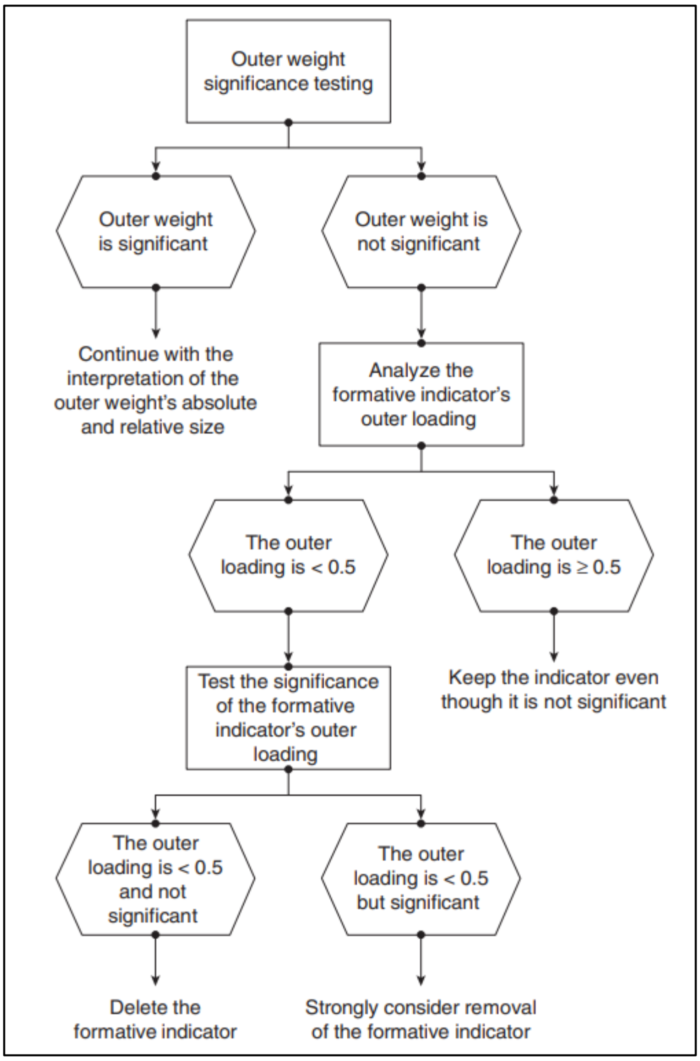

Figure 4.10 Decision Factors in Assessing Formative Indicators (Hair et al., 2017)

As for the procedure, the recommended bootstrap value is 5000 bootstrap (Hair et al., 2017). The occurrence of a VIF greater than 3.3 is proposed as an indication of pathological collinearity and also as an indication that a model may be contaminated by common method bias. Therefore, if all VIFs value of constructs resulting from a full collinearity test is equal to or lower than 3.3, the model can be considered free of common method bias (Kock, 2015). Common method bias, in the context of PLS-SEM, is a phenomenon that is caused by the measurement method used in an SEM study and not by the network causes and effects in the model being studied (Kock, 2015). Hence, if the VIF value is greater than 3.3, it is shown that the construct is facing a method bias.

The VIF value less than 5 shows a minor method bias, while the VIF value of 10 is considered major method bias. Consequently, the VIF threshold used in the common method bias test should arguably be somewhat higher than 3.3 when factor-based PLS-SEM algorithms are used (Kock, 2015). VIF of 5 could be employed when algorithms that incorporate measurement error are used (Kock, 2015; Kock & Lynn, 2012). Other than Kock & Lynn (2012), other scholars also agreed that the threshold of VIF below 5 is acceptable (Akinwande et al., 2015; de Souza Bido & da Silva, 2019; J. F. Hair et al., 2019; Hair et al., 2011; Kock, 2015; Latif et al., 2020; Pérez, et al., 2020; Olusegun et al., 2015). As mentioned by (Hair et al., 2017), if the level of collinearity is very high, as indicated by a VIF value of 5 or higher, one should consider removing one of the corresponding indicators.

4.6.8 The Structural Model

Following the evaluation of the measurement model, the second and final stage of the PLS-SEM analysis involves the structural model, which assesses the relationships between latent (unobserved) variables. This stage is used to construct the structural model and to test the proposed hypotheses. The structural model illustrates the interactions among the theoretical constructs. In PLS-SEM, latent variables are categorized as either exogenous or endogenous. Exogenous variables are those that serve solely as predictors of other variables, while endogenous variables are those influenced by at least one causal relationship. To establish the structural model, three key assessments were conducted: path coefficients, effect size, and variance explained, as detailed in the following subsections.

4.6.8.1 Explained Variance (R2)

The R^2 value represents the explanatory power of the path coefficients in relation to the observed manifest items. Its value ranges between 0 and 1, with higher values indicating a greater proportion of variance explained. Thus, a larger R^2 reflects stronger predictive accuracy of the model. The predictive strength of the theoretical model is determined by the robustness of its structural paths, which combine the variance explained (R^2) with the influence of exogenous constructs. This aligns with the primary objective of PLS-SEM, which emphasizes prediction (Chin, 2010).

4.6.8.2 Predictive Relevance (Q^2)

In addition to R^2 values as a criterion of predictive accuracy, this study also evaluates Stone-Geisser's Q^2 value (Geisser, 1974; Stone, 1974), which serves as an indicator of the model's predictive relevance. Q^2 values were obtained through the blindfolding procedure, applied with an omission distance between 5 and 10, as recommended by (Hair et al., 2017). Blindfolding is an iterative process in which individual data points are systematically omitted, replaced with mean values, and the model re-estimated. This approach enables the assessment of the model's predictive capacity by comparing predicted and original values; smaller discrepancies correspond to higher Q^2 values, reflecting stronger predictive relevance.

It is important to note that Q^2 is not purely an out-of-sample predictive measure but rather integrates elements of both in-sample explanatory power and out-of-sample prediction (Hair et al., 2017). A Q^2 value greater than zero indicates that the model possesses predictive relevance for the specified endogenous constructs (Götz et al., 2009; Hair et al., 2019b). Conversely, values of zero or below suggests a lack of predictive relevance. As a rule of thumb, Q^2 values above 0, 0.25, and 0.50 represent small, medium, and large predictive relevance, respectively, for the PLS-SEM path model (Hair Jr et al., 2019b). Formally, the Stone-Geisser test criterion be displayed as:

$$Q_j^2 = 1 - \frac{\sum_k E_{jk}}{\sum_k O_{jk}} \tag{4.1}$$

4.6.8.3 Size and Significance of Path Coefficient

Path coefficients represent the beta coefficients resulting from the least-squares or estimation and portray the significance between constructs (hypothesis testing). The goodness of the path is shown by the beta (β) and t-statistics value. A significant path indicates that the proposed causal relationship and hypothesis are empirically supported by the data of the study (Hair et al., 2011).

4.6.9 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is incorporated in this study as a multi-criteria decision-making (MCDM) technique to support the prioritization and comparative weighting of HBIM-retrofit variables and indicators identified from the literature review and conceptual framework development. The application of AHP is particularly relevant due to the complex and multidisciplinary nature of HBIM-retrofit projects, which involve balancing historic building retrofit characteristics and HBIM functionalities. Therefore, AHP supports the framework refinement stage by systematically evaluating the relative importance of the identified criteria through expert judgement upon the empirical structural validation using PLS-SEM.

Expert opinion was obtained using the Analytical Hierarchy Procss (AHP) and it is a fundamental approach in developing a decision making framework. It is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria. In this process, the decision-maker carried out pairwise comparison judgments, which are then used to develop overall priorities for ranking the alternatives (Saaty & Vargas, 2001). AHP is a general theory of measurement. It is used to derive ratio scales from both discrete and continuous paired comparisons in multilevel hierarchical structures.

These comparisons may be taken from actual measurements or from a fundamental scale that reflects the relative strength of preferences and feelings (Saaty & Vargas, 2001). The AHP has a concern with departure from consistency and the measurement of this departure, and with dependence within and between the groups of elements of its structure. Making the best decisions becomes an increasingly demanding task for managers of companies, governmental agencies and many other decision and policymakers (Brunelli, 2014). Many methods stemming from applied mathematics and operations research have proved useful to help decision-makers make informed decisions, and among these methods, there are also those requiring, as an input, subjective judgements from a decision-maker or an expert. In this context, AHP becomes a useful tool for analysing decisions among the expert (Brunelli, 2014).

AHP is highly recommended to be used to rank procedural evaluation (Saaty, 1986; Saaty & Sagir, 2012) and also in construction management (Darko et al., 2019). AHP involves breaking the problem down into finer parts so that one is called upon to give a judgement (Saaty & Sagir, 2012). Once the structure is established, it becomes easier to convey to others the influences which drive that decision. All possible factors should be included in the structure (Saaty & Sagir, 2012). Later, the process of prioritisation by the expert will weed out the unimportant or irrelevant factors. In case of extreme disagreements, the arguments of outliers can be given appropriate weightings, and they combine with the majority's positions.

The AHP combines multiplicity of judgements in a systematic was to obtain the best outcome, or mix of actions to be taken. Finally, and more significantly, these outcomes are derived in an agreeable way that are in harmony with our intuition and understanding and not forced by technical manipulations (Saaty & Sagir, 2012). A key aspect is that decision criteria are assessed with respect to their relative importance in order to allow trade-offs between them (Darko et al., 2019).

The AHP method in this research consists of three steps: (1) hierarchy formation - the first level of the hierarchy contains the decision goal, whereas the subsequent lower levels represent the progressive breakdown of the decision criteria, and sub criteria; (2) pairwise comparison - decision-makers (who are often domain experts) are asked to complete pairwise comparisons of the elements at each level of the hierarchy, assuming the elements at each level of the hierarchy, assuming the elements are independent of each other and (3) verification of consistency – expert judgement are necessary for determining the relative importance of each criterion and any alternatives to achieving decision goal (Darko et al., 2019). In this regard and considering the decision goal, the comparison is made between the relative importance of every two indicators in sub-criteria at the second level of the hierarchy.

This pairwise comparison is often based on a nine-point scale (Darko et al., 2019). Consistency verification is essential to ensuring an optimised outcome. To control the consistency of pairwise comparisons, a computation of consistency ratio was performed using the SuperDecisions software, and decision-makers are required to revise their initial judgements if the computed consistency ratio exceeds the threshold of 0.1 (Saaty, 1994). After all of the necessary pairwise comparisons and revisions have been made and the consistency ratio has been found to be less than 0.1, the judgements can be synthesised to prioritise the decision criteria together with their corresponding sub-criteria.

The AHP required small sample size to achieve sound and statistically robust result (Darko et al., 2019). The extant literature of AHP application in constructions indicates that there is no strict requirement on the minimum sample size for AHP analysis. However, some studies used sample sizes ranging from four to nine (Darko et al., 2019). These suggest that AHP can be performed with a small sample size to achieve useful decision results and models.

In this study, AHP is not intended to statistically validate the direct causal relationship of historic building retrofit characterics (HRC) and HBIM-retrofit functionality (HRF) to the enhanced performance (DP) of heritage building conservation projects as established in PLS-SEM model. Instead, AHP functions as a hierarchial, decision-support and prioritization mechanism to refine the relative importance of the identified HBIM-retrofit framework variables and indicators after the empirical relationship testing is conducted through PLS-SEM analysis.

4.6.9.1 Making Decision Hierarchy

To formulate a hierarchy of structure, the problem is decomposed into a hierarchy of goals, clusters and sub-cluster (refer Figure 4.11). This is the most important part of decision making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. The sequence can be described into three steps as follows;

1. Identify the objective of the process. This process begins with defining the overall objective or goal of the process.
2. Identify the cluster to achieve objectives. Criteria that contribute to the successful realisation of this goal are then identified.
3. Identify the sub-cluster. Specific sub-clusters related to each cluster can then be identified and included in the hierarchy.

In using the AHP to model a problem, one needs a hierarchy of structure to represent that problem, as well as pairwise comparisons to establish relations within the structure. The hierarchy of structure consists of the cluster and sub-cluster of variables. The cluster and sub-cluster of the research is derived from the finding from the PLS-SEM data analysis conducted prior to AHP, in which a final research framework consists of finalzied variables and indicators were established.

Initially, there are four identified clusters including pre-retrofit stage, retrofit design stage, implementation stage and post-retrofit stage. These four clusters are categorised as the development stages of HBIM-retrofit framework. The development stage (DS) is the main cluster of this research because the nature of a framework is usually derived from a timeline basis for the construction industries. Furthermore, according to Hamzeh (2009), procedural guidance is clearly tied to time-driven planning and sequencing, reflecting both timeline and flow in the work process implementation.

The sub-cluster of this research was identified from the findings of the PLS-SEM. There are seven main sub-clusters which include heritage aspects (HA), retrofit design criteria (DC), method of approach (MA), organizational (O), informational (I), process lifecycle (PL) and technical (T). Each of these sub-clusters consists of various indicators. Both clusters and sub-clusters identified further represented into the hierarchy of structure of this research.

Figure 4.11 shows the preliminary hierarchy of structure of the study before the PLS-SEM analysis. Based on the hierarchy of structure, the goal of the AHP assessment is to formulate a HBIM-retrofit framework for enhancing the peformance of heritage building conservation projects in Malaysia, followed by the four main clusters including the pre-design stage, design stage, construction stage and post-occupancy stage.

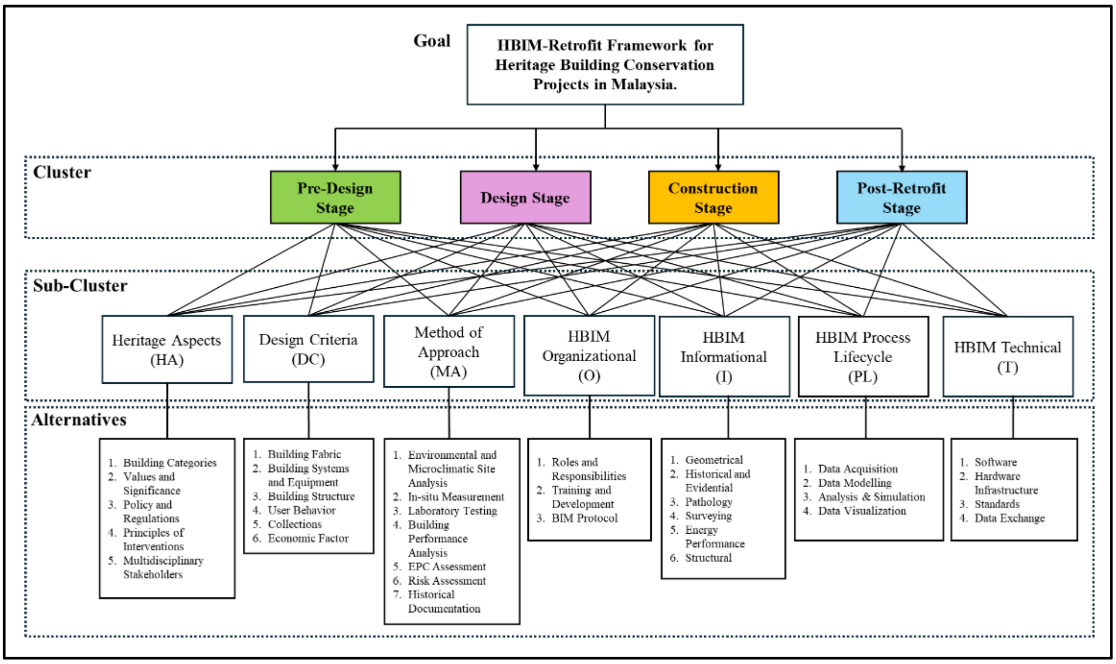

Figure 4.11 Hierarchy of Structure (Author)

4.6.9.2 Expert Criteria

In this research, the AHP questionnaire was distributed to selected experts. According to Darko et al. (2019), the AHP data analysis method typically requires between four and nine expert respondents. Accordingly, this study engaged six experts representing decision-makers from academia, private practice, and the public sector, all of whom are experienced professionals in heritage building conservation, to ensure a robust outcome. Before receiving the questionnaire, the experts were briefed by the researcher on the background of the study.

The weights derived from their judgments were then used to develop the HBIM-retrofit framework. The criteria for expert selection were adapted from similar studies by Jihad et al. (2021) and Lee et al. (2020), which emphasize: (1) a minimum of 10 years of relevant professional or academic experience, (2) professional recognition or possession of a PhD in a related field, and (3) at least a bachelor's degree in a relevant discipline. The selected experts were listed in Chapter Six.

A snowballing technique was employed to identify potential expert panellists. Candidates were approached through the LinkedIn platform and selected based on their professional background in heritage-built environment. The selected panel includes conservation architects in Malaysia, the Head of Historic Building Conservation from the National Heritage Department (NHD) and the Public Works Department (PWD), as well as senior council members of professional organizations related to heritage building conservation.

4.6.9.3 Design of Questionnaire for Expert Opinion

The questionnaire for expert opinion using the AHP method was systematically developed to capture interactions and feedback among indicators within the same sub-cluster (see Table 4.19). A sample questionnaire is provided in Appendix 2. An absolute measurement (scoring) approach was applied, requiring experts to rate the relative importance of indicators whether they are extremely important, very strongly important, strongly important, or moderately important.

The questionnaire was generated using SuperDecisions software, which automatically produced the complete set of pairwise comparison matrices. These pairwise comparisons enabled the assessment of each indicator against others within the same sub-cluster, supporting the objective of establishing a ranking for all indicators in the sub-clusters within a cluster. Table 4.19 shows the sample of pairwise comparisons question between regulations (HA3) and principles of intervention (HA4). Both indicators are the within the same sub-cluster, namely heritage aspect.

Table 4.19
Sample of Pairwise Comparison Question Between Indicators within the Sub-Cluster

sub-criteria	**← Level of Importance →**	**sub-criteria**
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Intervention

The sub-criteria will be displayed on each sides (on the left and right sides of the table), using the Saaty's scale of judgement (scale of 1-9) (Saaty & Vargas, 2001). Figure 4.12 shows the example of the measurement scale for the research questionnaire. Score of 1 represents equal importance between two criteria, 3 represents moderately important of one criterion over another, 5 represents strongly important, 7 represents very strongly important and 9 represents extremely important. The weight assigned to a criterion will be determined by the degree of influence of the criterion when compared to another with respect to another criterion within the same sub-cluster.

Scale	Extremely Important	Very Strongly Important	Strongly Important	Moderately Important	Equal	Moderately Important	Strongly Important	Very Strongly Important	Extremely Important	
Sub-Criteria	9	7	5	3	1	3	5	7	9	Sub-Criteria

Figure 4.12 Scale of Measurement (Saaty & Vargas, 2001)

After setting the priorities for the sub-cluster, and the pairwise comparison has been completed, finally, aggregates are scored by checking off their respective ratings under each indicator of sub-clusters and summing these ratings for all the sub-cluster.

4.6.9.4 Constructing Pairwise Comparison Matrices

Comparison matrices were developed to assess how elements at one level influence those at the next, allowing the relative impact of the lowest-level indicators on the overall objective to be calculated. This approach enables decision-makers to evaluate two alternatives at a time by breaking the main problem into smaller, manageable sub-problems. All pairwise evaluations are organised into a comparison matrix, where each indicator is assessed against others within the same group based on its contribution toward achieving the study's objective. These assessments, known as pairwise comparisons, are expressed in matrix form. This method effectively addresses the complexity of multi-criteria decisions through systematic comparison. Pairwise comparisons at each level are made according to three considerations:

• Importance – when determining the relative significance of objectives.
• Preference – when comparing alternatives in relation to an objective.
• Likelihood – when evaluating uncertain events based on their probability.

Values used in these comparisons are assigned using a predefined scale of relative importance. In AHP, paired comparison judgments are applied to sets of homogeneous elements, with the fundamental scale representing the intensity of each judgment. Table 4.20 shows the fundamental scale of judgement according to Saaty & Vargas (2001).

Table 4.20
The Fundamental Scale (Saaty & Vargas, 2001)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2 3	Weak, moderate importance	Experience and judgement slightly favour one activity over another.
4 5	Moderate plus strong importance	Experience and judgement strongly favour one activity over another
6 7	Strong plus very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8 9	Very, very strong extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rational	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

4.6.9.5 Consistency Ratio (CR)

In the Analytic Hierarchy Process (AHP), consistency ratio (CR) analysis is performed to evaluate the logical consistency of expert judgments obtained through pairwise comparisons. As AHP relies on subjective human evaluation, inconsistencies may arise when judgments violate transitivity (e.g., if A > B and B > C, then A should be > C). Ensuring consistency is therefore critical to maintaining the reliability and validity of the derived priorities (Saaty, 2008; Saaty & Vargas, 2001). The consistency of the pairwise comparison matrix is first assessed using the Consistency Index (CI), which is derived from the maximum eigenvalue (λ_{max})of the matrix:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4.2}$$

where n represents the number of criteria. The consistency ratio (CR) is then calculated by comparing the CI with the Random Index (RI), which represents the average consistency index obtained from randomly generated reciprocal matrices:

$$CR = \frac{CI}{RI} \tag{4.3}$$

A CR value of 0.10 or less is generally considered acceptable, indicating that the level of inconsistency is within a tolerable range (Saaty, 1994; Saaty, 2008). If the CR exceeds this threshold, the pairwise comparisons should be revised to improve consistency. This threshold has been widely adopted in AHP-based studies across various domains (Vaidya & Kumar, 2006). Consistency evaluation is essential because unreliable judgments can significantly affect the stability of the resulting priorities and decision outcomes (Ishizaka & Labib, 2011). Furthermore, the CR provides a diagnostic mechanism that enhances transparency and methodological rigour in multi-criteria decision-making processes (Saaty & Vargas, 2012).

In this study, CR analysis was conducted for all pairwise comparison matrices derived from expert evaluations. Only matrices that satisfied the acceptable consistency threshold were retained for further analysis. This ensures that the prioritisation of HBIM-retrofit indicators is based on consistent, reliable, and defensible expert judgments, thereby strengthening the robustness of the proposed framework.

4.6.9.6 Weights and Ranks Analysis

Following the consistency assessment, the relative weights of criteria and indicators were determined using the geometric mean method, which is commonly applied in the AHP for its computational simplicity and reliability. This method is particularly suitable when aggregating multiple expert judgments and has been shown to produce results consistent with the eigenvector approach (Saaty, 1980; Saaty, 2008). The geometric mean for each criterion is calculated as follows:

$$GM_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}} \tag{4.4}$$

where:

- GM_i= geometric mean of criterion i
- a_{ij}= pairwise comparison value
- n= number of criteria
- $\prod$= Product multiplication operator

After calculating the geometric mean for each row, the priority weight is calculated using normalization:

$$W_i = \frac{GM_i}{\sum_{i=1}^{n} GM_i} \tag{4.5}$$

where:

- Wi= normalized priority weight
- GM_i= geometric mean of criterion i

The resulting weights indicate the relative importance of each criterion within the hierarchical structure. Criteria with higher weights are considered more influential in achieving the overall decision goal. Subsequently, ranking analysis was conducted by arranging the weights in descending order. The highest weight corresponds to the highest priority, enabling the identification of the most critical HBIM-retrofit indicators across the three development stages (DS). The geometric mean method is widely adopted in AHP studies due to its robustness in handling group decision-making and its ability to maintain reciprocal properties of the comparison matrix (Ishizaka & Labib, 2011). In this study, it provides a reliable and transparent basis for deriving priority weights and supporting structured decision-making in heritage conservation.

4.7 Summary of Chapter

This chapter discussed the overall research methodology adopted to achieve the objectives of the study in developing an HBIM-retrofit framework for enhancing the performance of heritage building conservation projects in Malaysia. The chapter began by explaining the research philosophy, research approach, and strategy of enquiry, which were aligned with positivism, hypothetical-deductive reasoning, exploratory research, and quantitative methods. These methodological positions guided the overall research design and selection of appropriate research techniques.

The chapter further discussed the research techniques employed, including literature review, questionnaire survey, and expert validation. The literature review and content analysis were conducted to identify the underlying HBIM-retrofit variables, indicators, and performance criteria, which subsequently supported the development of the conceptual framework and hypotheses. In addition, the questionnaire survey was justified as the primary research instrument involving heritage conservation practitioners in Malaysia. The chapter also elaborated on the questionnaire design, operationalisation of variables, validity and reliability assessment, sampling techniques, population size determination, and data collection procedures to ensure the robustness and consistency of the research instrument.

Furthermore, the chapter explained the methods of data analysis adopted in the study. IBM SPSS software was used for descriptive statistical analysis, while SmartPLS software was employed for Partial Least Squares–Structural Equation Modelling (PLS-SEM) to assess the measurement model, structural model, and hypothesis testing. Finally, the Analytical Hierarchy Process (AHP) was discussed as part of the validation and prioritisation stage for the formulation of the final HBIM-retrofit framework. The procedures for pairwise comparison, consistency ratio analysis, geometric mean calculation, and ranking analysis were also explained to support the structured evaluation of HBIM-retrofit indicators across the three development stages. Overall, the methodological procedures discussed in this chapter provide a systematic and reliable foundation for the data analysis, findings, and framework development presented in the subsequent chapters.

CHAPTER 5
DATA ANALYSIS AND RESULTS

5.1 Introduction

This chapter discusses the results and data analysis which follows the proposed methods detailed in Chapter Four. The shared results in this chapter were obtained from the acquired data which involved three phases of statistical analysis. First the data screening and preliminary analysis was employed to achieve a worthy understanding of the features and potential issues of the dataset preceding further analysis, in addition to ensuring the significant outcomes of hypothesis generations, Secondly, the descriptive analysis was engaged using SPSS 27 software to explain the data features, analyze the demographic information of the respondents and the HBIM-retrofit model elements, Thirdly, the multivariate analysis using SmartPLS 4.0 software to conduct the Partial Least Square-Structural Equation Modelling (PLS-SEM) was chosen to assess the hypothetical model and indirectly summarize the findings for further discussion. The organization of this chapter is distributed into several sub-sections and analysis process as illustrated in Figure 5.1. At the end of the chapter, a summary will be included.

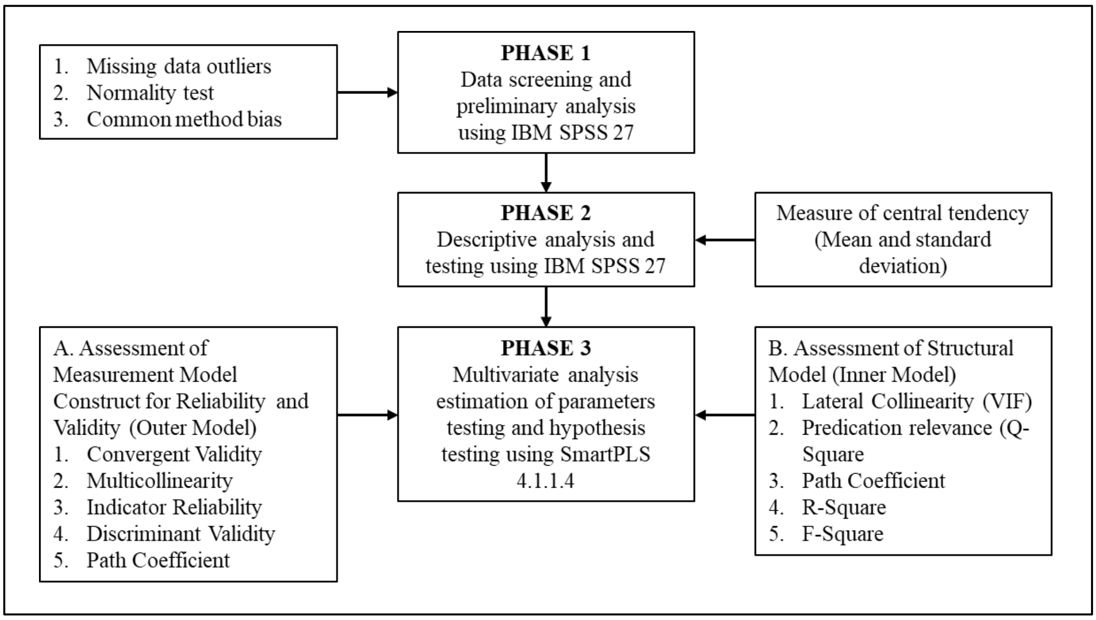

Figure 5.1 Main Data Analysis

5.2 Rate of Responses

Response rate is the amount of completed and returned questionnaires that is divided by the number of sample members that are eligible for the survey (Frohlich, 2002). To obtain a higher response rate will depend on the willingness of respondents to complete the questionnaires administered on them. Hence, to increase the survey response rate, (Frohlich, 2002), suggested that the researchers should observe some techniques as listed below.

1. Inform the respondents before distributing the questionnaire.
2. Insert a third-party logo on the front page of the survey.
3. Send questionnaire notifications by mail repetitively.
4. Write an honest please on the cover page of the survey
5. Always follow up the survey.
6. Make sure the research results are eventually provided.
7. Ensure the survey is given to the most suitable participant.
8. Ensure that the items in the questionnaire are well organized
9. Carry out a pilot study and utilize the prevailing scale for the real survey.

This study employed the strategies outlined above, with the exception of including a third-party logo. In addition, an online survey using Google Forms was distributed via email to the respondents. To enhance participation, follow-up reminders were conducted through phone calls and chat messages to targeted respondents toward the end of the data collection period. Hence, a total of 158 questionnaires were distributed over a period of 20 weeks (6 months), from early January 2025 to the end of June 2025. As shown in Table 5.1, a total of 102 questionnaires were acknowledged and retained for analysis. Six (6) responses were excluded due to suspicious response patterns, while an additional two (2) cases were removed after the outlier test.

This resulted in a final response rate of 59.5%. In survey-based research, the response rate is a critical indicator of data quality and representativeness. While there is no universal standard, a rate of above 50% is generally considered acceptable in social science research (Babbie, 2020; Baruch & Holtom, 2008). More specifically, Baruch & Holtom (2008), in their meta-analysis of organizational research surveys, reported that the average response rate for individual-level studies was 52.7%, and 35.7% for organizational-level studies. Therefore, the response rate of 59.5% achieved in this study is above the average benchmarks reported in the literature.

For the multivariate analysis, the response rate is also deemed adequate. Researchers generally recommend that the sample size should be 5 to 10 times larger than the number of constructs or variables in a study (Kotrlik & Higgins, 2001; Hair Jr et al., 2019), with some studies recommending a minimum of 10 times. Given that this study comprises nine (9) constructs, a minimum sample size of 90 is considered sufficient for analysis. Furthermore, Gefen et al. (2011) suggests that the sample size needed for PLS-SEM analysis can also be determined as 10 times the number of predictors. Since this study establishes two (2) predictors, the minimum requirement would be 20 respondents, which is well below the achieved sample size.

It is also noteworthy that SmartPLS software can process relatively small sample sizes, with a minimum as low as 30 cases (Chin, 1998). Additionally, the sample size of 94 surpassed the minimum requirement determined for linear multiple regression analysis, as calculated using G*Power 3.1 (refer to Chapter Four). In conclusion, the final sample size of 94 (n= 94) is not only adequate but also robust for the analyses undertaken in this study.

Table 5.1
Questionnaire Distribution and Decision

Items	Frequency	Percentage (%)
Questionnaires given out	158	100
Questionnaires returned	102	64.5
Questionnaires excluded	8	5
Usable Questionnaires	94	59.5

5.3 Data Screening and Preliminary Analysis

A thorough data screening process was carried out to ensure the quality and reliability of the questionnaire dataset before conducting the main analyses. The process began by checking for missing data to identify incomplete responses and determine whether removal or imputation was necessary. This was followed by detecting suspicious response patterns, such as straight-lining or unusually fast completion times, which may indicate careless answering. The dataset was then examined for normality, focusing on skewness and kurtosis to assess distributional suitability for multivariate analysis. Finally, common method bias was evaluated to reduce potential measurement errors from using a single self-report instrument. These steps ensured a clean and dependable dataset for further analysis.

5.3.1 Missing Data

Before further analysis and testing, the processing of data for missing responses was done by applying the Statistical Package for the Social Sciences (SPSS version 27). In this study, the screening of data aims to detect any missing values and data entry errors so that the accuracy of the data set can be maintained. Sekaran & Bougie, (2019) opined that there are several situations that could cause missing data. These include the inability of respondents to comprehend questions asked, difficulty in answering due to certain unforeseen circumstances, or unwillingness to respond. Thus, missing data is a normal phenomenon in data analysis which is well articulated by research scholars. For this study, no missing data was identified. This is because the survey was administered through an online form platform, which was designed to require participants to complete all items before being able to proceed to the next section or submit their responses. As for physical administered survey session, the researcher ensures that all sections of the questionnaire were answered to avoid missing responses. As a result, the dataset is complete and does not require further treatment for missing values.

5.3.2 Suspicious Response Pattern

Before key-in the data into SPSS 27, the researcher further examined the response patterns of each questionnaire received. The researcher observed the pattern of answers on the Likert scale questionnaire to ensure it does not represent a pattern often described as straight lining. The straight lining is when a respondent marks the same response for a high proportion of the question (Hair et al., 2017). For example, for the 5-point Likert scale, the response pattern is all 3s, (the middle response), then that respondent in most cases should be deleted from the data set. Other suspicious response patterns are diagonal lining and alternating extreme pole responses.

Inconsistency in the answers may also be addressed before analysing the data. Many surveys start with one or more screening questions. The purpose of a screening question is to ensure that only individuals who meet the prescribed criteria complete the survey. Out of 158 questionnaires distributed, 102 were received, and only 94 were further analysed and keyed into SPSS 27. Six of the questionnaires were observed to have suspicious response patterns whereas three shows the straight-lining answer, and the remaining shows inconsistency in their responses.

5.3.3 Assessment of Normality

Normality assessment is a preliminary step in quantitative data analysis that evaluates whether the data distribution follows a normal curve. Although the Partial Least Squares-Structural Equation Modeling (PLS-SEM) is considered a variance-based method that does not require multivariate normality (Hair Jr et al., 2019), testing for normality remains important for several reasons. First, it helps to understand the distributional characteristics of the dataset, detect potential data issues such as skewness, kurtosis, and outliers, and ensure that statistical results are not biased by extreme non-normality (Byrne, 2016).

Severe deviations from normality may affect indicator reliability, significance testing, and the interpretation of effect sizes, especially when employing parametric tests in conjunction with PLS-SEM (Kline, 2023). Furthermore, applying normality assessment prior to PLS-SEM analysis is necessary for two main reasons: (1) it provides a diagnostic check of the data to decide if transformations or robust methods (e.g., bootstrapping) are required, and (2) it increases transparency and credibility of the research by documenting the data quality before model estimation. Even though PLS-SEM is robust against violations of normality, awareness of distributional characteristics ensures that results are interpreted appropriately and methodological rigor is maintained.

5.3.3.1 Assessment of Outliers

Outliers are data points that deviate markedly from the overall pattern of a dataset. According to Barnett & Lewis (1994), an outlier is defined as *"an observation (or subset of observations) which appears to be inconsistent with the remainder of that set of data."* These unusual observations may arise from several possible sources, including natural variability within the data, measurement or recording errors, or structural changes in the phenomenon under investigation. The presence of outliers can influence statistical analyses, distort parameter estimates, and affect the validity of conclusions if not properly addressed. Therefore, identifying and carefully considering outliers is an essential step in quantitative research. To identify observations that are outside the values in the SPSS dataset, the outliers were checked by observing box plots in descriptive statistics and in the case of this study two (2) case observations are shown to have significant outliers and are marked with * (*68 and *58), and both items are removed from the usable questionnaires.

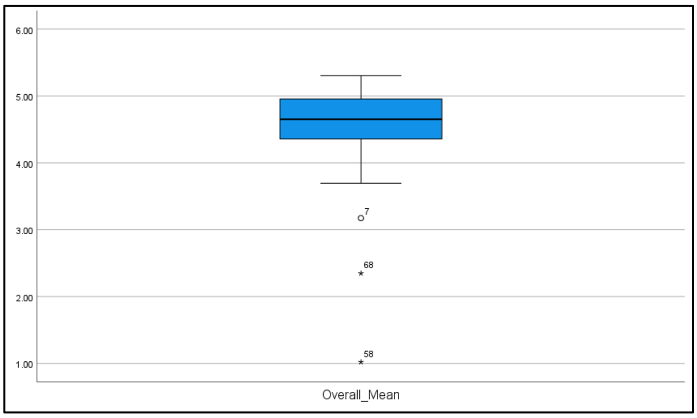

Figure 5.2 Boxplot Analysis of the Variables

5.3.3.2 Non-Normal Data Distribution

The PLS-SEM method appeals to many researchers as it enables the researcher to estimate a complex model with many constructs, indicator variables, and structural paths without imposing distributional assumptions on the data (Hair Jr et al., 2019). The use of PLS-SEM has advantages associated with data characteristics (distribution and scales) (Hair Jr et al., 2021). The advantage of data distribution in using PLS-SEM in social science studies as it almost always relies on non-normal data distribution (Hair Jr et al., 2019). Initially, the data set was tested through IBM SPSS 27 software in frequency assessment, including Q-Q plot assessment to the dependent variables (DV).

Figure 5.3 shows the Q-Q plot result of dependent variable (DV) in which the distributed data is approximately normal with minor deviations, indicating mild non-normality commonly found in survey-based research. Although this does not invalidate the dataset, it highlights the need for an analytical approach that is robust to non-normal distributions. PLS-SEM is therefore appropriate, as it is a variance-based, non-parametric technique that does not assume multivariate normality.

Hair Jr et al. (2019) emphasise that PLS-SEM remains reliable even when data deviates from normality because it relies on bootstrapping rather than parametric assumptions. Similarly, Ramayah et al. (2018) note that PLS-SEM is recommended for exploratory models and predictive research, particularly when moderate skewness or kurtosis is present. Hence, the data characteristics observed justify the use of PLS-SEM in this study.

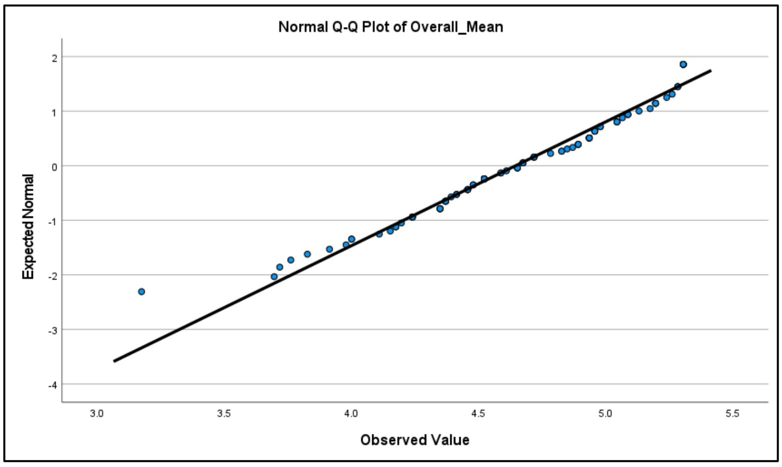

Figure 5.3 Normal Probability Q-Q Plot

5.3.3.3 Kolmogorov-Smirnov Test

In this research, the initial step to examine the distribution of the dataset was to conduct the Kolmogorov-Smirnov (K-S) test. This test is widely used to assess whether quantitative data significantly deviates from a normal distribution (Ghasemi & Zahediasl, 2012). When the p-value is greater than 0.05, the null hypothesis of normality cannot be rejected, implying that the data can be considered normally distributed (Lehmann & D'Abrera, 2006). In this study, a K-S test with Lilliefors Significance Correction was applied. The results, as reported in Table 5.2, show a K-S statistic of 0.073 with df = 94 and a significance value of p = 0.200.

Since the significance value exceeds the conventional threshold of 0.05, the null hypothesis of normality cannot be rejected. This outcome suggests that the overall mean data does not significantly deviate from a normal distribution, and the dataset can therefore be considered normally distributed. Establishing normality is important, as it supports the appropriateness of applying parametric statistical analyses, which typically assumes that the data follows a normal distribution (Field, 2018). However, it is also worth noting that in variance-based approaches such as PLS-SEM, normality is not a strict requirement, though confirming distributional assumptions provides greater robustness to the analysis (Hair Jr et al., 2019).

Table 5.2
Test of Normality

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Overall Mean Data	.073	94	.200

*. This is a lower bound of true significance.
[a.] Liliefors Significance Correction

5.3.3.4 Skewness and Kurtosis

Prior to conducting Partial Least Squares Structural Equation Modelling (PLS-SEM), it is important to examine the distributional properties of the dataset. Although PLS-SEM is a variance-based approach that does not strictly assume multivariate normality (Hair Jr et al., 2019), assessment of skewness and kurtosis remains useful for identifying potential deviations that may influence the robustness of the results, particularly in formative measurement models. Table 5.3 presents the descriptive statistics, including skewness and kurtosis, for all the constructs.

Table 5.3
Descriptive Analysis of Skewness and Kurtosis

Variables	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
HA_Mean	3.00	5.00	4.5979	0.45672	-1.182	1.374
DS_Mean	2.00	5.00	4.5266	0.64390	-1.721	3.637
DC_Mean	3.00	5.00	4.4202	0.51019	-0.660	-0.376
MA_Mean	2.17	5.00	4.5177	0.47043	-1.784	6.090
O_Mean	3.00	5.00	4.3723	0.60039	-0.754	-0.382
I_Mean	3.00	5.00	4.4876	0.52662	-0.758	-0.259
PL_Mean	3.00	5.00	4.3910	0.59519	-0.716	-0.301
T_Mean	3.00	5.00	4.4309	0.55770	-0.819	0.052
DP_Mean	2.86	7.00	5.6094	0.90355	-0.642	0.567

The results show that all constructs are negatively skewed, meaning that the data are clustered toward higher values of the scale. This is common in perception-based surveys, where respondents often provide favorable evaluations (Podsakoff et al., 2012). According to (Kline, 2023), skewness values between -2 and +2 are generally acceptable. In this dataset, all constructs fall within this range, with the most skewed items being DS_Mean (-1.721) and MA_Mean (-1.784), which remain within tolerable limits. Moreover, kurtosis values indicate the “peakedness” of the distribution. Values close to 0 suggest normality, while higher positive values indicate leptokurtic distributions (peaked), and negative values indicate platykurtic distributions (flat). Most constructs show kurtosis within acceptable thresholds (±7, as suggested by West, Finch, & Curran, 1995; Byrne, 2016). However, MA_Mean (6.090) and DS_Mean (3.637) indicate leptokurtic tendencies, suggesting that responses are tightly clustered around the mean. The analysis indicates that while the dataset exhibits negative skewness and certain leptokurtic distributions, the results remain within acceptable thresholds for PLS-SEM applications. The clustering of responses toward higher values reflects the positive perceptions of respondents, which is not uncommon in heritage conservation and HBIM-related research (López et al., 2018). Therefore, the dataset is deemed adequate and reliable for subsequent formative path model analysis using PLS-SEM.

5.3.4 Common Method Bias Test

The validity of statistical findings can be threatened when common method bias (CMB) is present in the data. To assess this issue, the current study applied Harman's single-factor test, a widely used diagnostic technique for detecting CMB (Podsakoff et al., 2003). The test was performed using SPSS version 27 through an unrotated principal component analysis. In this procedure, all variables are loaded onto a single factor with no rotation applied, and the amount of variance explained by the first factor is examined. According to Podsakoff et al. (2003), if a single factor accounts for more than 50% of the total variance, CMB may be a concern. The results indicated that no single factor emerged that explained more than 50% of the variance. The first factor accounted for 33.574%, which is well below the critical threshold. This finding suggests that common method bias is unlikely to be a serious issue in this study, thus supporting the validity of the dataset. The results are summarized in Table 5.4 below.

Table 5.4
Common Method Bias (Harman's Single Factor)

Component	Extraction Sums of Squared Loadings		
	Total (%)	Variance (%)	Cumulative (%)
1	17.065	33.574	33.574

5.4 Demographic Profiles

A sum of 94 respondents who participated in this survey were grouped based on their organization, designation, experience in conservation. A detail explanation is provided in the subsection below.

5.4.1 Designation of Respondents

The distribution of the respondents shown in Table 5.5 demonstrates that the survey successfully targeted key informants of the heritage-built environment. The dominance of senior professionals such as Conservators (37.2%), Directors/Associate Directors (29.8%), and Architects (13.8%) confirms that the dataset is primarily composed of individuals with decision-making authority, technical expertise, and design integration responsibilities. This is highly relevant, as these roles are directly accountable for shaping project strategies, approving budgets, determining conservation approaches, and implementing digital initiatives. The presence of these senior roles strengthens the content validity of the research, as the responses reflect informed judgments about organizational, informational, and technical layers of HBIM adoption in retrofit projects. Additionally, the inclusion of niche but complementary roles such as Academics (8.5%), Curators (3,2%) BIM Managers (2.1%), Contractors (2.1%), Town Planner (1.1%), Quantity Surveyors (1.1%) and Engineer (1.1%) provides a triangulation of perspectives, which enhances the construct validity of the findings by ensuring that both practical execution and policy considerations are represented.

Table 5.5
Designation of Respondents

No.	Category	Frequency	Percentage (%)
1.	Conservator	35	37.2
2.	Director / Associate	28	29.8
3.	Architect	13	13.8
4.	Academic	8	8.5
5.	Curator	3	3.2
6.	BIM Manager	2	2.1
7.	Contractor	2	2.1
8.	Quantity Surveyor	1	1.1
9.	Town Planner	1	1.1
10.	Engineer	1	1.1
	Total	94	100%

5.4.2 Length of Respondent's Experiences

Table 5.6 shows the distribution of the respondents based on length of experience. The data shows that most respondents are well-experienced professionals. The largest group (44.7%) reported between 11–20 years of involvement, while another 26.6% indicated more than 20 years of experience. Combined, this means that over 71%

of respondents have more than a decade of direct involvement in heritage conservation projects. Such a high proportion of senior practitioners provides strong credibility to the dataset, as their perspectives are grounded in extensive, long-term professional practice. Meanwhile, 15.9% of respondents reported 6–10 years of experience, and 12.8% indicated less than 5 years. This reflects the inclusion of early to mid-career professionals, ensuring that the dataset does not only represent established experts but also captures the voices of newer generations entering the field. Their perspectives are particularly important for understanding the adoption of emerging approaches such as HBIM, as younger professionals are often more exposed to digital technologies.

Table 5.6
Experience of Respondents

No.	Years of Experience	Frequency	Percentage (%)
1.	Above 20 years	25	26.6
2.	11 – 20 years	42	44.68
3.	6 – 10 years	15	15.96
4.	Less than 5 years	12	12.77
	Total	94	100

5.4.3 Types of Respondent's Organization

The results indicate in Table 5.7 demonstrate that most respondents are engaged in professional consultancy practices, with architectural consultancy firms (38.3%) and heritage conservation consultants (34.04%) forming the largest segments. This distribution is highly relevant to the study, as these two groups representing as practitioners which are most directly involved in the planning, design, and execution of heritage building projects. Their professional expertise ensures that the responses collected are both qualified and technically informed, which strengthens the credibility of the dataset. Respondents from government agencies and public sector organizations (14.89%) form the third largest group. This category includes departments such as architectural divisions, local authorities, and ministries overseeing heritage and construction. Their inclusion is crucial, as government bodies often act as the implementing bodies, regulators, or clients in heritage conservation projects. Their perspectives provide an institutional and policy-oriented dimension to the study, complementing the practitioner insights from the consultancy sector.

Another notable group comes from the education and academic sector (8.51%), which includes universities, academics, and training providers. Although numerically smaller, their contributions are significant because academic researchers and educators play a key role in advancing knowledge, developing methodologies, and training future practitioners in heritage conservation and digital technologies such as HBIM.

Finally, a small percentage (4.26%) of respondents belong to other professional services such as building surveying, town planning, engineering consultancy, and heritage tourism. These professionals, while fewer in number, add complementary viewpoints on the broader ecosystem of heritage building management. Their inclusion highlights the multidisciplinary character of conservation projects, which often require input beyond core architectural and conservation expertise.

Table 5.7
Type of Respondent's Organization

No.	Business Type	Frequency	Percentage (%)
1	Architectural Consultancy	36	38.3
2	Conservation Consultancy	32	34.04
3	Government Agencies	14	14.89
4	Academic Institutions	8	8.51
5	Other Professional Services	4	4.26
	Total	94	100

5.4.4 Location of Respondents

The results in Table 5.8 show that most of respondents are based in Kuala Lumpur (50.0%) and Selangor (22.3%), together representing more than 72% of the total sample. This concentration is unsurprising, given that these states are Malaysia's administrative, economic, and cultural hubs. Kuala Lumpur houses many key government agencies, universities, and heritage institutions, while Selangor supports many architectural, construction, and consultancy firms. Their dominance in the sample ensures that the perspectives of practitioners from the country's most active conservation and development zones are well represented. Pulau Pinang (13.8%) forms the third-largest group, which is particularly relevant due to George Town's status as a UNESCO World Heritage Site.

Hence, bringing valuable experience in managing historic urban landscapes and conservation projects under international recognition frameworks, providing depth to the study in terms of globally benchmarked practices. The remaining respondents come from other states such as Johor (4.3%), Perak (4.3%), and Kedah (3.2%), each of which has its own heritage assets and conservation initiatives. Though smaller in proportion, their representation is important in capturing regional variations in heritage management practices. States such as Melaka (1.1%), another UNESCO World Heritage city, and Sarawak (1.1%), which represents East Malaysia, also contribute to the dataset, ensuring that the study is not entirely dominated by Peninsular-centric perspectives.

Table 5.8
Location of Respondents

No.	Location	Frequency	Percentage (%)
1	Kuala Lumpur	47	50.0
2	Selangor	21	22.34
3	Pulau Pinang	13	13.83
4	Johor	4	4.26
5	Perak	4	4.26
6	Kedah	3	3.19
7	Melaka	1	1.06
8	Sarawak	1	1.06
	Total	94	100

5.4.4 Respondents' Engagement in Heritage Building Conservation Activities

The findings from Table 5.8 highlight that majority of respondents have extensive involvement in core heritage-built conservation practices, particularly adaptive reuse (76.6%), refurbishment (60.6%), and restoration (43.6%). These three project types are fundamental strategies in the conservation and sustainable management of heritage buildings. The high level of involvement indicates that respondents are not only familiar with preservation principles but also engaged in projects that seek to balance heritage value retention with modern functional requirements.

Rehabilitation (37.2%) and renovation (37.2%) are also strongly represented, underscoring the practical realities of maintaining heritage assets in Malaysia's evolving urban landscape. Meanwhile, retrofitting (25.5%) reflects growing attention to integrating modern building performance requirements (e.g., energy efficiency, structural upgrades) into heritage contexts, aligning with global discourses on sustainable heritage conservation.

Less frequently reported activities, such as conservation management plan and heritage impact assessment preparation (2.1% each), are nonetheless significant as they demonstrate awareness of formalized conservation management frameworks. Similarly, activities such as measured drawings, dilapidation reports, and digital heritage documentation, although less common, shows the gradual uptake of specialized technical documentation practices. The limited number of respondents reporting digital heritage initiatives (1.1%) suggests that the integration of advanced technologies such as HBIM, digital scanning, and 3D documentation remains at an early stage in the Malaysian context.

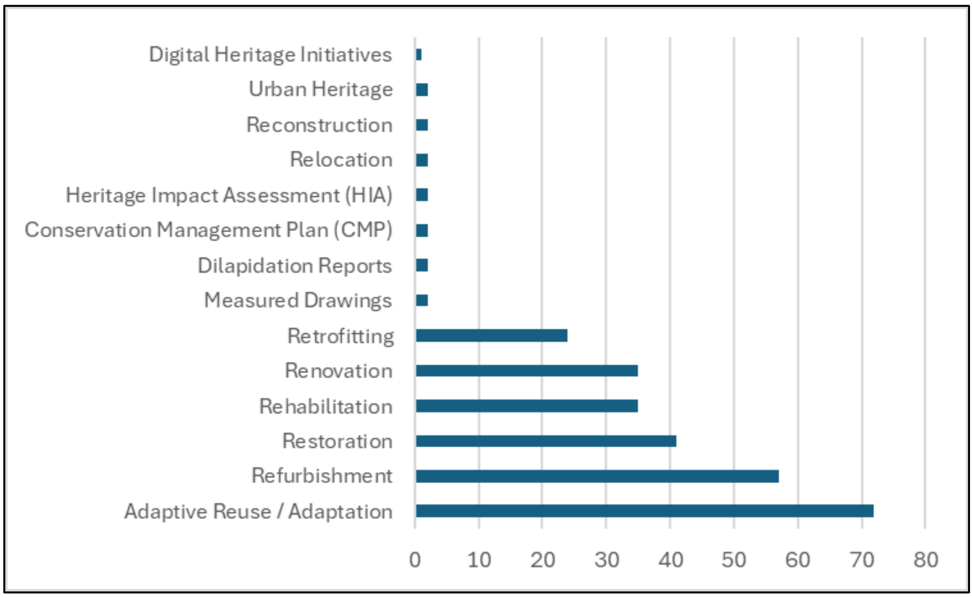

Figure 5.4 Respondent's Involvement in HB Conservation Projects

5.4.5 Respondent's Current State of HBIM Adoption

To evaluate the respondent's current state of awareness and adoption of Historic-Building Information Modelling (HBIM) among professionals, respondents were asked a series of questions covering their familiarity with the concept, sources of learning, level of understanding, organizational adoption, extent of usage, and willingness to attend future training. The results are presented through Figures 5.4 to 5.8, which illustrate the distribution of responses.

For the respondents' familiarity with HBIM shown in Figure 5.5, most respondents (74.5%) indicated that they were familiar with HBIM, while 25.5% reported no familiarity. This suggests that HBIM has gained significant recognition among heritage conservation professionals, although there remains a substantial proportion who have yet to be exposed to the concept. The finding aligns with global trends where HBIM is increasingly discussed but remains in an early stage of mainstream adoption (Ismail et al., 2021; Ali et al., 2018b; Said et al., 2025).

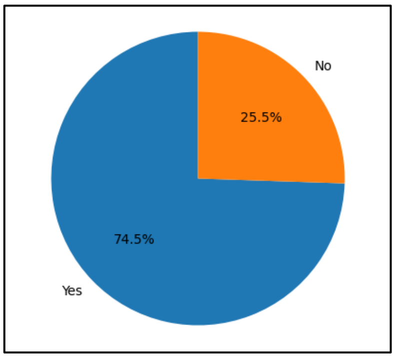

Figure 5.5 Respondent's Familiarity with HBIM

Respondents were asked where they first learned about HBIM. Figure 5.6 demonstrates the most common sources of exposure included academic publications (32.9%), colleagues and professional networks (26.8%), and seminars and conferences (23.1%). A smaller proportion cited formal education or training (11.4%), online platforms (5.8%), or self-directed learning. The results reflect the fragmented and informal pathways of HBIM knowledge is currently disseminated in Malaysia, with reliance on professional sharing and academic literature rather than structured training programs. HBIM knowledge in Malaysia is reaching practitioners largely via fragmented, informal channels rather than through coordinated curricula and systematic upskilling. This pattern aligns with Malaysian studies reporting limited HBIM readiness and specialist skills, and consequent need for guidelines and targeted training to support practice. Salleh et al. (2022), explicitly developed an HBIM implementation guideline to address method and skills gaps in Malaysian heritage projects, underscoring that structured know-how is still emerging.

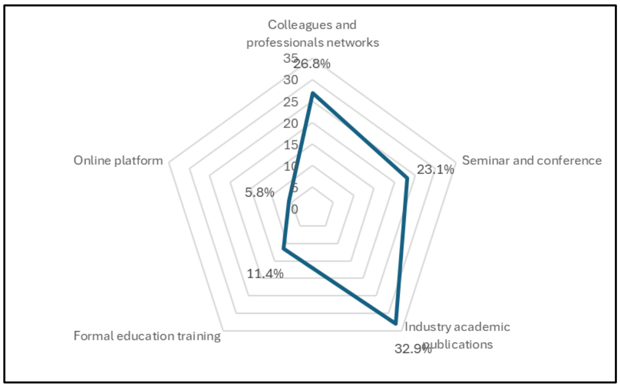

Figure 5.6 Source of HBIM knowledge

Figure 5.7 shows that in terms of understanding HBIM, 41.5% of respondents described their understanding as moderate, while 31.9% had only slight familiarity. A further 13.8% reported understanding HBIM well, and 5.3% very well, whereas 7.5%

admitted no understanding at all. This distribution highlights a knowledge gap, where awareness is widespread but deeper technical competence is limited. The results reinforce the need for formal capacity-building initiatives that move practitioners from “awareness” to “proficiency.”

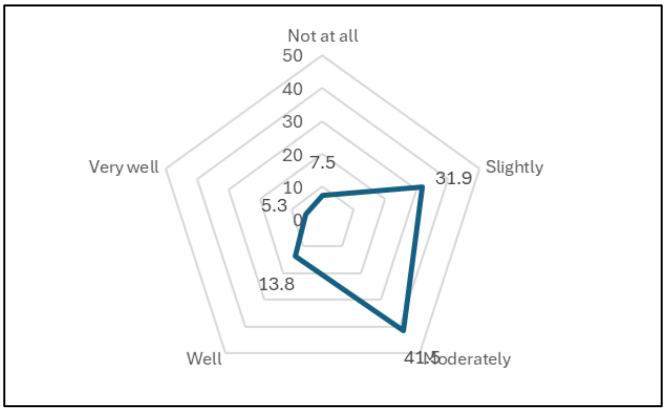

Figure 5.7 Understanding of HBIM

Furthermore, the respondents were asked whether their organizations applied HBIM in heritage conservation project. From the data shown in Figure 5.8, 73.4% or respondents reported no adoption, while 22.3% confirmed usage, and 4.3% were unsure. The results indicate that HBIM remains in a nascent stage of institutional adoption, suggesting barriers such as cost, lack of expertise, or organizational inertia as previously discussed in the earlier Chapter One and Two.

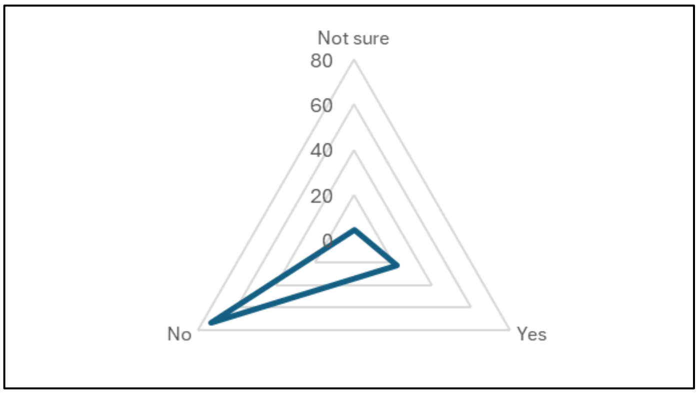

Figure 5.8 HBIM Use by Organization

Moreover, among organizations that applied HBIM in projects, the frequency of use was also limited. As illustrated in Figure 5.9, 52.1% reported no use at all, 23.4% rarely used HBIM, 21.3% sometimes used it, and only 3.2% reported using HBIM often. This further demonstrates that adoption is sporadic and non-systematic, with HBIM not yet embedded as a routine practice in heritage projects.

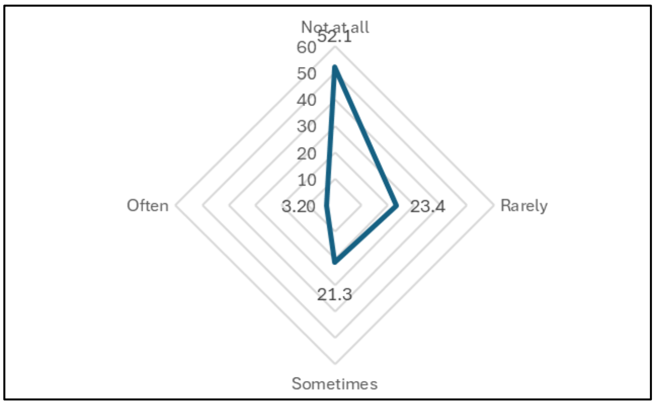

Figure 5.9 HBIM Adoption in Projects

5.5 Multivariate Analysis: Partial Least Squares–Structural Equation Modelling (PLS-SEM)

To further investigate the relationship between the endogenous and exogenous variables in this research, the PLS-SEM assessment was conducted using SmartPLS 4.0, which involves two stages: (1) formative measurement model evaluation and (2) structural model evaluation. SmartPLS 4.0 was selected because it is a widely adopted and user-friendly tool for PLS-SEM analysis, providing advanced functions for measurement and structural model assessment (Hair et al., 2017).

In PLS-SEM, there are two types of measurement models: reflective and formative. Reflective model indicators are interchangeable; removing one item does not alter the conceptual domain of the construct. In contrast, formative indicators are non-interchangeable, as each contributes a distinct meaning to the construct (Diamantopoulos & Winklhofer, 2001). Reflective measurement emphasizes maximizing the overlap among highly correlated indicators, whereas formative measurement minimizes overlap by capturing complementary aspects of the construct (Hair et al., 2017).

For reflective models, indicators are assumed to be caused by the construct and should therefore be highly correlated (Hulland, 1999). By contrast, formative measurement models assume that causal indicators form the construct through linear combinations (Hair et al., 2017). Within formative models, indicators can take the form of either composite or causal indicators (Hair et al., 2017). Following the guidelines of (Hair et al., 2017), this research adopts a formative measurement model. This choice is justified because the causal priority flows from the indicators to the construct (Diamantopoulos & Winklhofer, 2001), the construct is formed as a combination of its indicators (Coltman et al., 2008; Fornell & Bookstein, 1982), and the indicators are not interchangeable since each carries a specific and unique meaning (Coltman et al., 2008; (Jarvis et al., 2003). Consequently, deleting indicators from a formative construct would directly affect the definition of the construct itself.

In this study, the independent variables were derived from document reviews of HBIM-retrofit characteristics, which identified eight dimensions that are developed into two higher-order constructs. This path model defines the HBIM-retrofit framework, which consist of heritage aspect, development stage, retrofit design criteria, method of approach, organizational, informational, process lifecycle and technical. Thus, the removal of any variable could undermine the integrity of the model. Furthermore, the indicators for each variable were systematically abstracted from established retrofit and HBIM-retrofit guidelines, supplemented with insights from relevant literature, ensuring comprehensive coverage of the constructs under investigation.

5.6 Formative Measurement Model Evaluation

The formative measurement model evaluates the convergent validity, potential collinearity among indicators, and the significance and relevance of outer weights. It represents the part of the PLS-SEM path model that examines the relationship between latent variables and their associated measures. For reliable results, the number of algorithm iterations should remain below the maximum threshold (e.g., 300) (Hair et al., 2017). If the PLS-SEM algorithm fails to converge within this limit, it indicates that the procedure was unable to identify a stable solution (Hair et al., 2017).

5.6.1 Formative Measurement Model Evaluation – First Run

Figure 5.10 presents the formative model evaluation generated through the PLS algorithm (PLS-Algorithm 1). In formative measurement models, the outer weights are estimated using partial regression to determine the relative contribution of each indicator to its latent construct. The results show that the R^2 value of the dependent variable (DP) is 0.633, which represents a *substantial level of explanatory power* (Hair et al., 2017). This indicates that approximately 63.3% of the variance in performance (DP) of heritage building conservation projects in Malaysia is explained collectively by the formative constructs: heritage aspect (HA), development stage (DS), retrofit design criteria (DC), method of approach (MA), organizational (O), informational (I), process lifecycle (PL), and technical (T). According to (Hair et al., 2017), when all indicators are coded consistently (from "strongly disagree" to "strongly agree") and the hypothesized relationships are positive, the estimated path coefficients are expected to be positive. This condition is met in the present model, reinforcing the validity of the formative measurement specification.

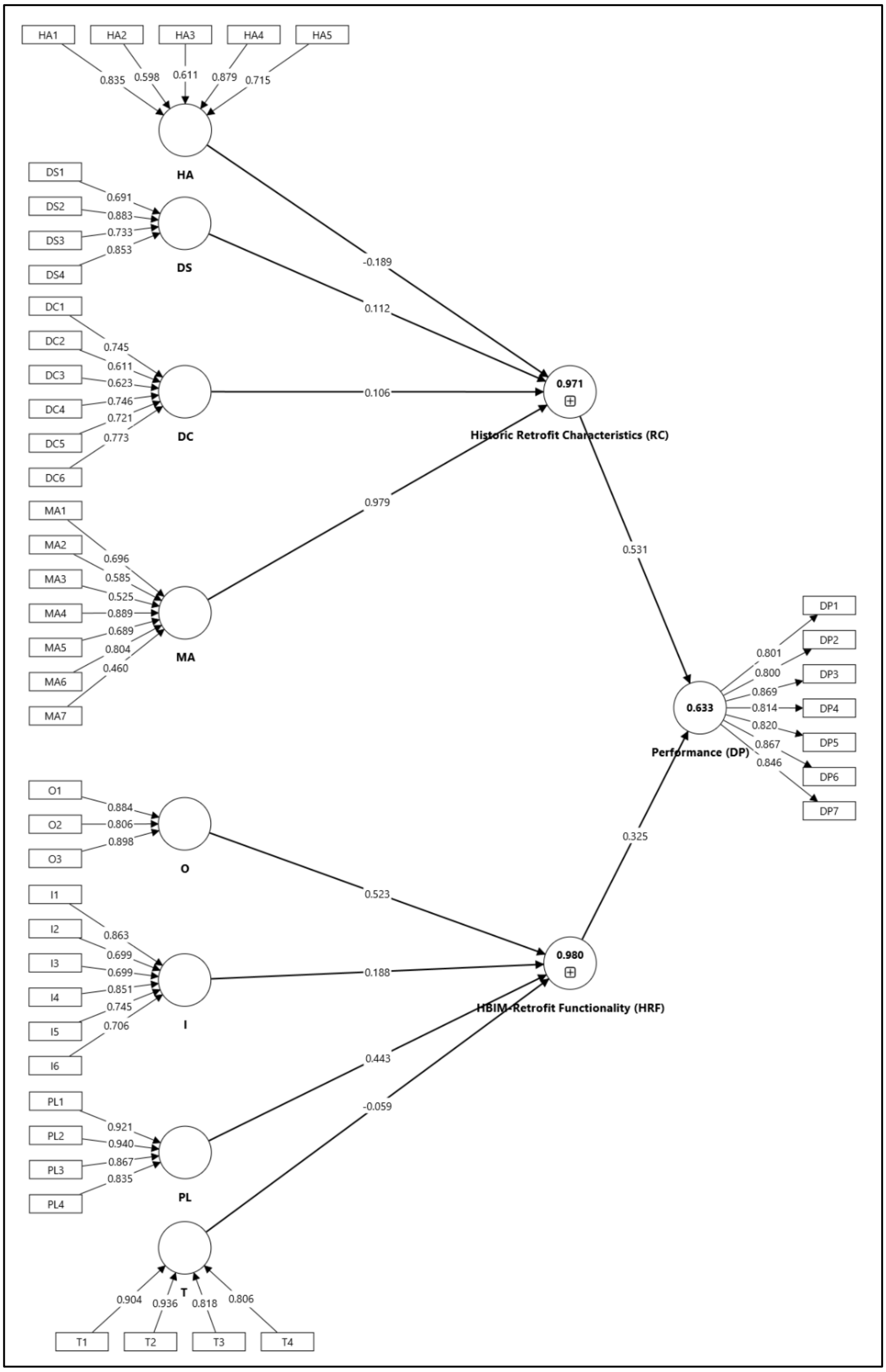

Figure 5.10 Formative Model Evaluation – First Run

5.6.2 Convergent Validity

Convergent validity refers to the extent to which a measure correlates positively with other measures of the same construct when assessed using different indicators (Hair et al., 2017). In the context of formative measurement models, this is commonly assessed through redundancy analysis (Chin, 1998). The logic of redundancy analysis lies in testing whether a formatively measured construct is strongly correlated with other (reflective) measures of the same construct using different indicators, which serves as an external criterion for validation (Götz et al., 2009). Hence, when evaluating formative measurement models, the formatively measured should demonstrate a high correlation with a reflective measure of the same variable (Chin, 1998).

The term "redundancy" arises because the construct is measured twice: once through its formative indicators and again through a reflective indicator. The strength of the path coefficient linking these two measures is therefore indicative of the validity of the formative indicators in capturing the construct of interest (Hair et al., 2017). Ideally, the path coefficient should be around 0.80, while a minimum of 0.70 is considered acceptable. This translates into an R^2 value of at least 0.50, confirming moderate convergent validity (Hair et al., 2017).

It is also important to note that, by design, formative indicator weights are often smaller than reflective indicator loadings, since formative constructs capture broader dimensions where not all indicators are equally influential (Götz et al., 2009). Nevertheless, a strong correlation between the formative construct and its reflective counterpart provides evidence that the designated set of formative indicators adequately represents the underlying construct.

5.6.2.1 HA Formative to HA Reflective

Figure 5.11 shows the result of the convergent validity for heritage aspect (HA). The results indicate a path coefficient of 0.642, which exceeds the recommended threshold of 0.60 for exploratory studies (Hair et al., 2021) and is within an acceptable range (Hair et al., 2017; Chin, 2010). This suggests that the formative indicators of HA adequately converge to explain the HAr reflective measures. Furthermore, the R^2 value of 0.412 demonstrates that approximately 41.2% of the variance in the reflective construct is explained by the formative construct. Although the R^2 reflects a moderate level of convergent validity, it still provides sufficient evidence of predictive relevance (Cohen, 2013; Hair Jr et al., 2019). Further, all of the indicator loadings for HA and HAr exceed 0.70, confirming strong reliability and supporting the unidimensionality of the construct. Hence, the results support the convergent validity of the HA construct (Hair et al., 2021), confirming that the formative indicators collectively represent the same underlying concept as the reflective measure.

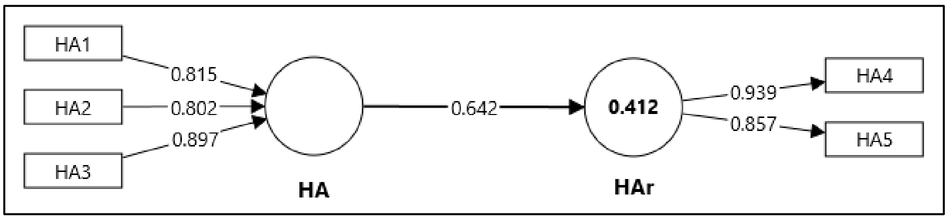

Figure 5.11 Path Coefficient HA Formatives to HA Reflective

5.6.2.2 DS Formative to DS Reflective

Figure 5.12 shows the result of the convergent validity for development stage (DS). The results reveal a path coefficient of 0.869, which is well above the recommended threshold of 0.70 (Hair et al., 2017; Chin, 2010). This indicates a strong convergence between the formative indicators and the reflective measure. In addition, the model explains 75.5% of the variance in the reflective construct (R^2= 0.755), which is considered *substantial* according to Cohen (2013). Together, these findings provide strong support for the convergent validity of the DS construct, confirming that the formative indicators robustly represent the same underlying concept captured by the reflective measure.

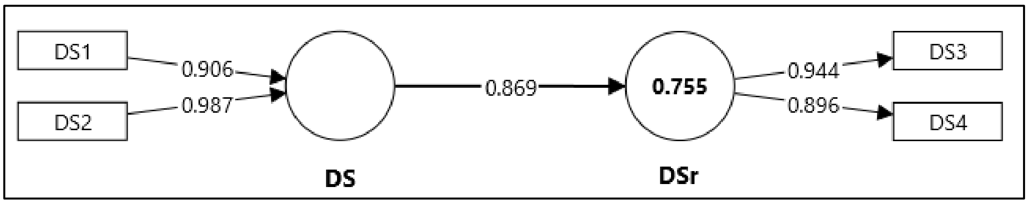

Figure 5.12 Path Coefficient DS Formatives to DS Reflective

5.6.2.3 DC Formative to DC Reflective

Figure 5.13 shows the result of the convergent validity for retrofit design criteria (DC). The results show a path coefficient of 0.716, which meets the recommended minimum threshold of 0.70 for establishing convergent validity (Hair et al., 2017; Chin, 2010). This indicates that the formative indicators of DC adequately converge with the reflective construct. Furthermore, the analysis demonstrates that the formative construct explains 51.3% of the variance in the reflective construct (R^2= 0.513), which is considered a *moderate level* of explanatory power (Cohen, 2013). Overall, these findings provide evidence supporting the convergent validity of the DC construct, confirming that its formative indicators capture the same underlying concept as the reflective measure.

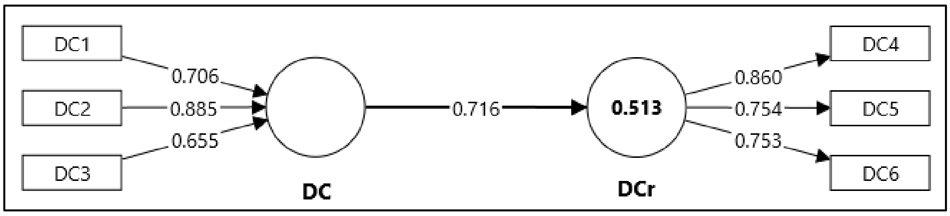

Figure 5.13 Path Coefficient DC Formatives to DC Reflective

5.6.2.4 MA Formative to MA Reflective

Figure 5.14 shows the result of the convergent validity for method of approach (MA). The results indicate a path coefficient of 0.785, which is above the recommended minimum threshold of 0.70 (Hair et al., 2017; Chin, 2010). This demonstrates that the formative indicators of MA strongly converge with the reflective construct. Moreover, the analysis reveals that the formative construct explains 58.5% of the variance in the reflective measure (R^2 = 0.585), which represents a *moderate-to-substantial* level of explanatory power (Cohen, 2013). These findings confirm the convergent validity of the MA construct, showing that its formative indicators consistently capture the same underlying concept as the reflective measure.

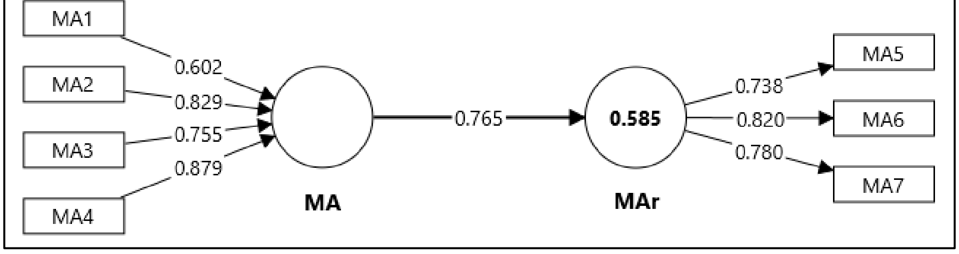

Figure 5.14 Path Coefficient MA Formatives to MA Reflective

5.6.2.5 O Formative to Or Reflective

Figure 5.15 shows the result of the convergent validity for organizational (O). The redundancy analysis produced a path coefficient of 0.708, which slightly exceeds the recommended threshold of 0.70 (Hair et al., 2017; Chin, 2010). This suggests that the formative indicators of O demonstrate adequate convergence with the reflective construct. Additionally, the results show that the formative construct explains 50.2% of the variance in the reflective measure ($R^2 = 0.502$). According to Cohen (2013), this represents a *moderate level* of explanatory power. Overall, these findings provide sufficient evidence to support the convergent validity of the O construct, confirming that its formative indicators capture the same underlying concept as the reflective measure.

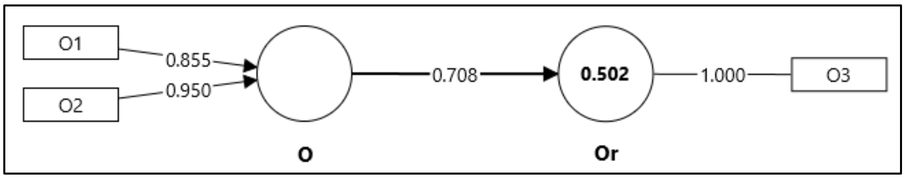

Figure 5.15 Path Coefficient O Formatives to O Reflective

5.6.2.6 Formative to Ir Reflective

Figure 5.16 shows the result of the convergent validity for informational (I). The results indicate a path coefficient of 0.822, which is well above the recommended minimum threshold of 0.70 (Hair et al., 2017; Chin, 2010). This demonstrates a strong degree of convergence between the formative indicators of I and their reflective measure. Furthermore, the analysis shows that the formative construct explains 67.6% of the variance in the reflective construct ($R^2 = 0.676$), which represents a *substantial level* of explanatory power according to Cohen (2013). Overall, these findings provide clear evidence for the convergent validity of the I construct, confirming that its formative indicators strongly capture the underlying concept represented by the reflective measure.

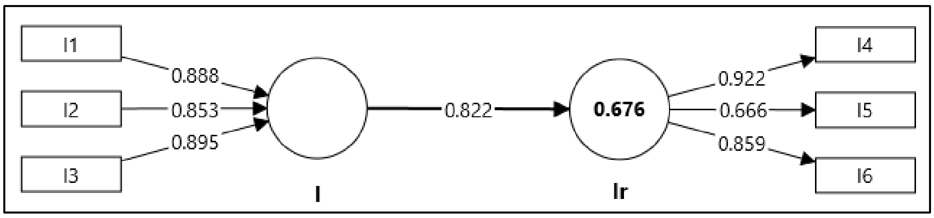

Figure 5.16 Path Coefficient I Formatives to I Reflective

5.6.2.7 PL Formative to PLr Reflective

Figure 5.17 shows the result of the convergent validity for process lifecycle (PL). The results show a path coefficient of 0.800, exceeding the recommended threshold of 0.70 (Hair et al., 2017; Chin, 2010). This demonstrates that the formative indicators of PL strongly converge with the reflective measure. In addition, the analysis reveals that the formative construct explains 64.0% of the variance in the reflective construct (R^2 = 0.640), which represents a *substantial level* of explanatory power (Cohen, 2013). Overall, these results provide solid evidence for the convergent validity of the PL construct, confirming that its formative indicators reliably represent the same underlying concept captured by the reflective measure.

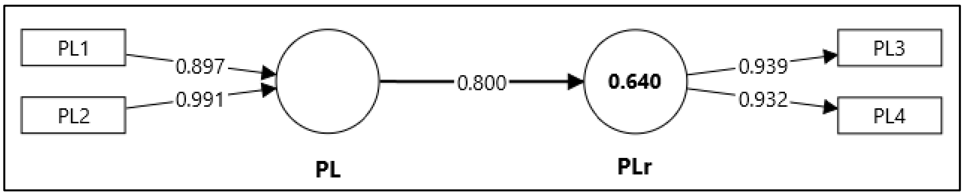

Figure 5.17 Path Coefficient PL Formatives to PL Reflective

5.6.2.8 T Formative to Tr Reflective

Figure 5.18 shows the result of the convergent validity for the technical (T). The results indicate a path coefficient of 0.775, which is above the recommended threshold of 0.70 (Hair et al., 2017; Chin, 2010). This suggests that the formative indicators of T adequately converge with the reflective construct. Furthermore, the formative construct explains 60.0% of the variance in the reflective measure (R^2 = 0.600), representing a *substantial level* of explanatory power (Cohen, 2013). Together, these findings confirm the convergent validity of the T construct, demonstrating that its formative indicators consistently capture the same conceptual domain as the reflective measure.

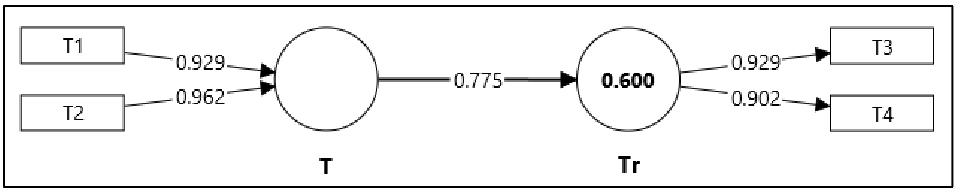

Figure 5.18 Path Coefficient T Formatives to T Reflective

5.6.2.9 DP Formative to DPr Reflective

Figure 5.19 shows the result of the convergent validity for the dependent variable performance (DP). The analysis reveals a path coefficient of 0.856, which is well above the recommended minimum threshold of 0.70 (Hair et al., 2017; Chin, 2010). This indicates a strong degree of convergence between the formative indicators of T and its reflective counterpart. Furthermore, the formative construct explains 73.2% of the variance in the reflective measure ($R^2 = 0.732$), which represents a *substantial level* of explanatory power according to Cohen (2013). Taken together, these findings provide strong evidence for the convergent validity of the T construct, confirming that the formative indicators robustly capture the same underlying concept represented by the reflective measure.

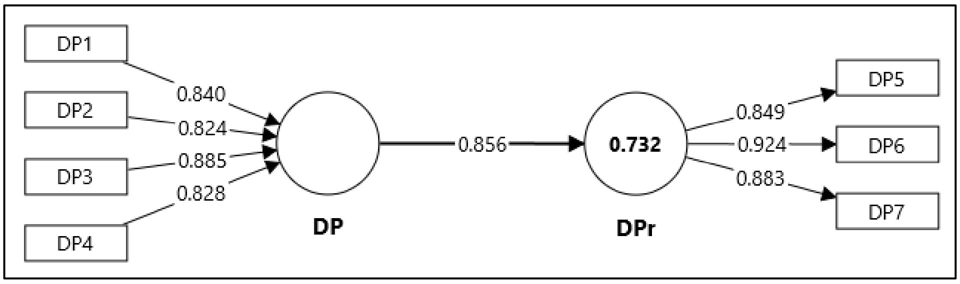

Figure 5.19 Path Coefficient DP Formatives to DP Reflective

5.6.3 Multicollinearity

Multicollinearity is the situation where items for a construct correlate highly with each other. Variance Inflation Factor (VIF) is utilised to assess the degree of multicollinearity among the indicators (Fornell & Bookstein, 1982). If the VIF values less than 5.0, it shows a minor method bias, while the VIF value of 10 is considered major method bias (Götz et al., 2009). Consequently, the VIF threshold used in the common method bias test should arguably be somewhat higher than 3.3 when factor-based PLS-SEM algorithms are used (Kock, 2015). Therefore, VIF of 5 is employed in this research (Kock, 2015; Kock & Lynn, 2012). Other than Kock & Lynn (2012), other scholars also agreed that the threshold of VIF below 5 is acceptable (Akinwande et al., 2015; J. F. Hair Jr et al., 2019; Hair et al., 2011; Latif et al., 2020; Olusegun et al., 2015). High collinearity is indicated when the VIF value reaches 5 or above, which requires researchers to address the collinearity issue with careful considerations.

5.6.3.1 Outer Variance Inflation Factor (VIF) Values

The outer VIF values presented in Table 5.9 indicate that all indicators fall below the threshold of 5, except for DS2 (retrofit design stage) with a VIF of 6.605 and DS3 (implementation stage) with a VIF of 5.994. These values suggest multicollinearity issues, which were addressed by removing one of the affected indicators. However, it is essential that the remaining indicators must continue to capture the construct's content from a theoretical perspective (Hair et al., 2017). Within the development stage (DS) construct, two indicators exceeded the recommended VIF threshold (> 5.0). As a result, DS2 was removed from the path model since it showed the highest VIF value.

The multicollinearity observed in DS2 (retrofit design stage) appears to stem from its close relationship with DS1 (pre-retrofit stage). This finding also aligns with the notion that historic building retrofit strategies are most effectively integrated during the earliest design phases, where input from relevant consultants can provide significant benefits (McCaig et al. 2018; Troi et al, 2015). Moreover, the remaining three indicators of the development stages (DS1, DS3 & DS4) are still inclusive, drawing similarities with conservation phase model adapted by Woodward & Heesom (2021); Baharuddin et al. (2024) and Yusoff & Brahim (2021).

Furthermore, indicator PL2 (3D modelling) recorded a VIF value close to the threshold of 5.0 (PL2= 4.482), suggesting potential multicollinearity concerns; hence, the item was considered and removed from the path model. This finding is justifiable, as HBIM 3D modelling is inherently integrated with HBIM data acquisition processes (Khalil et al. 2021; Khodier, 2016). In practice, data modelling activities are often embedded in the earliest stages of documentation and conservation workflows, since the modelling phase typically builds directly upon the acquired survey and scanning data (Bruno & Roncella, 2019; Khalil et al., 2021). Moreover, the remaining elements (PL1, PL3, and P4) continue to reflect the holistic concept of the HBIM process lifecycle (Khalil et al., 2021; Hull & Bryan, 2019; Kamaruzaman et al., 2020).

Consequently, integrating indicator 3D modelling with data acquisition is both conceptually and practically appropriate, as both processes function complementarily within HBIM-enabled conservation practices. Following the removal of DS2 and PL2, a second calculation run was conducted to examine whether the exclusion affected the reliability of the remaining indicators within the construct.

Table 5.9
Multicollinearity of Outer Model

No.	Indicator	Variance Inflation Factor (VIF)
1	HA1	1.702
2	HA2	1.787
3	HA3	2.140
4	HA4	2.477
5	HA5	1.714
6	DS1	3.396
7	**DS2**	**6.605**
8	**DS3**	**5.994**
9	DS4	2.015
10	DC1	1.919
11	DC2	1.896
12	DC3	1.903
13	DC4	2.098
14	DC5	1.454
15	DC6	1.409
16	MA1	1.763
17	MA2	2.439
18	MA3	1.933
19	MA4	2.396
20	MA5	1.706
21	MA6	1.751
22	MA7	2.053
23	O1	1.905
24	O2	2.206
25	O3	2.007
26	I1	2.860
27	I2	2.348
28	I3	2.503
29	I4	3.449
30	I5	1.403
31	I6	2.191
32	PL1	3.394
33	**PL2**	**4.482**
34	PL3	3.070
35	PL4	2.676
36	T1	2.985
37	T2	3.326
38	T3	2.761
39	T4	2.028
40	DP1	2.835
41	DP2	2.292
42	DP3	3.096
43	DP4	2.525
44	DP5	3.184
45	DP6	3.815
46	DP7	3.195

5.6.3.2 Inner Variance Inflation Factor (VIF) Values

In this study, two higher-order constructs (HOCs) were modeled using the repeated indicators approach. Since SmartPLS software does not directly provide inner VIF values for HOCs, collinearity was assessed at the lower-order construct (LOC) level, following the recommendations of Hair et al. (2017) and Sarstedt et al. (2019). The LOCs serve as proxies for the higher-order construct (HOCs), and their VIF values therefore indicate potential collinearity among exogenous variables. As shown in Table 5.10, all of the inner VIF values for the LOCs are below the threshold of 5.0. Thus, collinearity at both the LOC and HOC levels was deemed acceptable for the subsequent PLS-SEM analysis.

Table 5.10
Multicollinearity of Inner Model

No.	Exogenous Construct (LOC under HOC)	Dependent Variable	Inner VIF Values
1	Heritage Aspect (HA)	DP	1.846
2	Development Stage (DS)	DP	1.200
3	Retrofit Design Criteria (DC)	DP	1.890
4	Method of Approach (MA)	DP	1.891
5	Organizational (O)	DP	2.070
6	Informational (I)	DP	2.534
7	Process Lifecycle (PL)	DP	2.733
8	Technical (T)	DP	2.098

5.6.4 Formative Model Evaluation – Second Run

Figure 5.20 shows the second run (PLS-Algorithm 2) of formative measurement model evaluation. After omitting the two indicators (DS2 and PL2). The R^2 value decreased slightly from 0.633 to 0.626 after omitting DS2 and PL2. This reduction of 0.7% is minimal and does not materially affect the model's predictive accuracy or explanatory power. The value of 0.626 remains within the same interpretive category (moderate to substantial), demonstrating that the model continues to explain approximately 62.6% of the variance in dependent construct (Hair et al., 2017; Chin, 1998). This suggests that the removal of multicollinear indicators enhanced the reliability and parsimony of the measurement model (Hair et al., 2017; Kock & Lynn, 2012). Therefore, the researcher re-evaluated the VIF value of the second run formative measurement model as follows.

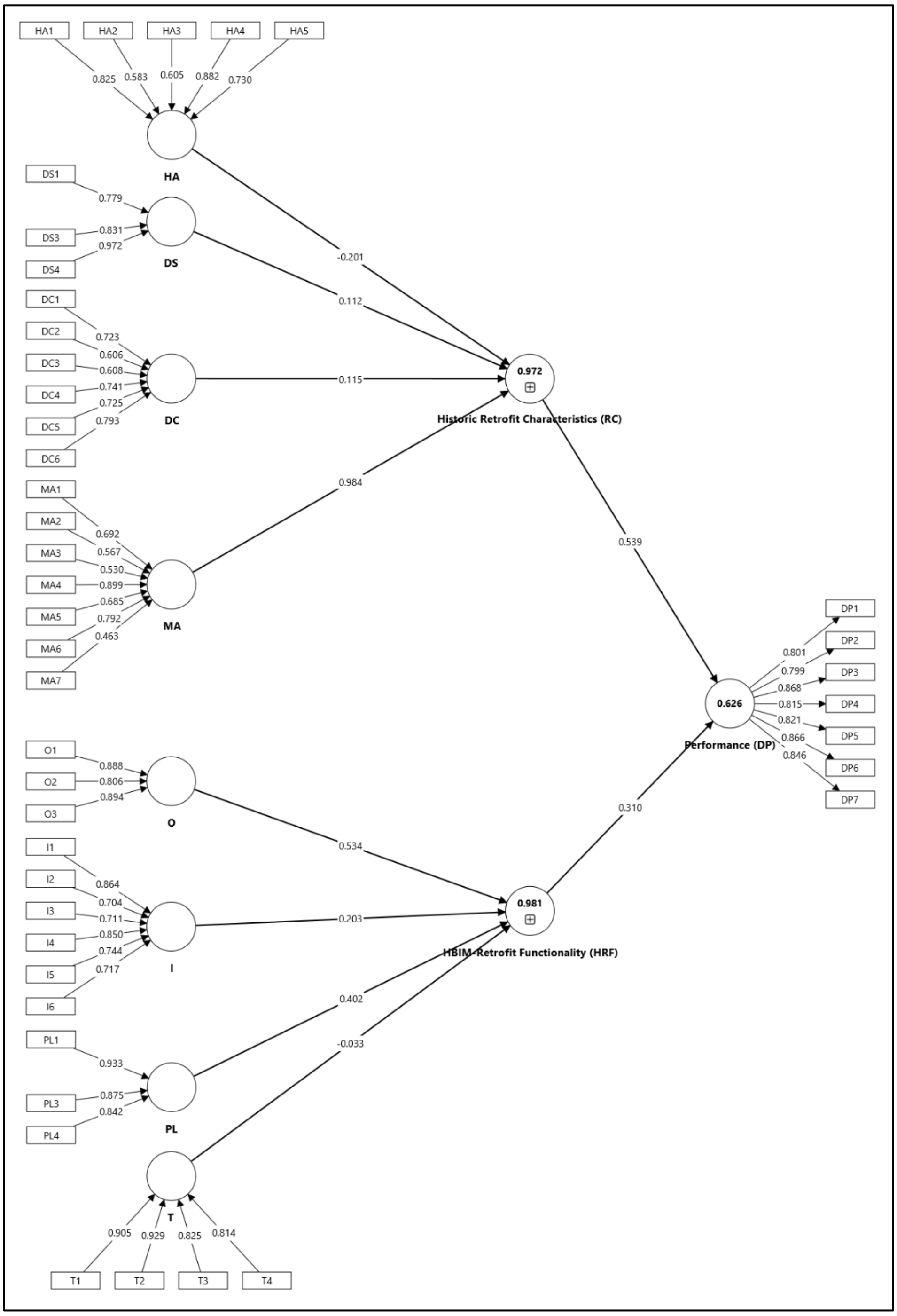

Figure 5.20 Formative Model Evaluation – Second Run

5.6.5 Outer Variance Inflation Factor (VIF) Values – Second Run

The Variance Inflation Factor (VIF) values were examined to detect further potential multicollinearity issues among the formative indicators. According to Hair et al. (2017), VIF values below 5.0 indicate no critical collinearity problem. As shown in Table 5.11, all indicators recorded VIF values well below the threshold after the removal of DS2 and PL2 indicators, which previously showed problematic levels. The highest VIF was 3.815 (DP6), and the lowest was 1.403 (I5), both within the acceptable range. This confirms that multicollinearity is no longer a concern in the outer model.

Table 5.11
Multicollinearity of Outer Model - Second Run

No.	Indicator	Variance Inflation Factor (VIF)
1	HA1	1.702
2	HA2	1.787
3	HA3	2.140
4	HA4	2.477
5	HA5	1.714
6	DS1	3.396
7	DS3	3.405
8	DS4	2.015
9	DC1	1.919
10	DC2	1.896
11	DC3	1.903
12	DC4	2.098
13	DC5	1.454
14	DC6	1.409
15	MA1	1.763
16	MA2	2.439
17	MA3	1.933
18	MA4	2.396
19	MA5	1.706
20	MA6	1.751
21	MA7	2.053
22	O1	1.905
23	O2	2.206
24	O3	2.007
25	I1	2.860
26	I2	2.348
27	I3	2.503
28	I4	3.449
29	I5	1.403
30	I6	2.191
31	PL1	2.064
32	PL3	2.563
33	PL4	2.638
34	T1	2.985
35	T2	3.326
36	T3	2.761
37	T4	2.028
38	DP1	2.835
39	DP2	2.292
40	DP3	3.096

41	DP4	2.525
42	DP5	3.184
43	DP6	3.815
44	DP7	3.195

5.6.6 Inner Variance Inflation Factor (VIF) Values – Second Run

Further, a second run of the inner VIF were conducted on the two higher-order constructs (HOCs). Since SmartPLS does not directly provide inner VIF values for HOCs, collinearity was assessed at the lower-order construct (LOC) level, following the recommendations of Hair et al. (2017) and Sarstedt et al. (2019). The LOCs serve as proxies for the higher-order construct, and their VIF values therefore indicate potential collinearity among exogenous variables. As shown in Table 5.12, all inner VIF values for the LOCs are below the threshold of 5.0. Thus, collinearity at both the LOC and HOC levels was deemed acceptable for subsequent PLS-SEM analysis.

Table 5.12
Multicollinearity of Inner Model - Second Run

No.	Exogenous Construct (LOC under HOC)	Dependent Variable	Inner VIF Values
1	Heritage Aspect (HA)	DP	1.877
2	Development Stage (DS)	DP	1.209
3	Retrofit Design Criteria (DC)	DP	1.851
4	Method of Approach (MA)	DP	1.842
5	Organizational (O)	DP	2.079
6	Informational (I)	DP	2.532
7	Process Lifecycle (PL)	DP	2.600
8	Technical (T)	DP	2.065

5.6.7 Path Coefficient

The results of the hierarchical component model (HCM) analysis revealed in Table 5.13 indicates that two lower-order constructs (LOCs), heritage aspects (HA) and technical (T) recorded negative path coefficients toward their respective higher-order constructs (HOCs), with $\beta = -0.201$ and $\beta = -0.059$, respectively. A negative weight suggests that these LOCs contribute less, or even inversely, to the formation of their

HOC. While this may initially appear problematic, such results are not uncommon in formative–reflective measurement models. In formative models, certain dimensions can exhibit opposing effects without undermining the validity of the higher-order construct as long as the construct retains its theoretical coherence (Becker et al., 2012; Hair Jr et al, 2019).

Further analysis shows that the negative contributions of HA and T, the higher-order constructs historic building retrofit characteristic (RC) ($\beta = 0.530$, $p < 0.05$) and HBIM-retrofit functionality (HRF) ($\beta = 0.323$, $p < 0.05$) as shown in Table 5.14. Both higher-order constructs demonstrated statistically significant path coefficients above the recommended threshold of 0.30 (Chin, 1998; Hair et al., 2017). This indicates that the HOCs remain a robust predictors of the dependent construct (DP). In other words, the multidimensional nature of the constructs allows certain LOCs to contribute less strongly or even negatively, while the overall conceptualization still performs adequately in explaining the variance in the outcome.

Furthermore, the strong positive loading of method of approach (MA, $\beta = 0.984$) on retrofit characteristic (RC) underscores its dominant influence within this higher-order construct, while organizational (O, $\beta = 0.523$) and process lifecycle (PL, $\beta = 0.444$) emerged as key contributors to HBIM-retrofit functionality (HRF). Conversely, the weaker contribution of I (informational, $\beta = 0.188$) and the negative weight of technical (T) highlight that these dimensions may play a less central role in shaping HRF. Nonetheless, their inclusion remains theoretically justified, as removing LOCs solely due to weaker or negative paths could risk omitting conceptually relevant aspects (Sarstedt et al., 2016).

Taken together, these findings highlight the value of using HCM in PLS-SEM, particularly for multidimensional constructs. Local irregularities, such as negative weights at the LOC level, do not diminish the explanatory power of the model at the higher-order level. Instead, they reflect the nuanced interplay between dimensions, where certain facets exert stronger influence than others. Overall, the results confirm the theoretical soundness and statistical validity of the model, with RC and HRF demonstrating substantial predictive relevance for DP.

Table 5.13
Path Coefficient of Lower Order Construct (Author)

No.	Construct Relationship	Path Coefficient (β)
1	HA → RC	-0.201
2	DS → RC	0.122
3	DC → RC	0.114
4	MA → RC	0.984
5	O → HRF	0.523
6	I → HRF	0.188
7	PL → HRF	0.444
8	T → HRF	-0.059

Table 5.14
Path Coefficient of Higher Order Construct (Author)

No.	Construct Relationship	Path Coefficient (β)
9	RC → DP	0.530
10	HRF → DP	0.323

5.6.8 Formative Constructs Outer Weights Significant Testing Result

The outer weights of formative indicators were further assessed using the bootstrapping technique, which tests the significance of each indicator's contribution to its construct. In formative measurement models, indicators define the construct, and their outer weights represent regression coefficients obtained by regressing the construct on its indicators (Hair et al., 2017). These weights capture the relative importance of each indicator, while outer loadings reflect their absolute contribution.

An indicator is considered statistically significant when its t-value exceeds 1.96 ($p < 0.05$, two-tailed) and the 95% Bias Corrected and Accelerated (BCa) confidence interval does not include zero (Hair et al., 2017). If an indicator's weight is non-significant, but its loading is above 0.50, it is deemed absolutely important and typically retained. Conversely, indicators with both non-significant weights and loadings below 0.50 require further consideration. In such cases, decisions regarding retention or removal should be guided by strong theoretical justification and an assessment of whether the indicator is redundant within the construct domain (Hair et al., 2017; Götz et al., 2009).

To ensure robust results, bootstrapping with 5,000 samples is conducted. Given the relatively small sample size (n < 100) and deviation from normality, the Bias Corrected and Accelerated (BCa) bootstrap method was employed, which provides more accurate confidence intervals under such conditions (Hair et al., 2019a). The formative construct evaluation thus considers both statistical criteria (significance of outer weights and loadings) and theoretical relevance, ensuring that the retained indicators comprehensively capture the domain of each construct.

Table 5.15 presents the detailed results of the significance testing. Several indicators emerged as statistically significant contributors to their respective constructs in which the t-value is exceeding 1.96 (p<0.05), including HA1 (t= 2.034, p=0.042), MA4 (t=3.187, p=0.001), MA6 (t= 2.649,p= 0.008), O1 (t= 3.263, p= 0.001), O3 (t= 3.705, p= 0.000), I1 (t=2.397, p=0.017), I5 (t= 2.484, p= 0.013), PL1 (t= 2.511, p= 0.012), T2 (t= 1.963, p= 0.050), and T4 (t=2.077, p= 0.038). The outer weights, t-values and p-values of these items confirm their strong and unique role in explaining their associated formative constructs.

In contrast, most of the indicators did not achieve statistical significance in terms of outer weights. Examples such as HA2 (t= 0.012, p= 0.991), DS1 (t= 0.307, p= 0.759), DC2 (t=0.234, p= 0.815), and MA2 (t= 0.325, p= 0.745) to illustrate this point. However, their outer loadings exceeded or approached the threshold of 0.50, indicating that these indicators remain absolutely important in representing the construct. As noted by Hair et al. (2017), such indicators should generally be retained in order to preserve the content validity of the construct.

Finally, a smaller group of indicators, including historical evidential data (I2) (t=0.355, p=0.723) and historical documentation (MA7) (t=0.179, p=0.858), demonstrated variation of non-significant outer weights, specifically with MA7 which recorded low outer loadings (< 0.50). Although both indicators are statistically weaker, these items were initially considered on the basis of theoretical justification, as they capture unique conceptual dimensions that would otherwise risk exclusion from the formative measurement model (Sarstedt et al., 2016).

Hence, examining its theoretical relevance and potential content overlap with other indicators is further conducted (Hair Jr et al. 2019). Specifically, I2 indicator reflects the role HBIM application in documenting and verifying information sources that provide evidence of a building's past, supporting its authenticity, significance, and conservation needs. (Parente et al., 2025; Bruno & Roncella, 2019), whereas MA7 emphasizes archival and evidence-based practices central to heritage conservation (López et al., 2018; Gigliarelli et al., 2022).

Upon closer examination, it was revealed that both indicators share similar characteristics, as their primary contribution lies in producing documentation informed by archival and evidence-based practice where MA7 primarily reflects conventional archival documentation practices, whereas I2 captures the integration of evidential and historical information within HBIM-supported informational processes. However, since MA7 recorded outer loadings below 0.50, hence it was excluded from the formative path model. In contrast, I2 achieved loadings above the 0.50 threshold and conceptually represents the same domain as MA7; therefore, I2 was retained and is considered as the more reliable indicator than the latter.

These results highlight that while some indicators emerge as stronger empirical drivers, the careful balance between statistical evidence and theoretical reasoning is essential (Hair Jr et al. 2019). Retaining I2 ensures comprehensive representation of heritage-specific constructs, while the removal of MA7 (historical documentation) enhances the model parsimony. This process reinforces both the robustness and validity of the measurement model, demonstrating that the final construct remains statistically sound while preserving conceptual completeness.

Table 5.15
Formative Construct Outer Weight and Loading Significant Test Result

Formative Construct	**Formative Indicators**	**Indicators**	**Outer Weight (Outer Loading)**	**t-value**	**p-value**	**95% BCa Confidence Interval**	**P<0.05**	**Decision (Y/N)**
HA	HA1	HB Categories	0.514 (0.825)	2.034	0.042	0.001 (0.953)	Yes	Yes
	HA2	Values and Significance	-0.003 (0.583)	0.012	0.991	-0.500 (0.467)	No	Yes
	HA3	Regulations	-0.104 (0.605)	0.395	0.693	-0.674 (0.362)	No	Yes
	HA4	Principles of Intervention	0.556 (0.882)	1.627	0.104	-0.031 (1.200)	No	Yes
	HA5	Multidisciplinary Stakeholders	0.207 (0.730)	0.654	0.513	-0.461 (0.763)	No	Yes
DS	DS1	Pre-Design	0.179 (0.779)	0.307	0.759	-0.985 (1.377)	No	Yes
	DS3	Construction	0.167 (0.831)	0.276	0.782	-1.105 (0.362)	No	Yes
	DS4	Post-Occupancy	0.742 (0.972)	1.500	0.134	-0.579 (1.431)	No	Yes
DC	DC1	Building Fabric	0.314 (0.723)	1.284	0.199	-0.129 (0.817)	No	Yes
	DC2	Building Systems	0.064 (0.606)	0.234	0.815	-0.498 (0.528)	No	Yes
	DC3	Building Structure	0.055 (0.608)	0.222	0.824	-0.450 (0.510)	No	Yes
	DC4	User Behaviour	0.208 (0.741)	0.919	0.358	-0.193 (0.690)	No	Yes
	DC5	Collections	0.281 (0.725)	1.451	0.147	-0.053 (0.696)	No	Yes
	DC6	Economic	0.432 (0.793)	1.888	0.059	-0.030 (0.865)	No	Yes
MA	MA1	Microclimatic Site Analysis	0.211 (0.692)	1.911	0.056	-0.067 (0.483)	No	Yes
	MA2	In-situ Measurement	-0.065 (0.567)	0.325	0.745	-0.574 (0.255)	No	Yes
	MA3	Laboratory Testing	-0.082 (0.530)	0.508	0.611	-0.398 (0.226)	No	Yes

	MA4	Building Performance Analysis	0.579 (0.899)	3.187	0.001	0.279 (0.999)	Yes	Yes
	MA5	EPC Assessment	0.108 (0.685)	0.623	0.534	-0.289 (0.403)	No	Yes
	MA6	Risk Assessment	0.364 (0.792)	2.649	0.008	0.164 (0.665)	Yes	Yes
	MA7	**Historical Documentation**	**0.033 (0.463)**	**0.179**	**0.858**	**-0.321 (0.413)**	**No**	**No**
O	O1	Roles and Responsibility	0.487 (0.888)	3.263	0.001	0.128 (0.745)	Yes	Yes
	O2	Training & Development	0.156 (0.806)	0.974	0.330	-0.139 (0.494)	No	Yes
	O3	BIM Protocol	0.494 (0.894)	3.705	0.000	0.249 (0.777)	Yes	Yes
I	I1	Geometrical	0.540 (0.864)	2.397	0.017	0.088 (0.985)	Yes	Yes
	I2	Historical Evidential	-0.081 (0.704)	0.355	0.723	-0.578 (0.337)	No	Yes
	I3	Pathology	-0.020 (0.711)	0.094	0.925	-0.465 (0.376)	No	Yes
	I4	Surveying	0.217 (0.850)	0.758	0.448	-0.311 (0.758)	No	Yes
	I5	Energy Performance	0.449 (0.744)	2.484	0.013	0.120 (0.808)	Yes	Yes
	I6	Structural	0.120 (0.717)	0.722	0.470	-0.183 (0.451)	No	Yes
PL	PL1	Data Acquisition	0.568 (0.933)	2.511	0.012	0.022 (0.931)	Yes	Yes
	PL3	Simulation and Analysis	0.354 (0.875)	1.787	0.074	-0.021 (0.759)	No	Yes
	PL4	Visualization	0.191 (0.842)	0.984	0.325	-0.153 (0.601)	No	Yes
T	T1	Software	0.330 (0.905)	1.319	0.187	-0.177 (0.772)	No	Yes
	T2	Hardware Infrastructure	0.462 (0.929)	1.963	0.050	0.056 (0.926)	Yes	Yes
	T3	Standards	0.427 (0.825)	0.515	0.607	-0.203 (0.449)	No	Yes
	T4	Data Exchange	0.291 (0.814)	2.077	0.038	-0.042 (0.521)	Yes	Yes

5.6.9 Formative Model Evaluation – Third Run

Figure 5.21 shows the formative measurement model for the third run after omitting MA7 indicator. The R^2 value has remained 0.626.

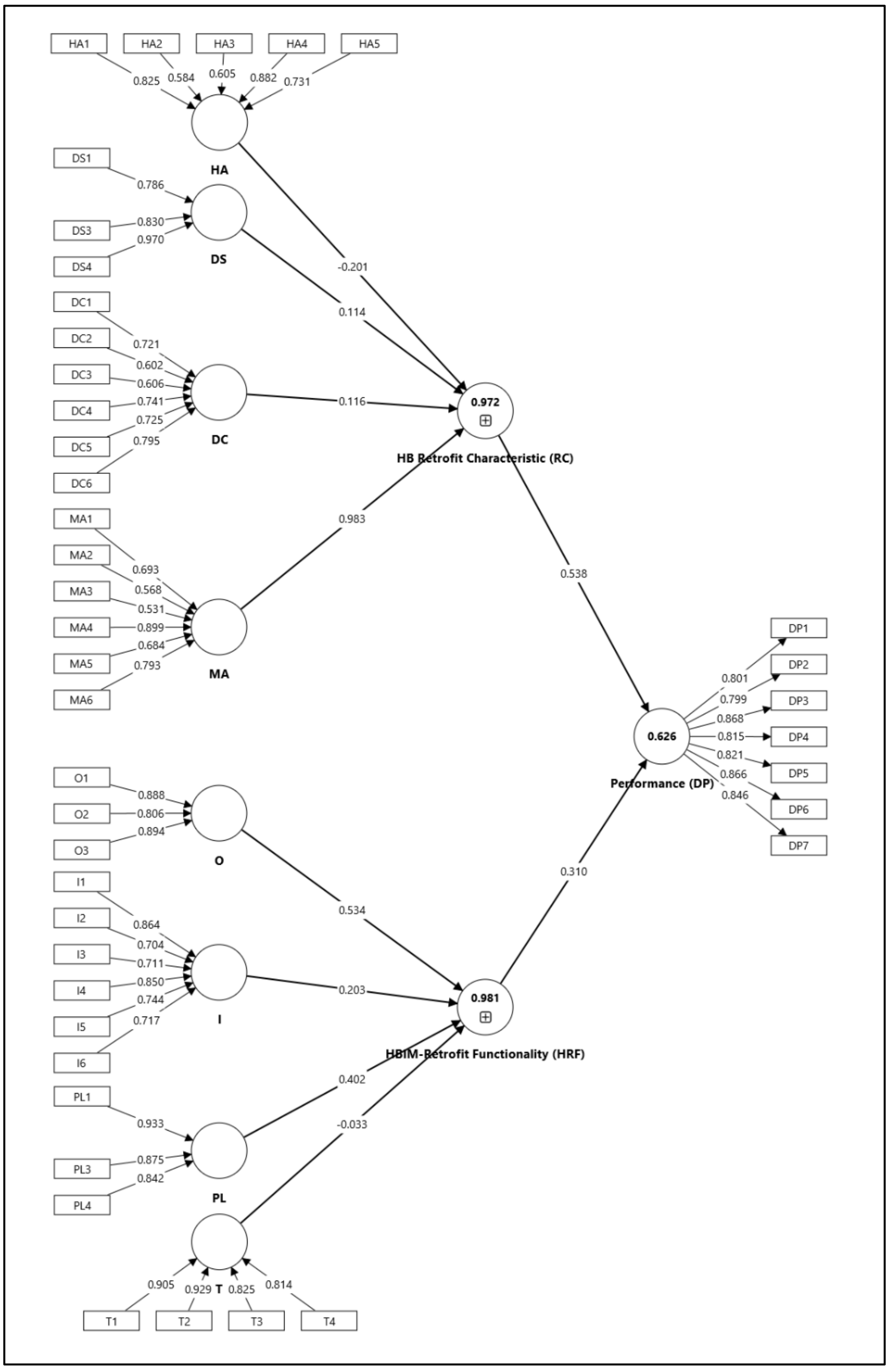

Figure 5.21 Formative Model Evaluation – Third Run

In conclusion, the formative measurement model in the third run (PLS-Algorithm 3) is established. The researcher omitted three indicators, including DS2 (retrofit design stage), PL2 (3D modelling), and MA7 (historical documentation). The researcher further evaluated the third run of the formative measurement model, to its structural model evaluation. The structural model evaluation assessment is meant to test the hypotheses of the research.

5.6.10 Structural Model Evaluation

Further from the measurement model assessment, a structural model evaluation is conducted to examine the relationships between latent variables by assessing the significance of their paths. Two main criteria are used: (1) evaluating the coefficient of determination (R^2) and (2) applying the blindfolding procedure to assess the predictive relevance (Q^2) of the path model (Hair et al., 2017). Paths that are insignificant or run counter to the hypothesized direction do not support the proposed hypotheses. Conversely, significant paths aligned with the hypothesized direction provide support for the relationships (Götz et al., 2009). The research hypotheses are therefore tested by estimating the significance of the structural paths through an appropriate resampling method and examining the absolute values of the hypothesized relationships (Götz et al., 2009).

5.6.11 Collinearity Assessment

Table 5.16 shows the VIF values of every IV to DV. The VIF values shown are all below the threshold of 5.0. Therefore, the collinearity among the predictor variables is not a critical issue in the structural model.

Table 5.16
VIF Value for IV to DV

No.	Construct	Variance Inflation Factor (VIF)
1	HA → RC	1.875
2	DS → RC	1.209
3	DC → RC	1.846
4	MA → RC	1.838
5	O → HRF	2.079
6	I → HRF	2.532
7	PL → HRF	2.600
8	T → HRF	2.065
9	RC → DP	2.062
10	HRF → DP	2.062

5.6.12 Coefficient of Determination - R^2 Value

The most widely used measure to evaluate the structural model is the coefficient of determination (R^2 value) (Hair et al., 2017). The R^2 value ranges between 0 and 1, with higher values indicating greater predictive accuracy. However, acceptable levels of R^2 depend largely on the complexity of the model and the research discipline. For instance, an R^2 of 0.20 is often considered high in consumer behaviour studies focusing on success drivers (Hair et al., 2017).

In structural models, R^2 values are reported for each endogenous latent variable and represent the proportion of variance explained by its exogenous predictors. For example, an R^2 value of 0.70 indicates that 70% of the variance in the construct is explained by its predictor variables. Thus, R^2 serves as a key indicator of predictive capability within the model.

Thresholds for interpreting R^2 values vary across methodological literature. Falk and Miller (1992) suggested that R^2 values of 0.10 or higher are adequate for assessing the explanatory power of an endogenous construct. Cohen (2013) proposed the following guidelines: 0.26 (substantial), 0.13 (moderate), and 0.02 (weak). Chin (1998) recommended a slightly stricter interpretation, classifying R^2 values of 0.67 as substantial, 0.33 as moderate, and 0.19 as weak. More recently, Hair et al. (2013) suggested that in marketing-related research, R^2 values of 0.75, 0.50, and 0.25 may be regarded, respectively, as substantial, moderate, and weak.

Based on these criteria, the R^2 value for the endogenous variable in this study, reported in Table 5.17, is 0.626. This indicates that 62.6% of the variance in performance (DP) is explained by its predictors (RC, HRF). Accordingly, the explanatory power of the model can be regarded as moderate, confirming that the model possesses an acceptable level of predictive capability.

Table 5.17
Dependent Variable – R^2 value

Dependent Variable	R^2	R^2 Adjusted	Result Interpretation
Performance	0.626	0.618	Cohen (2013) - Substantial Chin (1998) - Moderate Hair et al. (2017) - Moderate

5.6.13 Predictive Relevance Q^2 Value and Effect Size f^2 Value

In addition to examining the explanatory power of the model, this study also examined the predictive relevance (Q^2 value) of the endogenous constructs. Predictive relevance reflects the model's ability to forecast the values of endogenous constructs and indicators, thereby demonstrating its practical usefulness (Shmueli et al., 2019). The Q^2 statistic, proposed by Stone (1974) and Geisser (1974), is obtained through the blindfolding procedure in PLS-SEM.

Unlike R^2, which assesses the model's explanatory power, Q^2 evaluates its predictive accuracy, that is the extent to which the model can predict data points that were not used in the estimation process (Hair et al., 2019a). A Q^2 value greater than zero ($Q^2 > 0$) indicates that the exogenous constructs possess predictive relevance for the endogenous constructs under consideration. Conversely, values of Q^2 equal to or below zero suggest a lack of predictive relevance.

According to Chin (1998) and Hair Jr et al. (2021), the threshold values for interpreting Q^2 are as follows 0.02 (small), 0.15 (medium) and 0.35 for large predictive relevance. Table 5.18 shows the results of predictive relevance of Q^2 value. The results clearly support the model's predictive relevance regarding the endogenous latent variables as all values are greater than zero. The predictive relevance values are all greater than 0.50, thus, the IV represented by higher-order constructs has substantial predictive relevance to the DV.

Effect size (f^2) is crucial because it shows the practical influence of each exogenous construct on an endogenous construct. It helps identify meaningful predictors, validates theoretical assumptions, and supports clearer model interpretation and refinement (Hair et al., 2019). Cohen (1988) stated that f^2 values are interpreted as 0.02 (small), 0.15 (medium) and 0.35 for substantial effect size. Hence, the effect sizes for RC construct to DP shows a f^2 value of 0.376, and HRF construct to DP is 0.125. Therefore, in line with guidelines by Cohen (1988), the effects of these two latent variables can be considered as substantial.

Table 5.18
Results of Predictive Relevance and Effect Size

Predictor(s)	R^2 Value	f^2 Value	Q^2 Value
RC	0.972	0.376	0.971
HRF	0.981	0.125	0.961
DP	0.626	-	0.438

5.6.14 Hypothesis Testing

The structural model was assessed to evaluate the hypothesized relationships between historic retrofit characteristics, HBIM-retrofit functionality, and the performance of historic building conservation projects in Malaysia. Following (Hair et al., 2017), the significance of structural paths was determined using bootstrapping applying a two-tailed test, while predictive power was evaluated through the coefficient of determination (R^2) and cross-validated redundancy (Q^2). Hence, the results are shown in Table 5.19 below.

Table 5.19
Result of Hypothesis Testing

Hypotheses	Path Coefficient (β)	t-Value	p-Value	R^2 Value	Predictive Relevance Q^2	Result
H1: There is a significant positive relationship between the historic building retrofit characteristics and the performance of heritage building conservation projects in Malaysia.	0.538	5.814	0.000	0.626 (Substantial)	0.971	Supported
H2: There is a significant positive relationship between the HBIM-retrofit functionality and the performance of heritage building conservation projects in Malaysia.	0.310	3.363	0.001	0.626 (Substantial)	0.961	Supported

The analysis shows a path coefficient (β) of 0.538, with a t-value of 5.814 and a p-value of 0.000, indicating statistical significance (α) at a 0.05 level. The explained variance of the endogenous construct is R = 0.626, which is considered *substantial* (Hair et al., 2017). Furthermore, the cross-validated redundancy (Q^2 = 0.971) demonstrates strong predictive relevance (Chin, 2010). These results confirm that historic retrofit characteristics significantly contribute to the performance of conservation projects. This finding is consistent with previous studies highlighting the role of retrofit strategies in improving building performance and sustainability outcomes. Thus, H1 is supported.

The findings reveal a stronger path coefficient (β = 0.310), with a t-value of 3.363 and a p-value of 0.001 for H2, confirming significance (α) at a 0.05 level. Similar to H1, the R^2 value of 0.626 reflects substantial explanatory power, and the Q^2 value of 0.961 further validates predictive relevance. This outcome demonstrates that HBIM-retrofit functionality (HRF) exerts a slightly weaker positive influence on performance (DP) compared to retrofit characteristics (RC) alone. The result supports earlier arguments that digital tools such as HBIM improve project coordination, data integration, and performance evaluation in conservation projects (Volk et al., 2014; Khalil et al., 2021). Hence, H2 is supported.

5.7 Summary of Chapter

This chapter presented and discussed the key outcomes of the quantitative analysis conducted in this research. The analysis incorporated both descriptive and multivariate statistical techniques. It began with an overview of the respondents' demographic characteristics, followed by a detailed examination of the survey data. Descriptive statistics, specifically frequencies, means, and standard deviations were used to reveal the practical and contextual dimensions of HBIM adoption within the industry. This provided a solid foundation for understanding the underlying concepts and characteristics of HBIM-retrofit in Malaysia, thereby addressing Research Objective One. Subsequently, the main analysis involved assessing the formative measurement model and the structural model using PLS-SEM to fulfil Research Objective Two. The multivariate results confirmed the acceptance of two hypotheses, which supported the development of the HBIM-Retrofit framework. This framework was further refined through the removal of several indicators during the formative model evaluation. The next chapter will expand on these findings by offering a more thorough discussion of the results, including the formulation of the framework through the use of Analytical Hierarchy Process (AHP).

CHAPTER 6
FINDINGS AND DISCUSSION

6.1 Introduction

This chapter discusses the findings and discussion in respect of the three research objectives which are; (1), to investigate the underlying concepts and characteristics of HBIM-retrofit in influencing the performance of heritage building conservation projects; (2), To analyze the relationship between the HBIM-retrofit characteristic and the perceived performance of heritage building conservation projects; and (3), to formulate a structured HBIM-retrofit framework in enhancing the performance of heritage building conservation projects in Malaysia. Moreover, the primary intent of the Analytical Hierarchy Process (AHP) method established through the PLS-SEM assessment was also discussed alongside the procedures.

6.2 Findings on the HBIM-Retrofit Characteristics and Conceptual Framework

Objective One of this research is to investigate the underlying concepts and characteristics of HBIM-retrofit in influencing the performance of heritage building conservation projects in Malaysia. To achieve this, nine variables derived from a comprehensive literature review through document review and content analysis were identified. These variables are heritage aspect, development stages, retrofit design criteria, method of approach, organizational, informational, process lifecycle, technical and performance; were structured into three overarching domains that collectively form the HBIM-retrofit framework. These variables and their forty-six (46) associated indicators were operationalized and systematically mapped into a conceptual framework, underpinned by the task–technology fit (TTF) theory. The theory adapted is also vital in establishing the hypothesis for the conceptual framework which will be tested and empirically validated in PLS-SEM analysis. Prior to that, each domain within the framework underwent a rigorous face and content validation process, guided by established methodological recommendations from Davis (1992), Polit and Beck (2006), Polit et al. (2007), and Lynn (1986). This step was essential to ensure that the conceptualization of HBIM-retrofit framework realistically reflects the theoretical constructs and practical realities of the heritage conservation practice. The expert panel evaluation produced S-CVI (Ave) values ranging from 0.98 to 1.00 and S-CVI(UA) scores between 0.83 and 1.00 across all domains, exceeding the recommended minimum threshold of 0.83 for panels comprising six to eight experts (Polit et al., 2007; Lynn, 1986). These results confirm both the statistical adequacy and conceptual integrity of the HBIM-retrofit domains. Moreover, experts recommended the addition of an indicator related to Historical Documentation (HA7), demonstrating that the model accommodates practitioner's driven insights and remains grounded in real conservation needs.

The conceptual framework applies the foundational structure of the TTF model; however, the "utilization" component was intentionally excluded. This decision is empirically justified by the findings from the literature review and descriptive analysis, which reveal a low level of HBIM-retrofit adoption among practitioners and organizations. In contexts where actual system usage is minimal or inconsistent, utilization measures would yield weak or conceptually invalid results. Hence, the framework focuses on evaluating task–technology fit based on practitioners' knowledge, expectations and perceived performance impacts, consistent with recommendations in early-stage technology research.

The descriptive analysis provides essential contextual evidence supporting this adaptation. The HBIM awareness and adoption among heritage conservation professionals in Malaysia is characterized by four dimensions; familiarity, sources of knowledge, understanding and organizational use. The findings indicate an adoption landscape that is nascent and fragmented. Despite 74.5% of respondents reporting familiarity with HBIM, a substantial proportion remains unexposed or only vaguely aware of it, mirroring national trends where HBIM is conceptually recognized but remains underdeveloped in practice (Said et al., 2025; Ismail et al., 2021; Ali et al., 2018a). Thus, awareness alone does not equate to the level of competency required to influence conservation performance through HBIM-retrofit processes.

Furthermore, HBIM knowledge is primarily acquired through academic publications, professional networks and conferences rather than structured training programmes. This supports existing research which asserts that Malaysia lacks comprehensive HBIM education pathways or standardized training frameworks, limiting practitioners' ability to transition from basic awareness to advanced skill application (Said et al., 2025; Salleh et al., 2022; Ismail et al., 2021). Consequently, most respondents report only moderate or slight understanding of HBIM. This gap between awareness, readiness and technical competence is consistent with international findings that HBIM implementation demands specialized skillsets such as semantic modelling, 3D laser scanning and structured data management that are not yet widespread in the industry (Yusoff & Brahim, 2021; Baharuddin et al., 2024).

Organizational adoption is similarly limited with a significant 73.4% of respondents confirmed that their organizations do not use HBIM in conservation projects, and even among adopters, usage is infrequent and project specific. These results reflect barriers commonly noted in both Malaysian and international literature, including high implementation costs, technical constraints, lack of standards, and limited client requirements (Said et al., 2025; Ali et al., 2018a; Penjor et al., 2024; Salleh et al., 2022; Baharuddin et al. 2024). Such conditions impede the ability of organizations to embed HBIM into routine practice and therefore restrict the extent to which HBIM-retrofit characteristics can meaningfully influence conservation project performance.

In overall, the integration of literature review, conceptual framework development, expert validation, content and descriptive analysis ensures that Objective One is comprehensively achieved. Each methodological component contributes a distinct layer of conceptual, theoretical, practical, and contextual to establish a robust understanding of the underlying concepts and characteristics of HBIM-retrofit in influencing the performance of heritage building conservation projects in Malaysia.

Figure 6.1 illustrates the proposed conceptual framework developed based on the literature review, content validation, descriptive analysis, and underpinning Task-Technology Fit (TTF) theory. The framework conceptualizes the relationship between historic building retrofit characteristics (HRC), HBIM-retrofit functionality (HRF), and performance (DP) through seven performance measures consisting of time, cost, quality, design, environmental, relationship, and communication performance. This conceptual framework subsequently formed the basis for the empirical validation conducted through the PLS-SEM analysis.

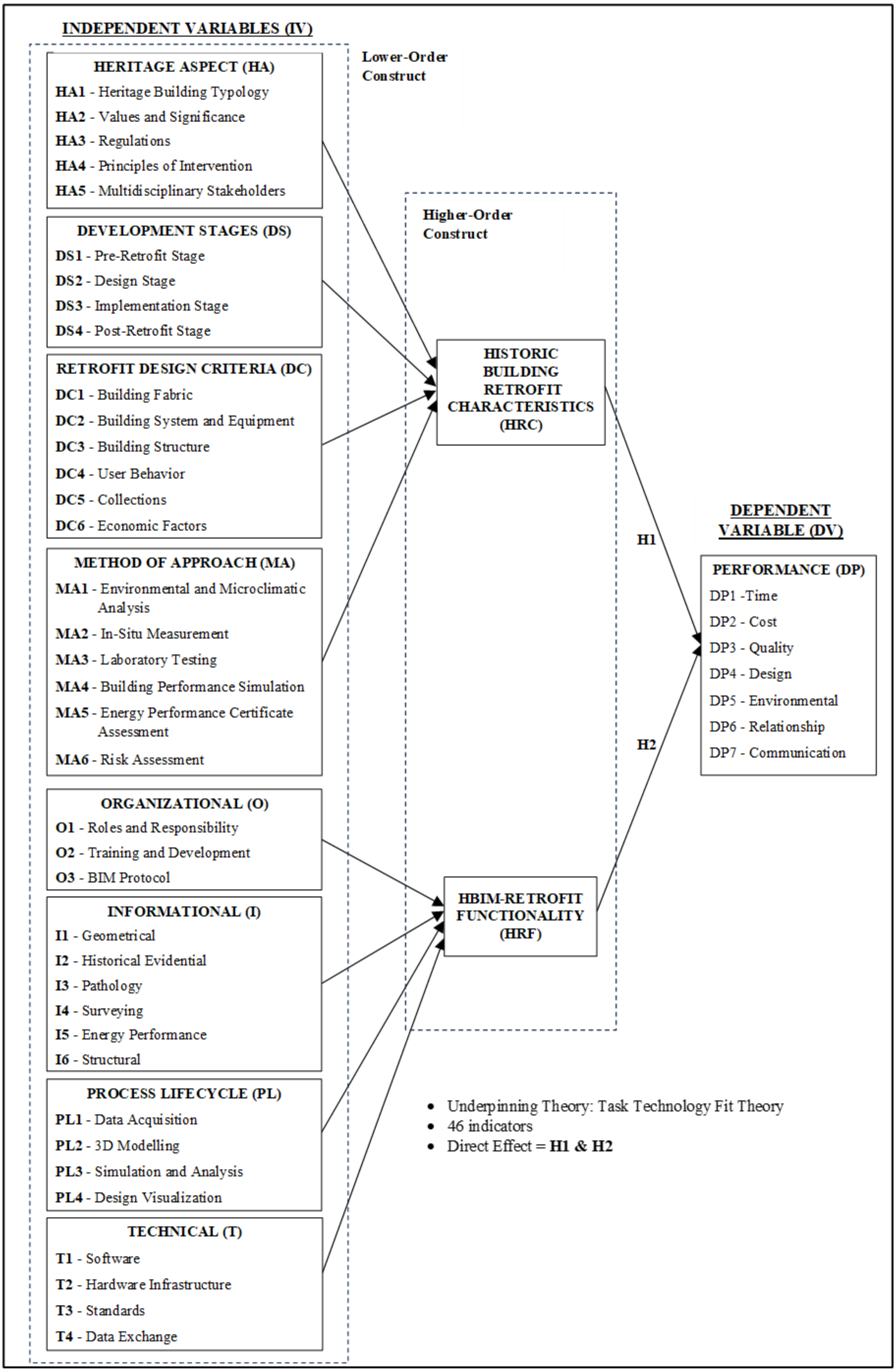

Figure 6.1 Conceptual Framework Before the PLS-SEM Analysis

6.3 Findings From PLS-SEM Analysis

Partial Least Squares Structural Equation Modelling (PLS-SEM) was employed to empirically validate and test the hypothesized relationship of the proposed HBIM-retrofit framework. PLS-SEM is particularly appropriate for exploratory and theory-building research involving complex models with multiple latent constructs and predictive relationships (Hair et al., 2019). The technique enables simultaneous evaluation of measurement and structural models, allowing assessment of multicollinearity, convergent validity, and the strength and significance of hypothesized relationships (Hair et al., 2017).

The PLS-SEM analysis was performed, comprising both the formative measurement model assessment and the structural model assessment. Findings from the formative measurement model assessment indicate that all required criteria for reliability and validity were satisfactorily met. The convergent validity was assessed through redundancy analysis and the results demonstrated that the constructs achieved adequate convergence with their respective endogenous variables.

Overall, the inner and outer model assessments confirm that the measurement model possesses acceptable exploratory capability and predictive relevance. Furthermore, findings from the first run of multicollinearity assessment of the measurement model (PLS-Algorithm 1), suggested two indicators were removed due issues with the Variance Inflation Factor (VIF). The item design stage (DS2) was removed because the VIF value is exceeding the cut-off value of 0.50, whereby 3D modelling (PL2) was considered for removal due VIF value of almost 0.50. Moreover, the omission of both items was carefully considered to not affect the overall theoretical perspective of the model and improves the validity and parsimony of the measurement model (Hair et al., 2017).

Furthermore, a second assessment run (PLS-Algorithm 2) was conducted to re-evaluate the multicollinearity of both the outer and inner measurement models following the removal of indicators DS2 and PL2. The results demonstrated that all remaining indicators achieved acceptable multicollinearity levels, with none recording VIF values exceeding the recommended threshold of 5.0. This indicates that the revised formative measurement model no longer suffered from critical collinearity issues, thereby improving the stability, validity, and reliability of the constructs for subsequent bootstrapping and structural model assessment. Next, the outer weights of formative indicators were conducted using the bootstrapping technique, which tests the significance of each indicator's contribution to its construct. From this, indicator MA7 of historical documentation demonstrated variation of non-significant outer weights and low outer loadings (<0.50) indicating a weak relative and absolute contribution within the formative construct. Further evaluation revealed substantial conceptual overlap with indicator I2 of historical evidential particularly in representing archival, evidential and documentation-related aspect within HBIM-supported conservation process. Hence, after justification based on Hair et al. (2017), the item was removed from the formative path model.

This finding may reflect the current practice within the Malaysian heritage conservation industry, where historical documentation is still commonly managed through conventional archival approaches rather than systematically integrated into HBIM-enabled retrofit workflows (Salleh et al., 2022; Idris et al., 2024). Consequently, the documentation-related domain was more reliably represented through I2 within the present framework. Therefore, the removal of MA7 was considered appropriate to improve model parsimony while preserving the conceptual completeness of heritage documentation within the HBIM-retrofit framework (Hair et al., 2019; Sarstedt et al., 2016). Table 6.1 shows the summary of the measurement model analysis.

Table 6.1
Summary of Measurement Model Analysis

Formative Construct	**Formative Indicators**	**PLS-Algorithm 1 (Initial Run)**		**PLS-Algorithm 2 (Refined Run)**		**Bootstrapping Results**			**Yes/ No**
		Outer VIF	**Inner VIF**	**Outer VIF**	**Inner VIF**	**Outer loading**	**t value**	**p value**	
Heritage Aspect (HA)	HA1	1.702	1.846	1.702	1.877	0.825	2.034	0.042	Yes
	HA2	1.787		1.787		0.583	0.012	0.991	Yes
	HA3	2.140		2.140		0.605	0.395	0.693	Yes
	HA4	2.477		2.477		0.882	1.627	0.104	Yes
	HA5	1.714		1.714		0.730	0.654	0.513	Yes
Development Stage (DS)	DS1	3.396	1.200	3.396	1.209	0.779	0.307	0.759	Yes
	DS2	**6.605**		-		-	-	-	**No**
	DS3	5.994		3.405		0.831	0.276	0.782	Yes
	DS4	2.015		2.015		0.972	1.500	0.134	Yes
Retrofit Design Criteria (DC)	DC1	1.919	1.890	1.919	1.851	0.723	1.284	0.199	Yes
	DC2	1.896		1.896		0.606	0.234	0.815	Yes
	DC3	1.903		1.903		0.608	0.222	0.824	Yes
	DC4	2.098		2.098		0.741	0.919	0.358	Yes
	DC5	1.454		1.454		0.725	1.451	0.147	Yes
	DC6	1.409		1.409		0.793	1.888	0.059	Yes

Method of Approach (MA)	MA1	1.763	1.891	1.763	1.842	0.692	1.911	0.056	Yes
	MA2	2.439		2.439		0.567	0.325	0.745	Yes
	MA3	1.933		1.933		0.530	0.508	0.611	Yes
	MA4	2.396		2.396		0.899	3.187	0.001	Yes
	MA5	1.706		1.706		0.685	0.623	0.534	Yes
	MA6	1.751		1.751		0.792	2.649	0.008	Yes
	MA7	2.053		2.053		**0.463**	0.179	0.858	**No**
Organizational (O)	O1	1.905	2.070	1.905	2.079	0.888	3.263	0.001	Yes
	O2	2.206		2.206		0.806	0.974	0.330	Yes
	O3	2.007		2.007		0.894	3.705	0.000	Yes
Informational (I)	I1	2.860	2.534	2.860	2.532	0.864	2.397	0.017	Yes
	I2	2.348		2.348		0.704	0.355	0.723	Yes
	I3	2.503		2.503		0.711	0.094	0.925	Yes
	I4	3.449		3.449		0.850	0.758	0.448	Yes
	I5	1.403		1.403		0.744	2.484	0.013	Yes
	I6	2.191		2.191		0.717	0.722	0.470	Yes
Process Lifecycle (PL)	PL1	3.394	2.733	2.064	2.600	0.933	2.511	0.012	Yes
	PL2	**4.482**		-		-	-	-	**No**
	PL3	3.070		2.563		0.875	1.787	0.074	Yes
	PL4	2.676		2.638		0.842	0.984	0.325	Yes
Technical (T)	T1	2.985	2.098	2.985	2.065	0.905	1.319	0.187	Yes
	T2	3.326		3.326		0.929	1.963	0.050	Yes
	T3	2.761		2.761		0.825	0.515	0.607	Yes
	T4	2.028		2.028		0.814	2.077	0.038	Yes
Performance (DP)	DP1	2.835	-	2.835	-	0.801	11.775	0.00	Yes
	DP2	2.292		2.292		0.799	11.558	0.00	Yes
	DP3	3.096		3.096		0.868	15.657	0.00	Yes
	DP4	2.525		2.525		0.815	12.751	0.00	Yes
	DP5	3.184		3.184		0.821	14.060	0.00	Yes
	DP6	3.815		3.815		0.866	16.511	0.00	Yes
	DP7	3.195		3.195		0.846	13.839	0.00	Yes

Next are the findings from the structural model assessment incorporating two elements of the assessments: exploratory and predictive power. The value of R^2 is 0.626 explaining that the HBIM-retrofit framework can predict the accuracy of 62.6% on performance of heritage building conservation projects in Malaysia. This value is regarded as much higher than the cut-off value suggested by Cohen (1998).

6.4 The Relationship Between HBIM-Retrofit Model and Performance

Objective Two is to analyze the relationship between the HBIM-retrofit characteristic and the performance of heritage building conservation projects in

Malaysia. Prior examining the relationship, the conceptual framework was developed, and two direct hypothesis (Hypothesis 1 and 2) were proposed to study the relationship of independent and dependent variables. Figure 6.2 shows the conceptual framework before conducting the path analysis in PLS-SEM. This conceptual framework aims to postulate the direct relationship of the two determined higher order constructs, namely the historic building retrofit characteristics and HBIM-retrofit functionality and proposes that both exert a direct and positive effect on performance.

The analysis from the structural model demonstrates that both historic building retrofit characteristics (RC) and HBIM-retrofit functionality (HRF) significantly influence to the enhanced performance (DP) of heritage building conservation projects, with RC ($\beta = 0.538$, $t = 5.814$, $p < 0.001$) exerting a stronger effect than HRF ($\beta = 0.310$, $t = 3.363$, $p = 0.001$). Collectively, these constructs explain 62.6% (R= 0.626) of the variance in the dependent variable (DP), supported by strong predictive relevance ($Q^2 = 0.438$), indicating that the HBIM-retrofit model provides meaningful explanatory and predictive power. The results align closely with task–technology fit theory, which posits that performance improves when the characteristics of a technology correspond to the requirements of the tasks being performed (Goodhue & Thompson, 1995).

Within the context of heritage building conservation, RC represents the "task characteristics," encompassing heritage aspects, development stages, retrofit design criteria, and method of approach decisions that define what must be accomplished in a conservation-driven design process. HRF represents the "technology functionalities," including the organizational, informational, process lifecycle, and technical functionalities of HBIM that enable structured documentation, integrated data usage, and collaborative workflows.

The significance of both constructs confirms that performance outcomes stem from the complementary interaction between well-defined retrofit tasks and the supportive capabilities of HBIM which are supported by previous studies. Moreover, consistent with findings from similar BIM-TTF studies showing that project performance improves when BIM functionalities align with user tasks (Hallén et al., 2023; Fazil et al., 2023).

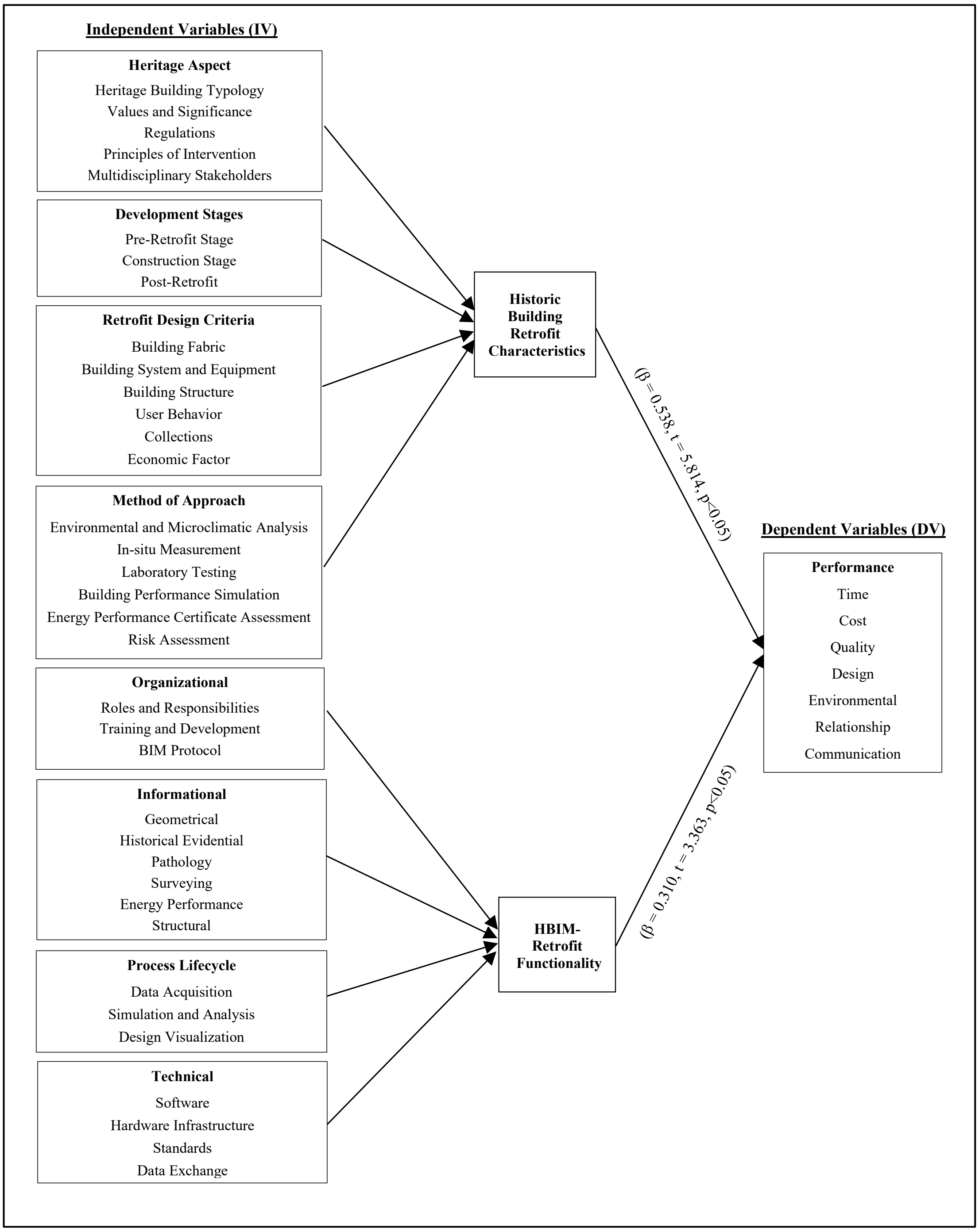

Figure 6.2 The Relationship of HBIM-Retrofit Model and Performance

6.5 The Final HBIM-Retrofit Framework in Enhancing the Performance of Heritage Building Conservation Projects in Malaysia

Figure 6.3 illustrates the final HBIM-retrofit framework established through the integration of the PLS-SEM findings. The framework comprises eight variables and forty-three (43) validated indicators organized within two higher-order domains, namely Historic Building Retrofit Characteristics (HRC) and HBIM-Retrofit

Functionality (HRF). The HRC domain includes heritage aspect, development stages, retrofit design criteria, and method of approach, while the HRF domain comprises organizational, informational, process lifecycle, and technical dimensions.

From the perspective of Task–Technology Fit (TTF) theory, the HRC domain represents the task requirements of heritage building conservation projects, whereas the HRF domain represents the technology capabilities provided by HBIM. The framework therefore demonstrates that enhanced project performance is achieved through the alignment between retrofit requirements and HBIM functionalities. Heritage retrofit activities define the operational demands of conservation projects, while HBIM provides the organizational, informational, and technical support required to execute these activities effectively. This explicit task–technology alignment operationalizes the TTF theory within the context of heritage building conservation projects in Malaysia.

The findings suggest that heritage retrofit performance is not solely dependent on the adoption of HBIM technology, but on the degree to which HBIM functionalities support conservation requirements throughout the retrofit lifecycle. This finding is consistent with Goodhue and Thompson (1995) and supports previous studies that emphasized the importance of integrating technical information, project workflows, and conservation requirements within heritage projects (Penjor et al., 2024; Salah et al., 2025; Gigliarelli et al., 2022). Furthermore, the framework addresses key challenges identified in Chapter Two, including information management complexities, multidisciplinary coordination, technical uncertainties, and conservation-sensitive interventions (McCaig et al., 2018; Khalil et al., 2021). The findings demonstrate that HBIM-retrofit implementation extends beyond digital modelling, where organizational coordination, lifecycle processes, informational integration, and technical management collectively contribute towards improved project performance.

The indicators within these variables were subsequently analysed using the Analytical Hierarchy Process (AHP) to determine their relative priorities across the pre-retrofit (DS1), implementation (DS3), and post-retrofit (DS4) stages. The resulting ranking patterns demonstrate that indicator priorities evolve according to the operational, technical, conservation, and management requirements of each development stage. Consequently, the framework establishes a structured and lifecycle-oriented HBIM-retrofit approach that supports systematic decision-making, multidisciplinary coordination, and enhanced conservation project performance in Malaysia.

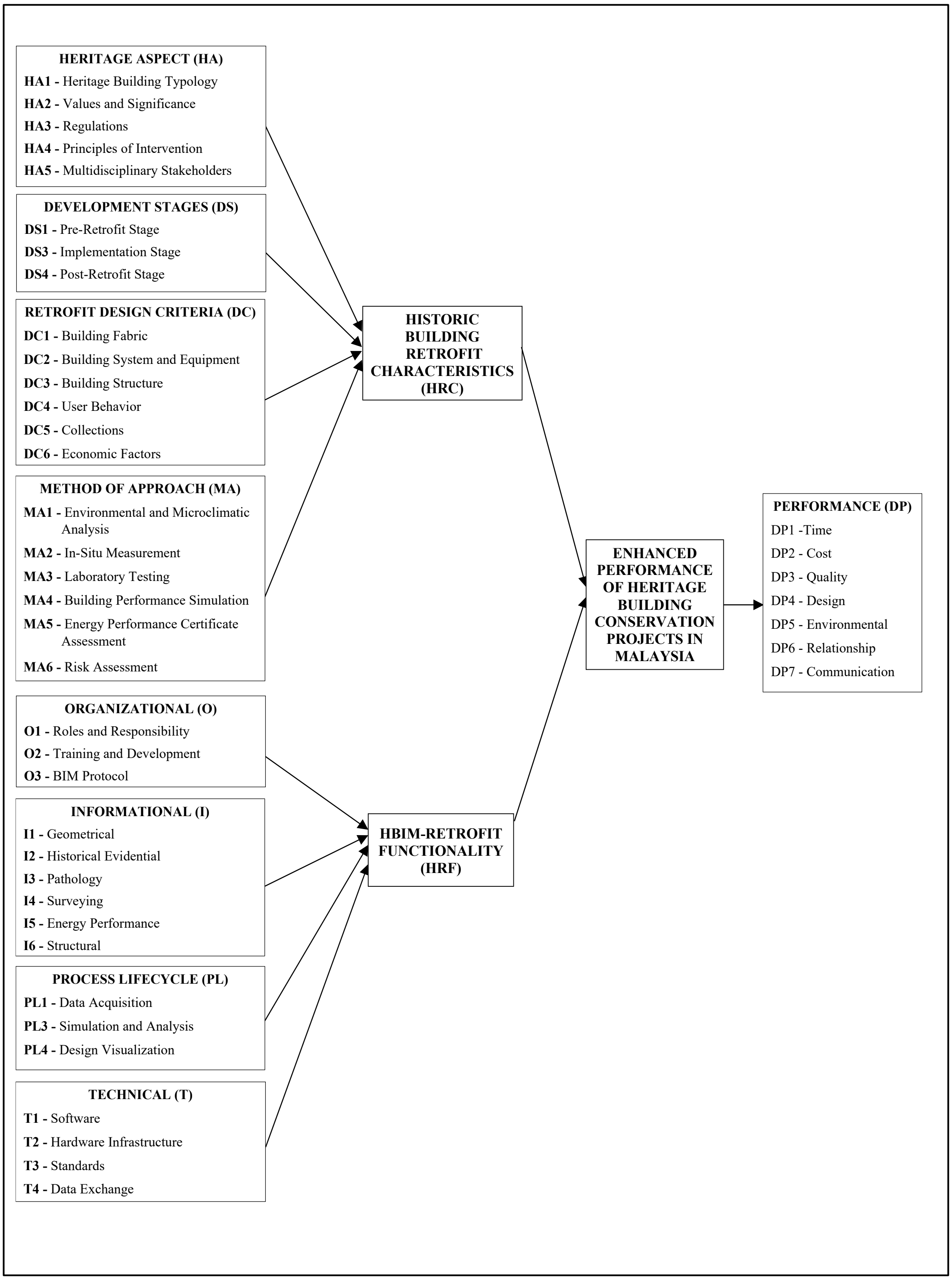

Figure 6.3 The Final HBIM-Retrofit Framework *(Author)*

6.6 The Formulation of HBIM-Retrofit Framework Through the Analytical Hierarchy Process (AHP)

While the PLS-SEM analysis confirms the statistical relationships, validity and predictive capability of the proposed HBIM-retrofit framework, the Analytical

Hierarchy Process (AHP) will serve as a complementary validation method by capturing expert-driven prioritisation of the same constructs, adopting the Multi Criteria Decision-Making (MCDM) method. This is to satisfy Objective Three of the research which is to formulate a structured HBIM-retrofit framework for enhancing the performance of heritage building conservation projects in Malaysia. The structured procedure of AHP expert validation and prioritization findings will be discussed in the next sub-section.

6.7 Expert Demographic Information

The researcher has distributed the questionnaire to ten (10) potential field experts, from which six (6) were then included in the study based on their professional background and years of experience in heritage building conservation works. Table 6.2 presents the profiles of these six experts, including their organisational affiliation, years of experience, academic qualifications, and professional roles. The selected experts represent a diverse mix of stakeholders, representing policymakers, practitioners, and implementing agencies in Malaysia.

Expert 1 is from Malaysia Institute of Architects (MIA) with more than thirty one years of experience, while Expert 2 is from Public Works Department (PWD) with more than twenty four years of experience, Expert 3 is a heritage building conservation consultant with more than 30 years of experience, Expert 4 is from Malaysia Green Building Council (MGBC) with more than 32 years of experience, Expert 5 is a council board member of National Heritage Department (NHD) with more than 31 years of working experience and Expert 6 is the Director of Heritage Conservation Division in National Heritage Department (JWN) with more than twenty four years of experience.

Out of all the six experts, in general, five of the highest education backgrounds is the Doctor of Philosophy (PhD), while one of the experts is a bachelor’s degree holder. The researcher has ensured that all the highest education background is relevant to the field of heritage building conservation. In this case, the built environment was observed to be the most relevant to the niche of this research. Therefore, the experts with the formal educational background of the said field are the most significant in becoming the expert panelist for the AHP method.

Table 6.2
Expert Demographic Information

Expert ID	Organisation	Year of Experience	Academic Qualification	Profession / Position
Expert 1	Persatuan Arkitek Malaysia (PAM) / Malaysian Institute of Architects (MIA)	31	Bachelor	Architect / Board Member
Expert 2	Jabatan Kerja Raya (JKR) / Public Works Department (PWD)	24	PhD	Senior Architect / Head of Department
Expert 3	Heritage Building Conservation Consultant	32	PhD	Registered Conservator
Expert 4	Malaysia Green Building Council (MGBC) / Taylor's University	36	PhD	Council Member / Architect / Professor
Expert 5	Jabatan Warisan Negara (JWN) / Universiti Sains Malaysia (USM)	31	PhD	Council Member / Registered Conservator / Professor
Expert 6	Jabatan Warisan Negara (JWN) / National Heritage Department (NHD)	24	PhD	Director / Board Member

The questionnaire was designed as nine units of two-way importance rather than directly writing a two-way comparison matrix so that the characters could be understood easily (Awad & Jung, 2021). Further, the finding from the AHP method among the expert's panellists also reflects consensus and validation among the expert over the variables and indicators in this research. Therefore, the briefing session allows the expert's panellist to significantly understand and be well-versed over the research conducted, including the research objective, research question, research problem and the contribution of knowledge of the research. In addition, the researcher also explained the establishment of the hierarchy of structure of the research, as it is derived from the data collection phase. The questionnaire sample set for this AHP method among the expert panellist can be referred to in Appendix 2.

6.8 Analytic Hierarchy Process (AHP)

Figure 6.4 presents the hierarchical structure developed based on the variables and indicators established from the PLS-SEM assessment in Chapter Five. These variables were identified through the questionnaire survey among heritage conservation practitioners (see Appendix 1). As suggested by Saaty & Vargas (2001), the variables and indicators were then organised into clusters, sub-clusters, and alternatives consistent with the overall aim of the research, forming the foundational hierarchy of structure required for further evaluation.

These elements were subsequently used to construct the expert judgement questionnaires administered through the SuperDecisions software (see Appendix 2). The hierarchical structure was analysed to determine the weightage and ranking of each indicator across the three historic building retrofit development stages, namely pre-retrofit, implementation, and post-retrofit stages. The inclusion of development stages as clusters in the AHP hierarchy is essential because HBIM contributes differently across each phase of the conservation project lifecycle, making stage-specific prioritisation critical for improving heritage project performance (Dore & Murphy, 2017; Brumana et al., 2020; López et al., 2018). Structuring the hierarchy around these stages also aligns the framework with established heritage conservation workflows in Malaysia, ensuring practical applicability and stronger decision-making support for national conservation bodies and agencies such as JWN and PWD (Harun, 2021).

Experts assessed the indicators through pairwise comparisons within the seven sub-clusters: heritage aspect, retrofit design criteria, method of approach, organizational, informational, process lifecycle, and technical. Figure 6.5 shows the SuperDecisions interface used to analyse the AHP data. Expert inputs were entered to calculate the consistency indices (CI) and generate priority weightages for each sub-cluster. The use of AHP is appropriate in this context, as it systematically captures expert judgement and quantifies the relative importance of indicators through pairwise comparison (Saaty & Vargas, 2001).

Similar applications in heritage-built research such as Zuraidi et al. (2018) in validating conservation criteria in managing defects to historic buildings and Aladayleh & Aladaileh, (2024) demonstrates the AHP applicability to BIM-based risk management for optimal performance in construction projects. Both studies demonstrate its suitability for verifying the relevance, internal coherence, and priority structure of validated framework components. Thus, AHP provides a robust mechanism to validate and refine the HBIM-retrofit framework developed in this study.

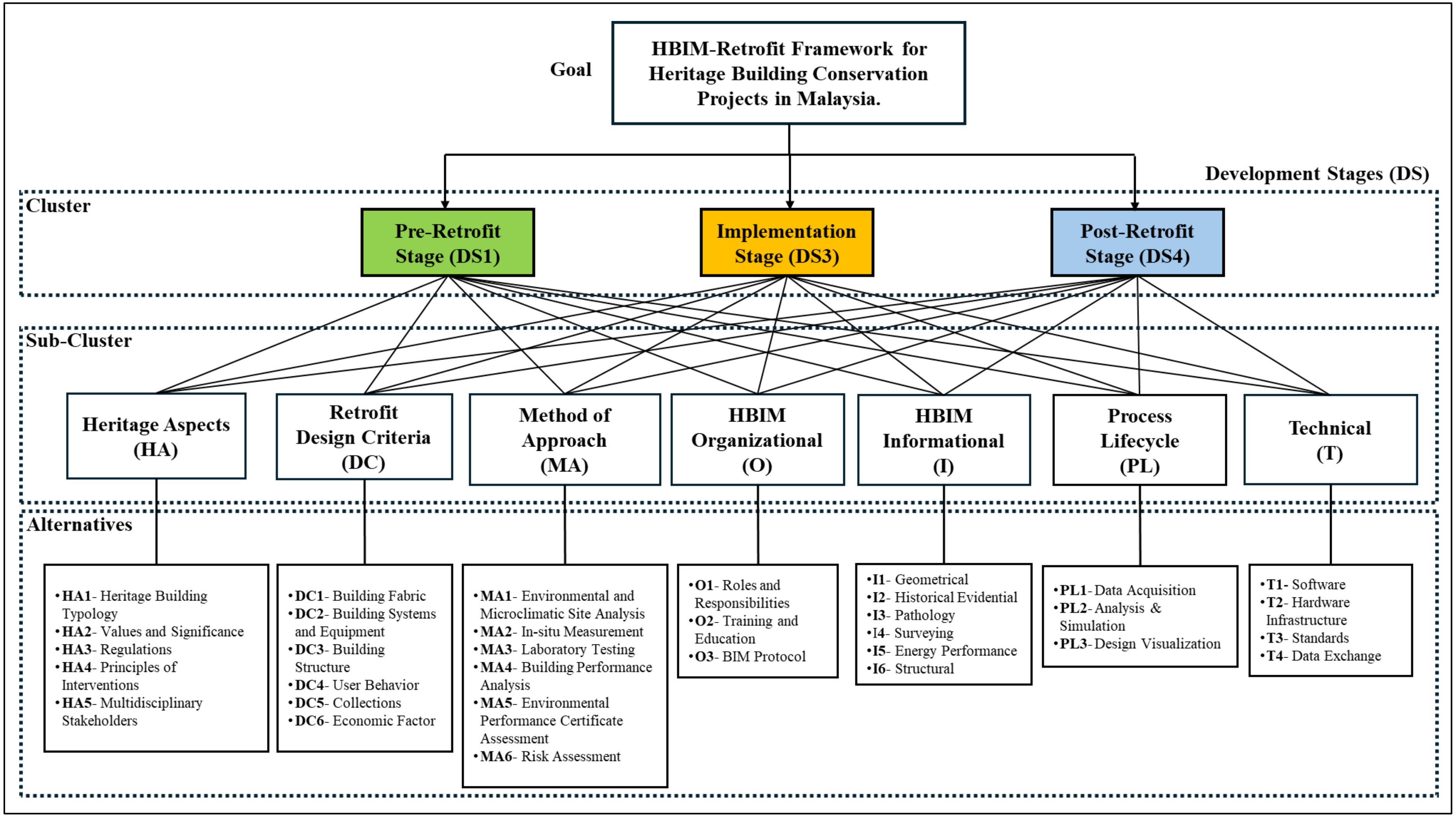

Figure 6.4 Hierarchy of Structure (Author)

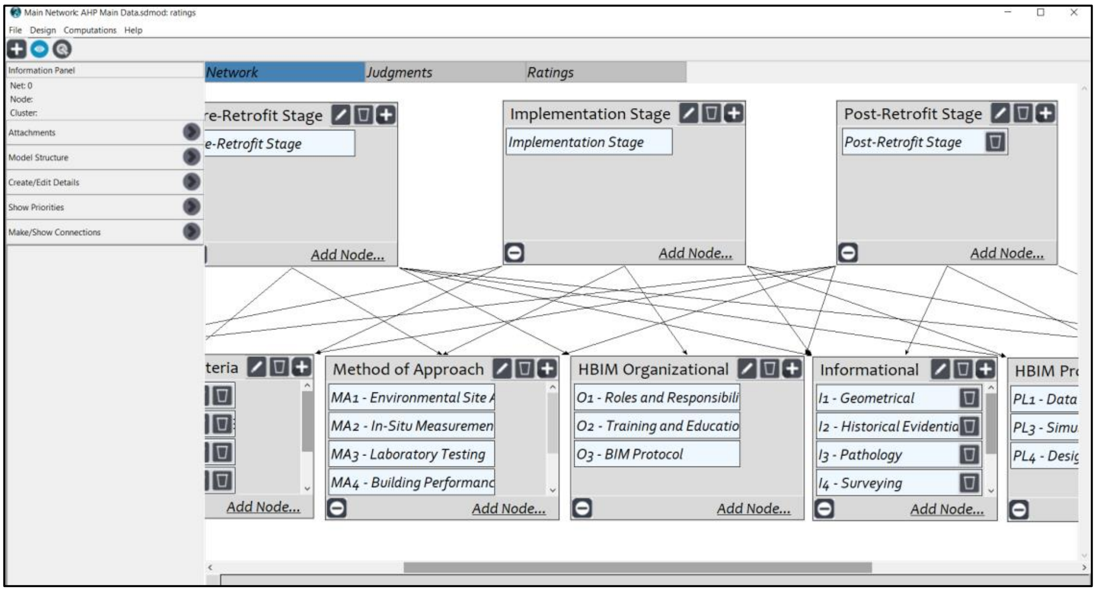

Figure 6.5 SuperDecisions Software Showing the Hierarchy of Structure

6.8.1 Multi Criteria Decision-Making (MCDM) Analysis

The AHP model adopted in this research is one of the approaches used to analyse Multi-Criteria Decision-Making (MCDM) method and techniques. The primary purpose of MCDM is to assist decision-makers in selecting the best alternative from a set of feasible options when multiple decision criteria are involved (Saaty & Vargas, 2001). All MCDM methods follow a set of general procedural steps, commonly referred to as a general model (Saaty & Vargas, 2001). The procedure for obtaining the AHP analysis results is discussed in the following subsection.

6.8.2 Pairwise Comparison

The data obtained from the expert panel's questionnaire responses were evaluated through a series of analytical steps. Figure 6.6 illustrates this process using the pairwise comparison response of expert 1 as an example, while the results from the remaining five experts are provided in Appendix 3. For example, within the pre-retrofit stage cluster, the sub-cluster criteria under the method of approach (MA) were compared against each other. The results generated in the SuperDecisions software show that in-situ measurement (MA1) is considered moderately important than environmental and microclimatic site analysis (MA1) in the method of approach for the pre-retrofit stage of HBIM-retrofitting, resulting in a reciprocal value of 1/3 = 3. All sub-cluster comparisons with respect to their parent cluster were organised into pairwise matrices. Each value in the matrix was normalised by dividing it by the sum of its column and the average of each row was then calculated, representing the estimated relative priority of the sub-clusters being compared. This procedure was repeated for all matrices of sub-clusters within the cluster.

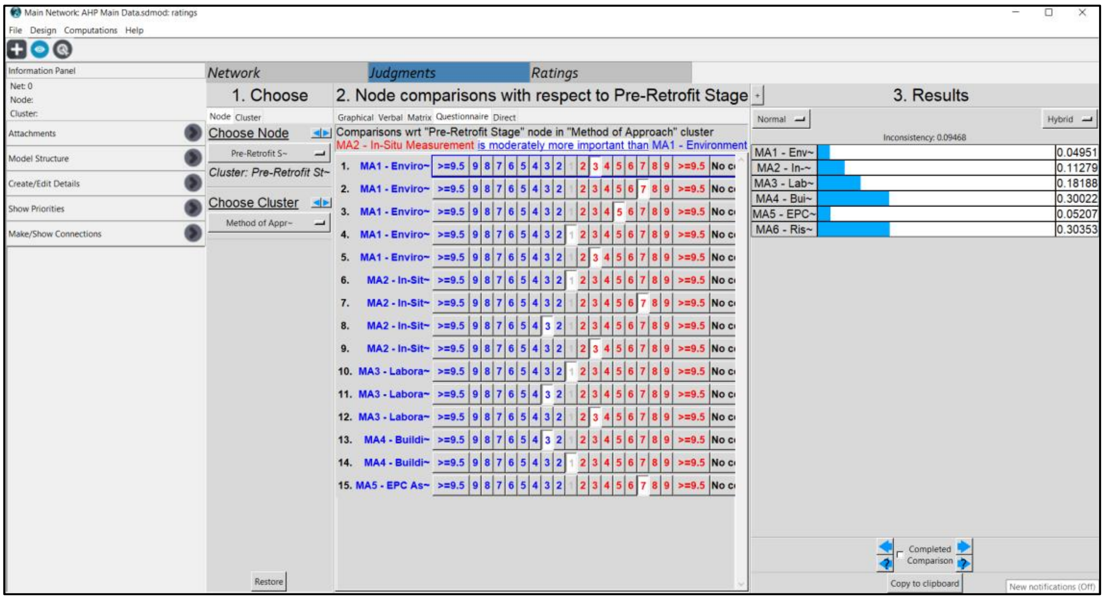

Figure 6.6 The Pairwise Comparison in the Questionnaire Mode

6.8.2.1 Pairwise Matrix of Sub-Clusters

Tables 6.3 to 6.23 present the sub-cluster matrices from Expert 1, illustrating the pairwise comparisons of indicators under the heritage aspect, retrofit design criteria, method of approach, HBIM organizational, informational, process lifecycle and technical criteria sub-clusters for the pre-retrofit, implementation, and post-retrofit stage clusters. These pairwise comparison results were subsequently converted into weight values. In addition, the SuperDecisions software generated inconsistency values for each assessment, indicating the reliability of the comparisons made between each sub-cluster and its parent cluster. The researcher ensured that all inconsistency values were ≤ 0.10 for every sub-cluster to cluster relationship before proceeding with the weight analysis.

Table 6.3
Sub-Cluster Matrix of Heritage Aspect for Pre-Retrofit Stage

Sub-Cluster	HA1	HA2	HA3	HA4	HA5
HA1	1	9	7	5	3
HA2	0.11	1	3	2	7
HA3	0.14	0.33	1	5	7
HA4	0.2	0.5	0.2	1	7
HA5	0.33	0.14	0.14	0.14	1

Table 6.4
Sub-Cluster Matrix of Retrofit Design Criteria for Pre-Retrofit Stage

Sub-Cluster	DC1	DC2	DC3	DC4	DC5	DC6
DC1	1	0.33	0.11	1	1	0.11
DC2	3	1	0.33	5	3	0.20
DC3	9	3	1	9	9	0.33
DC4	1	0.20	0.11	1	0.33	0.11
DC5	1	0.33	0.11	3	1	0.11
DC6	9	5	3	9	9	1

Table 6.5
Sub-Cluster Matrix of Method of Approach for Pre-Retrofit Stage

Sub-Cluster	MA1	MA2	MA3	MA4	MA5	MA6
MA1	1	0.33	0.14	0.20	1	0.33
MA2	3	1	1	0.14	3	0.33
MA3	7	1	1	1	2	0.33
MA4	5	7	1	1	3	1.00
MA5	1	0.33	1	0.33	1	0.14
MA6	3	3	3	1	7	1

Table 6.6
Sub-Cluster Matrix of HBIM Organizational for Pre-Retrofit Stage

Sub-Cluster	O1	O2	O3
O1	1	3	0.33
O2	0.33	1	0.14
O3	3	7	1

Table 6.7
Sub-Cluster Matrix of HBIM Informational Criteria for Pre-Retrofit Stage

Sub-Cluster	I1	I2	I3	I4	I5	I6
I1	1	0.25	2	0.50	5	5
I2	4	1	5	0.33	3	5
I3	0.50	0.2	1	0.2	1	5
I4	2	3	5	1	3	5
I5	0.20	0.33	1	0.33	1	5
I6	0.20	0.20	0.20	0.20	0.20	1

Table 6.8
Sub-Cluster Matrix of HBIM Process Lifecycle for Pre-Retrofit Stage

Sub-Cluster	PL1	PL3	PL4
PL1	1	1	0.33
PL3	1	1	0.33
PL4	3	3	1

Table 6.9
Sub-Cluster Matrix of HBIM Technical Criteria for Pre-Retrofit Stage

Sub-Cluster	T1	T2	T3	T4
T1	1	1	3	3
T2	1	1	5	5
T3	0.33	0.20	1	1
T4	0.33	0.20	1	1

Table 6.10
Sub-Cluster Matrix of Heritage Aspect for Implementation Stage

Sub-Cluster	HA1	HA2	HA3	HA4	HA5
HA1	1	0.20	0.33	0.14	0.11
HA2	5	1	3	0.20	0.20
HA3	3	0.33	1	0.20	0.14
HA4	7	5	5	1	3
HA5	9	5	7	0.33	1

Table 6.11
Sub-Cluster Matrix of Retrofit Design Criteria for Implementation Stage

Sub-Cluster	DC1	DC2	DC3	DC4	DC5	DC6
DC1	1	0.33	0.14	5	3	0.14
DC2	3	1	0.20	3	5	0.20
DC3	7	5	1	7	7	0.33
DC4	0.20	0.33	0.14	1	2	0.14
DC5	0.33	0.20	0.14	0.5	1	0.11
DC6	7	5	3	7	9	1

Table 6.12
Sub-Cluster Matrix of Method of Approach for Implementation Stage

Sub-Cluster	MA1	MA2	MA3	MA4	MA5	MA6
MA1	1	0.20	0.14	0.20	1	0.33
MA2	5	1	1	1	3	0.33
MA3	7	1	1	1	3	0.33
MA4	5	1	1	1	1	0.14
MA5	1	0.33	0.33	1	1	0.14
MA6	3	3	3	7	7	1

Table 6.13
Sub-Cluster Matrix of HBIM Organizational for Implementation Stage

Sub-Cluster	O1	O2	O3
O1	1	3	0.33
O2	0.33	1	1
O3	3	1	1

Table 6.14
Sub-Cluster Matrix of HBIM Informational Criteria for Pre-Retrofit Stage

Sub-Cluster	I1	I2	I3	I4	I5	I6
I1	1	0.33	1	1	5	0.33
I2	3	1	0.20	1	3	0.20
I3	1	5	1	0.20	1	0.20
I4	1	1	5	1	3	0.20
I5	0.20	0.33	1	0.33	1	0.20
I6	3	5	5	5	5	1

Table 6.15
Sub-Cluster Matrix of HBIM Process Lifecycle for Implementation Stage

Sub-Cluster	PL1	PL3	PL4
PL1	1	1	3
PL3	1	1	2
PL4	0.33	0.50	1

Table 6.16
Sub-Cluster Matrix of HBIM Technical Criteria for Pre-Retrofit Stage

Sub-Cluster	T1	T2	T3	T4
T1	1	1	3	3
T2	1	1	5	5
T3	0.33	0.20	1	1
T4	0.33	0.20	1	1

Table 6.17
Sub-Cluster Matrix of Heritage Aspect for Post-Retrofit Stage

Sub-Cluster	HA1	HA2	HA3	HA4	HA5
HA1	1	3	5	3	5
HA2	0.33	1	3	1	3
HA3	0.20	0.33	1	0.33	1
HA4	0.33	1	3	1	3
HA5	0.20	0.33	1	0.33	1

Table 6.18
Sub-Cluster Matrix of Retrofit Design Criteria for Post-Retrofit Stage

Sub-Cluster	DC1	DC2	DC3	DC4	DC5	DC6
DC1	1	3	3	3	5	3
DC2	0.33	1	1	0.33	3	1
DC3	0.33	1	1	3	3	3
DC4	0.33	3.00	0.33	1	2	0.33
DC5	0.20	0.33	0.33	0.5	1	0.33
DC6	0.33	1	0.33	3	3	1

Table 6.19
Sub-Cluster Matrix of Method of Approach for Post-Retrofit Stage

Sub-Cluster	MA1	MA2	MA3	MA4	MA5	MA6
MA1	1	0.20	0.25	0.14	0.20	0.14
MA2	5	1	3	0.20	0.20	0.33
MA3	4	0.33	1	0.33	0.14	0.20
MA4	7	5	3	1	0.33	2
MA5	5	5	7	3	1	1
MA6	7	3	5	0.5	1	1

Table 6.20
Sub-Cluster Matrix of HBIM Organizational for Post-Retrofit Stage

Sub-Cluster	O1	O2	O3
O1	1	3	0.33
O2	0.33	1	0.11
O3	3	9	1

Table 6.21
Sub-Cluster Matrix of HBIM Informational Criteria for Post-Retrofit Stage

Sub-Cluster	I1	I2	I3	I4	I5	I6
I1	1	0.33	0.33	0.20	0.33	0.14
I2	3	1	0.33	0.33	0.14	0.20
I3	3	3	1	0.33	1	0.20
I4	5	3	3	1	1	0.33
I5	2	7	1	1	1	1
I6	7	5	5	3	1	1

Table 6.22
Sub-Cluster Matrix of HBIM Process Lifecycle for Post-Retrofit Stage

Sub-Cluster	PL1	PL3	PL4
PL1	1	0.33	1
PL3	3	1	3
PL4	1	0.33	1

Table 6.23
Sub-Cluster Matrix of HBIM Technical Criteria for Post-Retrofit Stage

Sub-Cluster	T1	T2	T3	T4
T1	1	3	0.14	0.20
T2	0.33	1	0.11	0.14
T3	7	9	1	3
T4	5	7	0.33	1

6.8.3 Inconsistency Ratio

The inconsistency ratio (IR) provides evidence that the expert judgments are logically coherent, enhancing the reliability of the aggregated weights (Pant et al., 2022; Saaty & Vargas, 2001). An example of computation of IR values using SuperDecisions software is shown in Figure 6.7 below, with the IR values are displayed at the top priorities screen. The results shows that the IR value is 0.09468. A ratio less than 0.10 or below (≤ 0.10) is desirable (Mu & Pereyra-Rojas, 2016; Saaty & Vargas, 2001), so this is an acceptable level of inconsistency; therefore, it does not require for the re-evaluation of judgments by the experts.

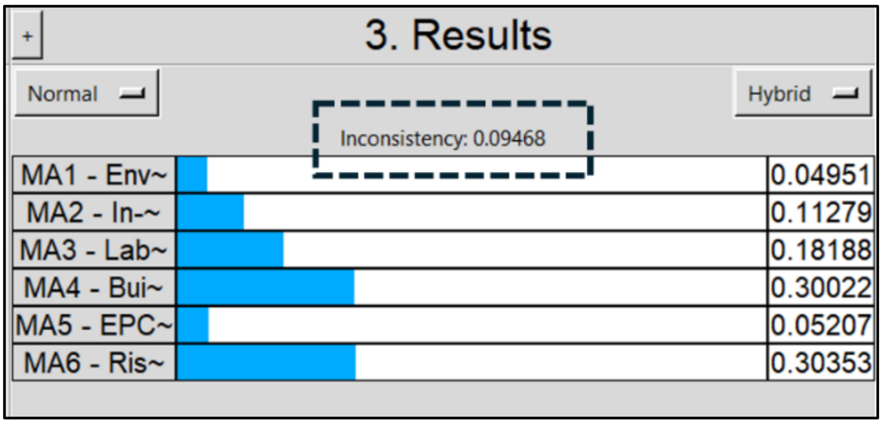

Figure 6.7 Inconsistency Ratio of Pairwise Comparison for Method of Approach (MA)

6.8.4 Weights and Ranks of Sub-Clusters to Clusters

After ensuring that all inconsistency ratio (IR) values were ≤ 0.10 based on the data collected from the six selected experts, the weights of each sub-cluster were compiled into tables for all six experts. These compiled weights were then used to calculate the geometric mean for each indicator within the sub-clusters. The computed geometric mean values (R) derived from the six experts are presented in Table 6.24. The geometric mean in this context represents the consensus value achieved across all experts, reflecting the collective judgment for each indicator thus strengthens construct validity and reduces individual bias (Escobar & Moreno-Jimenéz, 2007). To illustrate this process, the calculation of the geometric mean for the first indicator under the method of approach (MA) sub-cluster to environmental microclimatic site analysis (MA1) is provided as an example below (Umar, 2018).

$$\text{Geometric mean} = Power(R_1 \times R_2 * \ldots R_n \, , 1/nR) \quad (6.1)$$

Where: Power (0.049×0.079×0.031×0.203×0.222×0.149, 0.16) = 0.104 (6.2)

Moreover, the research conducted this geometric mean equation to every indicator in each sub-cluster to every cluster established.

6.8.4.1 Weights and Ranks of Pre-Retrofit Stage

Table 6.24 shows the weight and rank of sub-clusters (heritage aspect, retrofit design criteria, method of approach, organizational, informational, process lifecycle and technical) respected to the pre-retrofit stage cluster from the six different experts. The aggregate results demonstrate that principles of intervention (HA4) are the most influential sub-cluster with the highest weight (0.300) and is ranked 1. This is followed by regulations (HA3) with the weight of 0.250, ranked 2, values and significance (HA2) hold moderate importance in weights (0.220) and is ranked 3, heritage building typology (HA1) obtains a lower relative priority (0.087), ranked 4. The least prioritized element is multidisciplinary stakeholders (HA5), which are the least weight (0.080) and ranked 5.

Within the retrofit design criteria (DC) cluster, the experts identified building structure (DC3) as the most critical criterion (weight = 0.372), and ranked 1, followed by collections (DC5), which has the second highest weight (0.140), ranked 2, and thirdly is the building fabric (DC1) (weight = 0.117, rank = 3). Economic factor (DC6) emerges with a mid-range importance (weight = 0.116, and is ranked 4, building systems and equipment (DC2) have a slightly lower weight (0.110), and is ranked 5, and user behaviour (DC4) was the least important weight (0.061), and is ranked 6.

The higher tier of method of approach (MA) cluster reveals that risk assessment (MA6) is placed as the top priority in terms of weight (0.270) and ranked 1. This is followed by building performance analysis (MA4) (weight = 0.173, rank = 2) and laboratory testing (MA3) (weight = 0.154, rank = 3). Moreover, in-situ measurement (MA2) scored moderately important weights (0.140) and is ranked 4. The least prioritized methods in this cluster are the environmental performance certificate assessment (MA5) (weight = 0.127, rank = 5) and environmental microclimatic site analysis (MA1) (weight = 0.104, rank = 6), though its relevance increases in subsequent development stages.

Within the organizational (O) sub-cluster, training and education (O2) is the most important (weight = 0.369, rank = 1) followed by roles and responsibilities (O1) which is ranked second (weight = 0.305) and BIM protocol (O3) has the lowest weight (0.198, rank = 3). The informational attributes reveal structural (I6) as the most important sub-cluster (weight = 0.256, rank = 1), the second priority is historical evidential (I2) (weight = 0.215, rank = 2), surveying (I4) ranks third (weight = 0.170) followed by pathology (I3) (weight = 0.144, rank = 4). The energy performance (I5) and geometrical (I1) have lower weights (0.081 and 0.078; ranks 5 and 6 respectively).

For process lifecycle (PL) considerations, simulation and analysis (PL3) is the most prominent (weight = 0.414, rank = 1), suggesting that early-stage predictive modelling plays a vital role in shaping retrofit feasibility and performance. Design visualization (PL4) follows (weight = 0.252, rank = 2) and data acquisition (PL1) is ranked third (weight = 0.213).

The HBIM technical (T) aspects are led by hardware infrastructure (T2) (weight = 0.256, rank = 1). Standards (T3) are the second-highest priority (weight = 0.244, rank = 2), indicating the relevance of technical guidelines and interoperability conventions. software (T1) ranks third (weight = 0.233) and data exchange (T4) is ranked lowest (weight = 0.216, rank = 4).

Table 6.24
The Weight and Rank of Sub-Clusters Respected to the Pre-Retrofit Stage Cluster

Cluster		Pre-Retrofit Stage (DS1)													
		Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Expert 6		Aggregates	
Code	**Sub-Cluster**	**Weight**	**Rank**	**Weight**	**Rank**	**Weight**	**Rank**	**Weight**	**Rank**	**Weight**	**Rank**	**Weight**	**Rank**	**Weight**	**Rank**
HA	**Heritage Aspect**														
HA1	Heritage Building Typology	0.033	5	0.044	5	0.049	5	0.066	5	0.234	3	0.220	4	**0.087**	**4**
HA2	Values and Significance	0.257	2	0.080	3	0.177	3	0.288	1	0.304	2	0.241	1-3	**0.220**	**3**
HA3	Regulations	0.490	1	0.445	1	0.203	2	0.219	3	0.075	4	0.241	1-3	**0.250**	**2**
HA4	Principles of Intervention	0.167	3	0.377	2	0.416	1	0.244	2	0.349	1	0.241	1-3	**0.300**	**1**
HA5	Multidisciplinary Stakeholders	0.051	4	0.053	4	0.155	4	0.182	4	0.036	5	0.054	5	**0.080**	**5**
DC	**Retrofit Design Criteria**														
DC1	Building Fabric	0.038	5	0.064	5	0.109	3	0.181	3-4	0.217	2-3	0.146	3	**0.117**	**3**
DC2	Building Systems and Equipment	0.115	3	0.033	6	0.089	4	0.181	3-4	0.217	2-3	0.080	4	**0.110**	**5**
DC3	Building Structure	0.294	2	0.376	2	0.493	1	0.243	1	0.392	1	0.403	1	**0.372**	**1**
DC4	User Behaviour	0.031	6	0.065	4	0.046	6	0.190	2	0.032	6	0.043	5	**0.061**	**6**
DC5	Collections	0.048	4	0.222	3	0.205	2	0.108	5	0.071	4-5	0.293	2	**0.140**	**2**
DC6	Economic Factor	0.474	1	0.239	1	0.057	5	0.096	6	0.071	4-5	0.033	6	**0.116**	**4**
MA	**Method of Approach**														
MA1	Environmental Microclimatic Site Analysis	0.049	6	0.079	5	0.031	6	0.203	2-3	0.222	1-2	0.149	3-4	**0.104**	**6**
MA2	In-Situ Measurement	0.113	4	0.045	6	0.185	2	0.262	1	0.135	4	0.149	3-4	**0.140**	**4**

MA3	Laboratory Testing	0.174	3	0.208	2	0.165	3	0.075	6	0.204	3	0.106	6	**0.154**	**3**
MA4	Building Performance Analysis	0.301	2	0.163	3	0.137	4-5	0.149	4	0.107	5-6	0.158	2	**0.173**	**2**
MA5	EPC Certificate Assessment	0.056	5	0.116	4	0.137	4-5	0.203	2-3	0.107	5-6	0.129	5	**0.127**	**5**
MA6	Risk Assessment	0.304	1	0.386	1	0.344	1	0.105	5	0.222	1-2	0.306	1	**0.270**	**1**
O	**HBIM Organizational**														
O1	Roles and Responsibilities	0.242	2	0.486	1	0.333	1-3	0.097	3	0.454	1-2	0.366	2	**0.305**	**2**
O2	Training and Education	0.087	3	0.435	2	0.333	1-3	0.700	1	0.454	1-2	0.497	1	**0.369**	**1**
O3	BIM Protocol	0.669	1	0.077	3	0.333	1-3	0.202	2	0.090	3	0.135	3	**0.198**	**3**
I	**HBIM Informational**														
I1	Geometrical	0.095	4	0.069	5	0.024	6	0.071	6	0.082	5	0.138	4	**0.078**	**6**
I2	Historical Evidential	0.156	3	0.228	3	0.473	1	0.099	5	0.352	1	0.141	3	**0.215**	**2**
I3	Pathology	0.044	6	0.291	1	0.115	4	0.149	4	0.139	4	0.217	2	**0.144**	**4**
I4	Surveying	0.192	2	0.096	4	0.123	3	0.310	1	0.180	3	0.122	5	**0.170**	**3**
I5	Energy Performance	0.047	5	0.055	6	0.085	5	0.199	2	0.059	6	0.061	6	**0.081**	**5**
I6	Structural	0.463	1	0.258	2	0.177	2	0.169	3	0.186	2	0.318	1	**0.256**	**1**
PL	**HBIM Project Lifecycle**														
PL1	Data Acquisition	0.200	2-3	0.096	3	0.333	1-3	0.100	3	0.549	1	0.224	2	**0.213**	**3**
PL3	Simulation & Analysis	0.200	2-3	0.798	1	0.333	1-3	0.674	1	0.209	3	0.609	1	**0.414**	**1**
PL4	Design Visualization	0.600	1	0.104	2	0.333	1-3	0.225	2	0.240	2	0.165	3	**0.252**	**2**
T	**HBIM Technical**														
T1	Software	0.348	2	0.235	3	0.096	4	0.250	1-4	0.238	2	0.240	2-3	**0.233**	**3**
T2	Hardware Infrastructure	0.448	1	0.362	1	0.187	3	0.250	1-4	0.083	4	0.331	1	**0.256**	**1**
T3	Standards	0.101	3-4	0.135	4	0.381	1	0.250	1-4	0.478	1	0.240	2-3	**0.244**	**2**
T4	Data Exchange	0.101	3-4	0.266	2	0.335	2	0.250	1-4	0.198	3	0.188	4	**0.216**	**4**

6.8.4.2 Weights and Ranks of Implementation Stage

The consolidated aggregate weights and ranks for all sub-clusters within the implementation stage, derived from the geometric mean of six expert panellists' responses were shown in Table 6.25. The results reflect the relative ordering of priorities as computed within each thematic cluster. For the heritage aspects (HA) cluster, principles of intervention (HA4) recorded the highest aggregate weight (0.298) and is ranked 1. This is followed by regulations (HA3) with a weight of 0.195 and ranked 2 as well as values and significance (HA2) with a weight of 0.163, ranked 3. Multidisciplinary Stakeholders (HA5) achieved a weight of 0.129, ranked 4, while Heritage Building Typology (HA1) recorded the lowest weight of 0.078, ranked 5.

Within the retrofit design criteria cluster (DC), building Structure (DC3) shows the highest aggregate weight (0.347), placing it in rank 1. This is followed by Building Fabric (DC1) at 0.151 (ranked 2) and Building Systems and Equipment (DC2) at 0.118 (ranked 3). Economic Factor (DC6) holds a weight of 0.092 (ranked 4), while collections (DC5) records 0.091 (ranked 5). User Behaviour (DC4) has the lowest weight of 0.078 (ranked 6).

In the method of approach (MA) cluster, risk assessment (MA6) ranks first with an aggregate weight of 0.329. Laboratory testing (MA3) follows with a weight of 0.189 (ranked 2), and building performance analysis (MA4) ranks third with a weight of 0.157. EPC certificate assessment (MA5) has a weight of 0.111 (ranked 4), while in-situ measurement (MA2) records 0.101 (ranked 5). The lowest-ranked sub-cluster is environmental microclimatic site analysis (MA1) with a weight of 0.072 (ranked 6)

For the HBIM organizational (O) cluster, roles and responsibilities (O1) achieves the highest aggregate weight of 0.527 (rank 1). This is followed by training and education (O2) at 0.262 (rank 2). BIM protocol (O3) records the lowest weight of 0.144 (rank 3). Within the HBIM informational (I) cluster, structural information (I6) is ranked first with an aggregate weight of 0.302. Historical evidential (I2) follows with a weight of 0.299 (rank 2). Pathology (I3) is ranked third with a weight of 0.152. Surveying (I4) records a weight of 0.110 (rank 4). Geometrical (I1) follows with 0.063 (rank 5), while energy performance (I5) has the lowest weight of 0.062 (rank 6).

For the process lifecycle (PL) cluster, data acquisition (PL1) is ranked first with an aggregate weight of 0.421. Simulation and analysis (PL3) follow with a weight of 0.285 (rank 2), and design visualization (PL4) ranks third with a weight of 0.191. Within the technical cluster (T), data exchange (T4) records the highest aggregate weight of 0.242 (rank 1). Hardware infrastructure (T2) is ranked second with a weight of 0.220. Standards (T3) follow closely at 0.200 (rank 3). Software (T1) records an aggregate weight of 0.196 (rank 4).

Table 6.25
The Weight and Rank of Sub-Clusters Respected to the Implementation Stage Cluster

Cluster		Implementation Stage (DS3)													
		Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Expert 6		Aggregates	
Code	Sub-Cluster	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
HA		**Heritage Aspect**													
HA1	Heritage Building Typology	0.033	5	0.038	5	0.044	5	0.124	4	0.171	4	0.104	4	**0.078**	**5**
HA2	Values and Significance	0.113	3	0.066	4	0.112	4	0.087	5	0.291	2	0.563	1	**0.163**	**3**
HA3	Regulations	0.061	4	0.449	1	0.151	3	0.299	1	0.189	3	0.178	2	**0.195**	**2**
HA4	Principles of Intervention	0.466	1	0.368	2	0.416	1	0.225	3	0.298	1	0.124	3	**0.298**	**1**
HA5	Multidisciplinary Stakeholders	0.325	2	0.077	3	0.275	2	0.262	2	0.049	5	0.029	5	**0.129**	**4**
DC		**Retrofit Design Criteria**													
DC1	Building Fabric	0.074	4	0.061	5	0.094	4	0.281	1	0.260	2	0.248	3	**0.151**	**2**
DC2	Building Systems and Equipment	0.111	3	0.027	6	0.043	6	0.216	3	0.227	3	0.251	2	**0.118**	**3**
DC3	Building Structure	0.301	2	0.369	1	0.388	1	0.244	2	0.328	1	0.384	1	**0.347**	**1**
DC4	User Behaviour	0.038	5	0.075	4	0.168	3	0.142	4	0.037	6	0.050	4	**0.078**	**6**
DC5	Collections	0.028	6	0.220	3	0.257	2	0.055	6	0.094	4	0.041	5	**0.091**	**5**
DC6	Economic Factor	0.445	1	0.245	2	0.047	5	0.060	5	0.051	5	0.022	6	**0.092**	**4**
MA		**Method of Approach**													
MA1	Environmental Microclimatic Site Analysis	0.051	6	0.067	5	0.028	6	0.082	5	0.203	1-2	0.044	6	**0.072**	**6**
MA2	In-Situ Measurement	0.156	3	0.027	6	0.090	4	0.135	4	0.203	1-2	0.060	5	**0.101**	**5**

MA3	Laboratory Testing	0.171	2	0.346	2	0.087	5	0.167	3	0.137	5-6	0.255	3	**0.189**	**2**
MA4	Building Performance Analysis	0.125	4	0.079	3	0.095	3	0.275	1	0.137	5-6	0.269	2	**0.157**	**3**
MA5	EPC Certificate Assessment	0.061	5	0.068	4	0.238	2	0.079	6	0.159	3-4	0.090	4	**0.111**	**4**
MA6	Risk Assessment	0.434	1	0.411	1	0.459	1	0.260	2	0.159	3-4	0.280	1	**0.329**	**1**
O	**HBIM Organizational**														
O1	Roles and	0.318	2	0.487	1	0.741	1	0.333	1-3	0.600	1	0.778	1	**0.527**	**1**
O2	Training and Education	0.221	3	0.435	2	0.203	2	0.333	1-3	0.200	2-3	0.180	2	**0.262**	**2**
O3	BIM Protocol	0.459	1	0.077	3	0.055	3	0.333	1-3	0.200	2-3	0.042	3	**0.144**	**3**
I	**HBIM Informational**														
I1	Geometrical	0.177	3	0.066	5	0.030	6	0.057	6	0.056	6	0.027	5	**0.063**	**5**
I2	Historical Evidential	0.181	2	0.238	3	0.332	2	0.236	2	0.351	1	0.449	1	**0.299**	**2**
I3	Pathology	0.057	5	0.305	1	0.131	3	0.243	1	0.092	4-5	0.150	3	**0.152**	**3**
I4	Surveying	0.146	4	0.086	4	0.076	4	0.147	4-5	0.166	3	0.044	4	**0.110**	**4**
I5	Energy Performance	0.049	6	0.051	6	0.035	5	0.147	4-5	0.092	4-5	0.025	6	**0.062**	**6**
I6	Structural	0.448	1	0.253	2	0.396	1	0.171	3	0.241	2	0.304	2	**0.302**	**1**
PL	**HBIM Project Lifecycle**														
PL1	Data Acquisition	0.443	1	0.527	1	0.088	3	0.454	1-2	0.600	1	0.796	1	**0.421**	**1**
PL3	Simulation & Analysis	0.387	2	0.260	2	0.352	2	0.454	1-2	0.200	2-3	0.121	2	**0.285**	**2**
PL4	Design Visualization	0.169	3	0.214	3	0.599	1	0.091	3	0.200	2-3	0.083	3	**0.191**	**3**
T	**HBIM Technical**														
T1	Software	0.348	2	0.235	3	0.112	3	0.368	1	0.118	3-4	0.097	3	**0.196**	**4**
T2	Hardware Infrastructure	0.449	1	0.123	4	0.062	4	0.301	2	0.118	3-4	0.643	1	**0.220**	**2**
T3	Standards	0.101	3-4	0.292	2	0.289	2	0.200	3	0.487	1	0.051	4	**0.200**	**3**
T4	Data Exchange	0.101	3-4	0.350	1	0.536	1	0.131	4	0.276	2	0.208	2	**0.242**	**1**

6.8.4.3 Weights and Ranks of Post-Retrofit Stage

The consolidated aggregate weights and ranks for all sub-clusters within the post-retrofit stage are derived from the geometric mean collected from the six expert panellists' responses were shown in Table 6.26.

Within the heritage aspect (HA) cluster, indicator values and significance (HA2) recorded the highest aggregate weight (0.312), positioning it as ranked 1. This is followed by principles of intervention (HA4*)* with an aggregate weight of 0.296, placed at rank 2. Regulations (HA3) obtained an aggregate weight of 0.146, thus ranked 3, while heritage building typology (HA1) attained an aggregate weight of 0.094, corresponding to rank 4. The lowest weight was recorded for multidisciplinary stakeholders (HA5) at 0.065, placing it at rank 5.

In the retrofit design criteria (DC) cluster, user behaviour (DC4) achieved the highest aggregate weight (0.246), ranked 1. The second-highest weight is observed in building structure (DC3) at 0.184, ranked 2. Building fabric (DC1) follows with an aggregate weight of 0.153, assigned ranked 3. Economic factor (DC6) recorded a weight of 0.142, placing it at rank 4. Collections (DC5) obtained an aggregate value of 0.130, ranked 5, while building systems and equipment (DC2) shows the lowest aggregate weight of 0.070, ranked 6.

In the method of approach (MA) cluster, EPC certificate assessment (MA5) represents the sub-cluster with the highest aggregate weight of 0.265, thus ranked 1. This is followed by risk assessment (MA6) at 0.249, positioning it at rank 2. Building performance analysis (MA4) attained an aggregate weight of 0.224, ranked 3, while laboratory testing (MA3) recorded 0.101, ranked 4. In-situ measurement (MA2) shows a weight of 0.068, ranked 5, and environmental microclimatic site analysis (MA1) is lowest with 0.063, placed at rank 6.

Within the organizational cluster (O), roles and responsibilities (O1) recorded the highest aggregate weight of 0.392, ranked 1. This is followed by BIM protocol (O3) with 0.283, positioned at rank 2. The lowest aggregate weight belongs to training and education (O2) at 0.173, ranked 3.

For the informational cluster (I), structural (I6) achieved the highest aggregate weight of 0.241, making it ranked 1. Energy performance (I5) follows with a weight of 0.199, ranked 2, while pathology (I3) attained 0.187, positioned at rank 3. Historical evidential (I2) shows an aggregate weight of 0.183, ranked 4, followed by surveying (I4) at 0.104, ranked 5. The lowest weight is geometrical (I1) at 0.052, ranked 6.

For the process lifecycle (PL), the sub-cluster with the highest aggregate weight is data acquisition (PL1) at 0.404, assigned rank 1. Simulation and analysis (PL3) is positioned at rank 2 with an aggregate weight of 0.260, while design visualisation (PL4) is ranked 3, with a recorded weight of 0.239.

Lastly, the technical cluster (T) shows standards (T3) emerged as the sub-cluster with the highest aggregate weight of 0.269, therefore ranked 1. Data exchange (T4) follows with 0.214, ranked 2, while hardware infrastructure (T2) recorded 0.196, positioned at rank 3. The lowest weight in this cluster is software (T1) at 0.194, ranking at number 4.

Table 6.26
The weight and rank of sub-clusters respected to the post-retrofit stage cluster

Cluster		Post-Retrofit Stage (DS4)													
		Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Expert 6		Aggregates	
Code	Sub-Cluster	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
HA	**Heritage Aspect**														
HA1	Heritage Building Typology	0.446	1	0.059	4	0.027	5	0.081	4	0.083	4-5	0.081	3-4	**0.094**	**4**
HA2	Values and Significance	0.194	2-3	0.096	3	0.440	1	0.518	1	0.408	1	0.401	1-2	**0.312**	**1**
HA3	Regulations	0.073	4-5	0.399	2	0.091	3	0.165	2-3	0.165	3	0.081	3-4	**0.146**	**3**
HA4	Principles of	0.194	2-3	0.406	1	0.366	2	0.165	2-3	0.260	2	0.401	1-2	**0.296**	**2**
HA5	Multidisciplinary Stakeholders	0.073	4-5	0.038	5	0.076	4	0.068	5	0.083	4-5	0.033	5	**0.065**	**5**
DC	**Retrofit Design Criteria**														
DC1	Building Fabric	0.357	1	0.065	5	0.057	5	0.312	1	0.172	2	0.116	4	**0.153**	**3**
DC2	Building Systems and Equipment	0.117	5	0.028	6	0.025	6	0.143	4	0.124	5	0.040	6	**0.070**	**6**
DC3	Building Structure	0.208	2	0.128	4	0.213	3	0.254	2	0.112	6	0.159	3	**0.184**	**2**
DC4	User Behaviour	0.121	3	0.185	3	0.358	1	0.196	3	0.276	1	0.358	1	**0.246**	**1**
DC5	Collections	0.050	6	0.286	2	0.271	2	0.048	5	0.157	4	0.102	5	**0.130**	**5**
DC6	Economic Factor	0.144	4	0.306	1	0.073	4	0.045	6	0.158	3	0.222	2	**0.142**	**4**
MA	**Method of Approach**														
MA1	Environmental Microclimatic Site Analysis	0.030	6	0.067	5	0.027	6	0.182	3	0.140	6	0.022	6	**0.063**	**6**

MA2	In-Situ Measurement	0.091	4	0.023	6	0.032	5	0.071	5	0.162	2-5	0.068	5	**0.068**	**5**
MA3	Laboratory Testing	0.058	5	0.131	4	0.112	4	0.055	6	0.162	2-5	0.079	4	**0.101**	**4**
MA4	Building Performance Analysis	0.248	2	0.141	3	0.225	2	0.349	1	0.162	2-5	0.200	3	**0.224**	**3**
MA5	EPC Certificate Assessment	0.350	1	0.382	1	0.180	3	0.237	2	0.208	1	0.207	2	**0.265**	**1**
MA6	Risk Assessment	0.221	3	0.254	2	0.421	1	0.104	4	0.162	2-5	0.421	1	**0.249**	**2**
O	**HBIM Organizational**														
O1	Roles and	0.230	2	0.486	1	0.304	2	0.258	2	0.428	1-2	0.785	1	**0.392**	**1**
O2	Training and Education	0.077	3	0.435	2	0.177	3	0.104	3	0.428	1-2	0.065	3	**0.173**	**3**
O3	BIM Protocol	0.692	1	0.077	3	0.519	1	0.636	1	0.143	3	0.149	2	**0.283**	**2**
I	**HBIM Informational**														
I1	Geometrical	0.041	6	0.044	6	0.026	6	0.136	6	0.057	6	0.025	6	**0.052**	**6**
I2	Historical Evidential	0.060	5	0.140	4	0.265	2	0.185	2	0.142	5	0.411	1	**0.183**	**4**
I3	Pathology	0.120	4	0.322	1	0.304	1	0.155	4-5	0.214	2	0.073	4	**0.187**	**3**
I4	Surveying	0.197	3	0.054	5	0.049	5	0.155	4-5	0.159	4	0.056	5	**0.104**	**5**
I5	Energy Performance	0.221	2	0.232	2	0.162	4	0.206	1	0.257	1	0.094	3	**0.199**	**2**
I6	Structural	0.362	1	0.207	3	0.194	3	0.163	3	0.171	3	0.339	2	**0.241**	**1**
PL	**HBIM Project Lifecycle**														
PL1	Data Acquisition	0.200	2-3	0.526	1	0.708	1	0.428	1-2	0.379	1	0.290	2	**0.404**	**1**
PL3	Simulation & Analysis	0.600	1	0.260	2	0.179	2	0.428	1-2	0.331	2	0.055	3	**0.260**	**2**
PL4	Design Visualization	0.200	2-3	0.213	3	0.113	3	0.142	3	0.289	3	0.655	1	**0.239**	**3**
T	**HBIM Technical**														
T1	Software	0.085	3	0.235	2-3	0.235	2	0.241	3	0.129	4	0.243	2	**0.194**	**4**
T2	Hardware Infrastructure	0.042	4	0.357	1	0.152	4	0.142	4	0.178	3	0.647	1	**0.196**	**3**
T3	Standards	0.583	1	0.172	4	0.441	1	0.309	1-2	0.389	1	0.051	4	**0.269**	**1**
T4	Data Exchange	0.290	2	0.235	2-3	0.172	3	0.309	1-2	0.303	2	0.059	3	**0.214**	**2**

6.9 Findings and Discussions from AHP

The synthesis and findings presented in this section are derived from a structured research process designed to establish and validate the HBIM-retrofit framework for heritage building conservation projects in Malaysia. This framework was then refined through expert validation, ensuring that each criterion reflected practical relevance and contextual suitability within Malaysia's heritage conservation environment. Following this, the Analytical Hierarchy Process (AHP) was applied to prioritise the sub-criteria across the pre-retrofit, implementation, and post-retrofit stages. The resulting rankings and radar charts provide a clear understanding of shifting priorities across stages. Furthermore, findings from the prioritized results were the discussed critically in relation to the literature review.

6.9.1 The Heritage Aspect of HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.27 shows the ranking of heritage aspect for the three development stages, including the pre-design stage, implementation stage and post-retrofit stage. In general, the results shown based on the ranking sequence of each indicator in the heritage aspect for the three different development stages of historic building retrofit demonstrated a relevant reference for practitioner's in determining the best options, hence supports in organising for future conservation project.

Table 6.27
Ranking of Heritage Aspect in the Three Development Stages *(Author)*

Rank	Pre-Retrofit Stage (DS1)	Implementation Stage (DS3)	Post-Retrofit Stage (DS4)
1	HA4 - Principles of Intervention	HA4 - Principles of Intervention	HA2 - Values and Significance
2	HA3 - Regulations	HA3 - Regulations	HA4 - Principles of Intervention
3	HA2 - Values and Significance	HA2 - Values and Significance	HA3 - Regulations
4	HA4 - Heritage Building Typology	HA5 - Multidisciplinary Stakeholders	HA4 - Heritage Building Typology
5	HA5 - Multidisciplinary Stakeholders	HA4 - Heritage Building Typology	HA5 - Multidisciplinary Stakeholders

Figure 6.8 shows the radar of the heritage aspect (HA) sub-criteria for the three-development stage. The closer the point to the centre of 0, the higher it's ranking. Therefore, it can be concluded that, for both pre-retrofit (DS1) and implementation stage (DS3), the best heritage aspect consideration would be the principles of intervention, regulations and values & significance. The post-retrofit stage (DS4) shows that the highest in ranking is value and significance, followed by principles of intervention and regulations. The radar represents the options and recommendations in determining the best options for the heritage aspects in implementing the HBIM-retrofit framework in enhancing heritage building conservation projects in Malaysia.

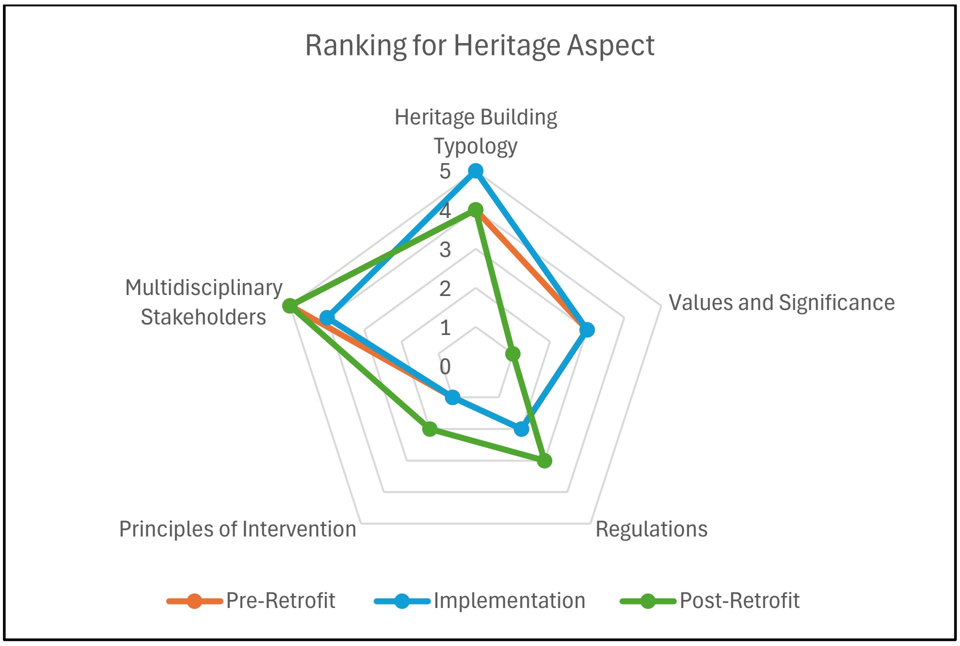

Figure 6.8 Ranking for Heritage Aspect in Three Development Stages

Table 6.27 and Figure 6.8 show that principles in interventions emerged as the highest-ranked in heritage aspect (HA) during the pre-retrofit stage (DS1), followed by regulations (HA3) and values and significance (HA2). This highlights the importance of establishing the HBIM-retrofit-based assessment and decision-making before any physical retrofit works are carried out. During this stage, retrofit planning requires careful evaluation of the building significance, existing fabric conditions, intervention limits, and suitability of proposed retrofit approaches to avoid unnecessary alterations to heritage elements. Webb (2017) emphasised that early retrofit decisions must adhere to conservation principles to ensure that subsequent interventions do not compromise heritage significance and authenticity. Similarly, McCaig et al. (2018), Heritage (2007), and Troi and Bastian (2015) stressed that pre-retrofit planning should prioritise minimal intervention, reversibility, and respect for the original building fabric before introducing performance upgrades. Therefore, the findings indicate that principles in interventions become the primary consideration during the pre-retrofit stage as they guide the overall retrofit strategy, scope of intervention, and conservation compatibility of subsequent retrofit works.

Principles in interventions (HA2) also remained the highest-ranked heritage aspect during the implementation stage (DS3), followed by regulations (HA3) and values and significance (HA2). This finding highlights the importance of maintaining conservation-sensitive practices throughout retrofit execution to minimise irreversible damage to heritage buildings. During this stage, physical interventions, material integration, and system upgrades require careful control of workmanship and material compatibility. National Park Service (2013) emphasised that retrofit works should remain minimal, reversible where feasible, and compatible with the historic character of the building. Similarly, Historic Scotland (2021) and McCaig et al. (2018) stressed that poor workmanship or inappropriate materials during implementation may compromise both building performance and heritage significance. Leijonhufvud et al. (2021) further highlighted the importance of continuous conservation supervision and monitoring during retrofit execution to ensure conservation compatibility and adaptive decision-making throughout the implementation process.

The values and significance (HA2) emerged as the highest-ranked heritage aspect during the post-retrofit stage (DS4), followed by principles in intervention (HA4) and regulations (HA3). This finding highlights the importance of ensuring that retrofit outcomes continue to preserve the cultural, historical, and aesthetic significance of heritage buildings after the completion of retrofit works. Şahin et al. (2015) defined heritage values as the tangible and intangible significance of historic buildings, including architectural, historical, and communal values. Similarly, Heritage (2007) emphasised that evidential, historical, aesthetic, and communal values should remain key considerations throughout conservation processes. Buda et al. (2021) further argued that post-retrofit evaluation should balance long-term building performance with the preservation of heritage significance. Therefore, the findings indicate that values and significance become the primary consideration during the post-retrofit stage to ensure that retrofit interventions continue to support both conservation objectives and the cultural identity of the heritage building.

Overall, the findings demonstrate that heritage aspect (HA) priorities evolve across the retrofit lifecycle according to the conservation requirements of each development stage. Principles in interventions (HA4) were prioritised during the pre-retrofit (DS1) and implementation stages (DS3) to support conservation-sensitive planning and execution, while values and significance (HA2) became more important during the post-retrofit stage (DS4) to ensure the continued preservation of heritage identity and significance after retrofit completion.

6.9.2 The Retrofit Design Criteria for HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.28 shows the ranking of retrofit design criteria (DC) for the three development stages, including the pre-design stage (DS1), implementation stage (DS3) and post-retrofit stage (DS4). In general, the results shown are based on the ranking sequence of each indicator in the retrofit design criteria (DC) for the three different development stages of historic building retrofit demonstrated a relevant reference for practitioner's in determining the best options, hence supports in organising and management of future conservation project.

Table 6.28
Ranking of the Retrofit Design Criteria in the Three Development Stages *(Author)*

Rank	Pre-Retrofit Stage (DS1)	Implementation Stage (DS3)	Post-Retrofit Stage (DS4)
1	DC3 - Building Structure	DC3 - Building Structure	DC4 - User Behaviour
2	DC5 - Collections	DC1 - Building Fabric	DC3 - Building Structure
3	DC1 - Building Fabric	DC2 - Building Systems and Equipment	DC1 - Building Fabric
4	DC6 - Economic Factor	DC6 - Economic Factor	DC6 - Economic Factor
5	DC2 - Building Systems and Equipment	DC5 - Collections	DC5 - Collections
6	DC4 - User Behaviour	DC4 - User Behaviour	DC2 - Building Systems and Equipment

Figure 6.9 shows the radar chart of retrofit design criteria (DC) priorities across the three-development stages. Within the pre-retrofit stage (DS1), the best retrofit design criteria consideration would be the building structure (DC3), collections (DC5) and building fabric (DC1). The implementation stage however highly prioritizes on building structure (DC3), building fabric (DC1) and building systems and equipment (DC2) whereas the post-retrofit stage (DS3) shows that the highest in ranking is user behaviour (DC4), followed by building structure (DC3) and building fabric (DC1). The radar chart represents the options and recommendations in determining the best options for the heritage aspects in implementing the HBIM-retrofit framework in enhancing heritage building conservation projects in Malaysia.

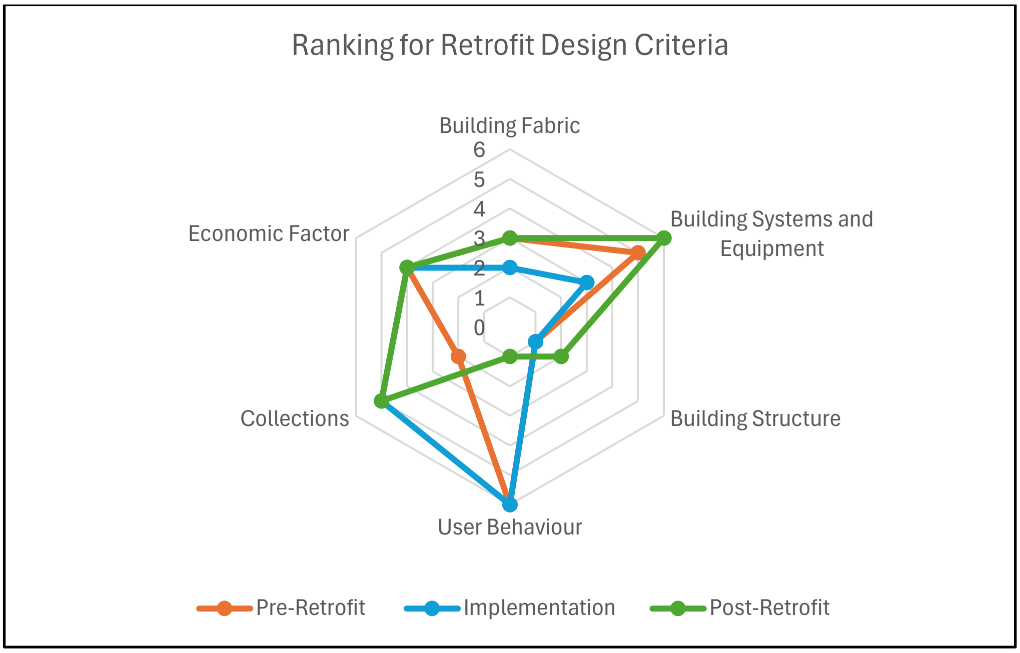

Figure 6.9 The Ranking of Retrofit Design Criteria in Three Development Stages

Table 6.28 and Figure 6.9 reveal that the retrofit design criteria (DC) priorities change significantly across the three development stages, indicating that retrofit decision-making requires different strategic focuses throughout the project lifecycle. In the pre-retrofit stage (DS1), building structure (DC3) ranked the highest, followed by collections (DC5) and building fabric (DC1), reflecting the concerns on vulnerability of heritage buildings to ageing, material deterioration, structural damage, and environmental hazards, requiring careful evaluation to preserve structural safety and integrity (Ercan, 2018; Vicente et al., 2017). Guh and Altoontash (2006) further stressed that structural retrofit is necessary to improve long-term structural stability and resilience in heritage buildings.

During the implementation stage (DS3), building structure (DC3) remained the highest-ranked criterion, followed by building fabric (DC1) and building systems and equipment (DC2). During this stage, retrofit interventions often involve physical modifications, strengthening works, and integration of new systems within existing heritage structures, which may introduce technical risks and uncertainties. Bansal (2018) explained that structural refurbishment plays a significant role in improving stability, safety, and building performance during retrofit implementation. Similarly, Webb (2017) emphasised that structural interventions in historic buildings must carefully balance performance improvement with conservation sensitivity to minimise damage to the original heritage fabric.

Interestingly, user behaviour (DC4) emerged as the highest-ranked criterion during the post-retrofit stage (DS4), followed by building structure (DC3) and building fabric (DC1). This highlights the importance of occupant practices, operational management, and maintenance behaviour in influencing the long-term performance of retrofitted heritage buildings. Historic England (2024) and Webb (2017) emphasised that building performance outcomes are strongly affected by how users operate and manage the building after retrofit interventions are completed. Similarly, McCaig et al. (2018) highlighted that occupancy patterns, comfort expectations, and user habits significantly influence energy consumption in historic buildings. Ben and Steemers (2014) further demonstrated that positive behavioural changes by occupants can contribute substantial energy savings beyond the impact of physical retrofit improvements alone.

Overall, the ranking patterns across the three retrofit development stages indicate that heritage retrofit priorities evolve throughout the project lifecycle. The findings demonstrate that structural stability is prioritised during the pre-retrofit (DS1) and implementation stages (DS3), while user behaviour (DS4) becomes more significant during the post-retrofit stage (DS4). This suggests that successful heritage retrofit projects require not only effective technical interventions, but also continuous operational management and stakeholder awareness to sustain long-term building performance and conservation objectives.

6.9.3 The Method of Approach for HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.29 shows the ranking of method of approach (MA) for the three development stages, including the pre-design stage (DS1), implementation stage (DS3) and post-retrofit stage (DS4). In general, the results shown based on the ranking sequence of each indicator in the method of approach (MA) for the three different development stages of historic building retrofit demonstrated a relevant reference for conservation practitioners to prioritize the suitable options in the management of future HBIM-enabled retrofit projects.

Table 6.29
Ranking of Method of Approach in the Three Development Stages *(Author)*

Rank	Pre-Retrofit Stage (DS1)	Implementation Stage (DS3)	Post-Retrofit Stage (DS4)
1	**MA6 -** Risk Assessment	**MA6 -** Risk Assessment	**MA5 -** Energy Performance Certificate Assessment
2	**MA4 -** Building Performance Simulation	**MA3 -** Laboratory Testing	**MA6 -** Risk Assessment
3	**MA3 -** Laboratory Testing	**MA4 -** Building Performance Simulation	**MA4 -** Building Performance Simulation
4	**MA5 -** Energy Performance Certificate Assessment	**MA5 -** Energy Performance Certificate Assessment	**MA3 -** Laboratory Testing
5	**MA2 -** In-Situ Measurement	**MA2 -** In-Situ Measurement	**MA2 -** In-Situ Measurement
6	**MA1 -** Environmental Microclimatic Analysis	**MA1 -** Environmental Microclimatic Analysis	**MA1 -** Environmental Microclimatic Analysis

Figure 6.10 shows the radar chart of method of approach (MA) priorities across the three-development stages. In the pre-retrofit stage (DS1), the highly prioritize items within the retrofit design criteria (DC) is the risk assessment (MA6), building performance simulation (MA4) and laboratory testing (MA3). For the implementation stage (DS3), higher priorities are allocated for risk assessment (MA6), laboratory testing (MA3) and building performance simulation (MA4) whereas the post-retrofit stage (DS4) shows that the highest in ranking is environmental performance certificate assessment (MA5), followed by risk assessment (MA6) and building performance simulation (MA4). The radar chart represents the options and recommendations in

determining the suitable options for method of approach in implementing the HBIM-retrofit framework for enhancing the performance of heritage buildings conservation projects in Malaysia.

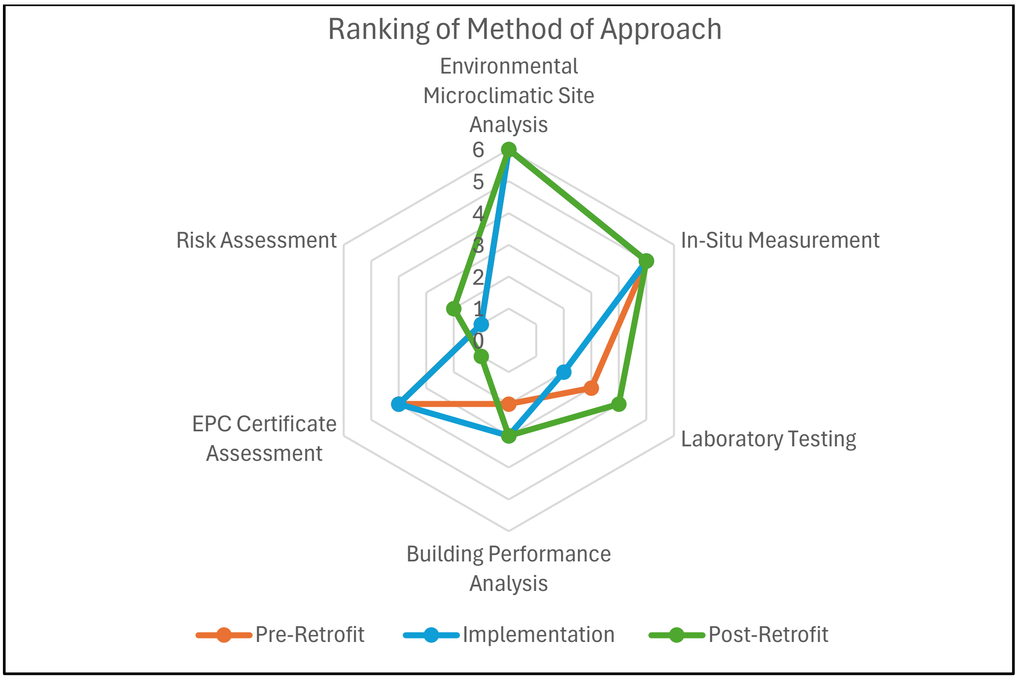

Figure 6.10 The Ranking of Method of Approach in Three Development Stages

Table 6.29 and Figure 6.10 show that risk assessment (MA6) emerged as the highest-ranked method of approach, followed by building performance simulation (MA4) and laboratory testing (MA3) during the pre-retrofit stage (DS1), highlighting the importance of conducting comprehensive evaluations before any retrofit intervention is undertaken. During the pre-retrofit stage (DS1), decision-making requires careful assessment of potential risks associated with building fabric, technical compatibility, heritage significance, environmental impact, and economic feasibility to minimise unintended consequences during retrofit implementation. McCaig et al. (2018) and May and Griffiths (2015) emphasised that risk assessment is essential in evaluating the suitability of energy efficiency interventions while balancing conservation requirements and technical performance. Similarly, Polo López et al. (2021) highlighted the importance of assessing technical compatibility and heritage sensitivity during retrofit decision-making. Angrisano et al. (2021) further stressed that early risk evaluation supports sustainable retrofit planning through lifecycle and environmental considerations.

Risk assessment (MA6) remained the highest-ranked method of approach during the implementation stage followed by laboratory testing (MA3) and building performance simulation (MA4), highlighting the importance of evaluating technical and conservation risks during the execution of retrofit works. During this stage, retrofit activities involve direct physical interventions, material installation, and integration of new systems within existing heritage structures, requiring continuous assessment to minimise damage to the original fabric. National Park Service (2013) emphasised that implementation works should remain minimal, reversible where feasible, and compatible with the historic character of the building. Similarly, Historic Scotland (2021) and McCaig et al. (2018) stressed that poor workmanship and incompatible materials during execution may compromise both heritage significance and retrofit performance. May and Griffiths (2015) further highlighted that improper installation during implementation may lead to moisture entrapment, thermal bridging, and accelerated material deterioration.

Energy Performance Certificate (EPC) assessment (MA5) emerged as the highest-ranked method of approach during the post-retrofit stage (DS4) followed by risk assessment (MA6) and building performance simulation (MA4), highlighting the importance of evaluating retrofit outcomes after project completion. Post-retrofit assessment focuses on verifying whether retrofit interventions achieve the intended energy, environmental, and conservation objectives during building operation. Historic Scotland (2021) and McCaig et al. (2018) emphasised that post-retrofit evaluation should assess thermal comfort, moisture performance, and user satisfaction against both energy and conservation benchmarks. Gigliarelli et al. (2022) emphasizes a long-term review of retrofit measures is needed to ensure continued compatibility with heritage values. Berg and Donarelli (2019) further highlighted that EPC assessments support sustainability evaluation and informed operational decision-making in historic retrofit projects, while GBI (2019) provides sustainability benchmarks for existing buildings in the Malaysian context.

Overall, the ranking patterns across the three retrofit development stages indicate that method of approach (MA) priorities evolved throughout the project lifecycle. The findings demonstrate that risk assessment (MA6) is prioritised during the pre-retrofit (DS1) and implementation stages (DS3), while user EPC assessment (MA5) becomes more significant during the post-retrofit stage (DS4). This suggests that the pre-retrofit and implementation stages place greater emphasis on identifying and managing technical, material, and conservation risks prior to and during physical retrofit interventions, whereas the post-retrofit stage prioritises verification of actual energy performance, environmental efficiency, and operational compatibility of the retrofitted heritage building after project completion.

6.9.4 The HBIM Organizational for HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.30 shows the ranking of organizational (O) for the three development stages, including the pre-design stage (DS1), implementation stage (DS3) and post-retrofit stage (DS4). In general, the results shown based on the ranking sequence of each indicator in the organizational (O) for the three different development stages of historic building retrofit demonstrated a relevant reference for practitioners to prioritize the best options in the management of future HBIM-enabled retrofitting project.

Table 6.30
Ranking of HBIM Organizational in the Three Development Stages *(Author)*

Rank	Pre-Retrofit Stage (DS1)	Implementation Stage (DS3)	Post-Retrofit Stage (DS4)
1	O2 - Training and Education	O1 - Roles and Responsibilities	O1 - Roles and Responsibilities
2	O1 - Roles and Responsibilities	O2 - Training and Education	O3 - BIM Protocol
3	O3 - BIM Protocol	O3 - BIM Protocol	O2 - Training and Education

Figure 6.11 shows the radar chart of HBIM organizational (O) priorities across the three-development stages. In the pre-retrofit stage (DS1), the highly prioritize items is training and education (O2), roles and responsibilities (O1) and BIM protocol (O3). For the implementation stage (DS3), higher priorities are allocated for roles and responsibilities (O1), training and education (O2) and BIM protocol (O3) whereas the post-retrofit stage (DS4) shows that the highest in ranking is roles and responsibilities (O1), followed by BIM protocol (O3) and training and education (O2). The radar chart represents the options and recommendations in determining the best options for organizational in implementing HBIM-retrofit framework to enhance the performance of heritage buildings conservation projects in Malaysia.

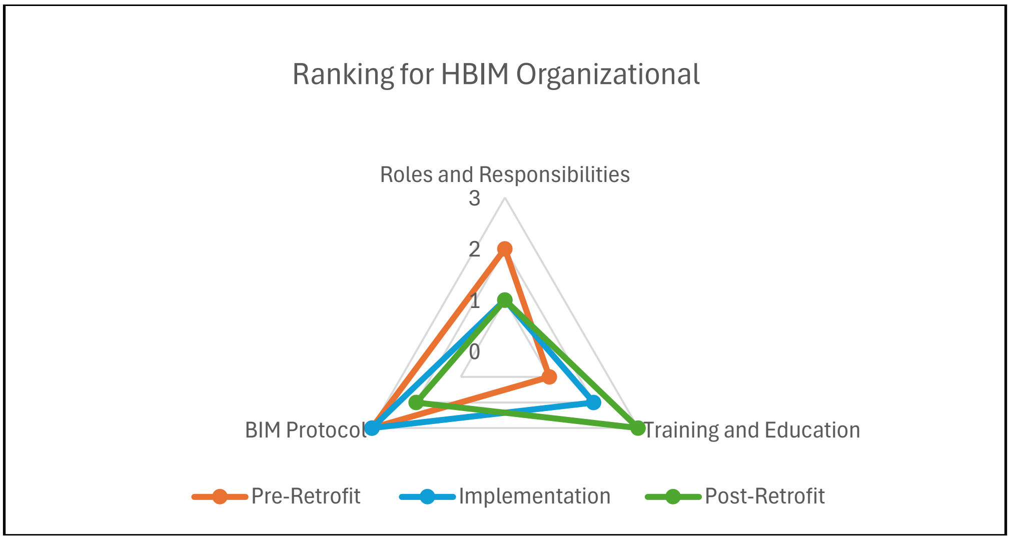

Figure 6.11 The Ranking of HBIM Organizational in Three Development Stages

Table 6.30 and Figure 6.11 show that training and education (O2) emerged as the highest-ranked HBIM organizational during the pre-retrofit stage (DS1) followed with roles and responsibilities (O1) and BIM protocol (O3). This highlights the importance of developing stakeholder competency prior to retrofit planning and assessment activities. During this stage, project teams are required to conduct whole-building assessments, significance evaluations, and risk analysis to determine appropriate retrofit strategies. Lee et al. (2020) and Edwards (2021) emphasised that early-stage retrofit planning requires comprehensive assessment and informed decision-making, while McCaig et al. (2018) and Historic Scotland (2021) stressed the importance of technical investigations during the pre-retrofit stage. The findings also reflect the need for specialised HBIM competency in managing the complexity of historic buildings. Ali et al. (2018a) identified lack of training and expertise as a major barrier to HBIM-retrofit implementation in Malaysia, while Khalil (2017) highlighted the technical complexity of historic buildings compared to conventional buildings. Therefore, the findings indicate that training and education are prioritised during the pre-retrofit stage to improve stakeholder readiness and support effective retrofit planning and assessment.

Roles and responsibilities (O1) emerged as the highest-ranked HBIM organizational (O) indicator during the implementation stage (DS3), followed with training and education (O2) and BIM protocol (O3), highlighting the importance of clear stakeholder coordination during retrofit execution. During this stage, retrofit works involve multidisciplinary collaboration, physical interventions, and integration of technical systems, requiring clear allocation of responsibilities to ensure conservation-compatible execution. National Park Service (2013), Historic Scotland (2021), and McCaig et al. (2018) emphasised that implementation activities require careful control of workmanship, material compatibility, and intervention methods to minimise irreversible damage to heritage buildings. The findings also reflect the importance of defined organizational roles within HBIM-retrofit implementation. Gigliarelli et al. (2022) highlighted that clear role definition improves accountability and coordination among project stakeholders, while Succar (2009) and Messner et al. (2019) emphasised that well-defined responsibilities support structured collaboration and decision-making during BIM implementation.

Roles and responsibilities (O1) remained the highest-ranked HBIM organizational (O) indicator during the post-retrofit stage (DS4), highlighting the importance of clear stakeholder coordination in post-retrofit monitoring, operation, and maintenance activities. During this stage, retrofit projects require continuous performance evaluation and operational management to ensure long-term compatibility with heritage values and building performance. McCaig et al. (2018) and Historic Scotland (2021) emphasised the importance of post-retrofit monitoring and long-term review of retrofit measures. The findings also reflect the importance of clearly defined organizational responsibilities in managing HBIM-based post-retrofit processes. Gigliarelli et al. (2022) highlighted that clear role definition improves accountability and coordination, while Succar (2009) and Messner et al. (2019) emphasised that well-defined responsibilities support effective collaboration and operational decision-making.

Overall, the findings indicate that HBIM organizational (O) priorities evolve across the retrofit development stages, where training and education (O2) are prioritised during the pre-retrofit stage to strengthen stakeholder readiness, while roles and responsibilities (O1) become more critical during the implementation (DS3) and post-retrofit stages (DS4) to support coordinated execution, monitoring, and long-term conservation management.

6.9.5 The HBIM Informational for HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.31 presents the ranking of HBIM informational (I) indicators across the pre-design stage (DS1), implementation stage (DS3), and post-retrofit stages (DS4). Overall, the ranking patterns highlight how each stage prioritises different aspects of the HBIM informational (I). These results provide a useful reference for practitioners, helping them identify and select the most suitable options when planning and managing HBIM-retrofitting projects.

Table 6.31
Ranking of HBIM Informational in the Three Development Stages *(Author)*

Rank	Pre-Retrofit Stage (DS1)	Implementation Stage (DS3)	Post-Retrofit Stage (DS4)
1	I6 - Structural	I6 - Structural	I6 - Structural
2	I2 - Historical Evidential	I2 - Historical Evidential	I5 - Energy Performance
3	I4 - Surveying	I3 - Pathology	I3 - Pathology
4	I3 - Pathology	I4 - Surveying	I2 - Historical Evidential
5	I5 - Energy Performance	I1 - Geometrical	I4 - Surveying
6	I1 - Geometrical	I5 - Energy Performance	I1 - Geometrical

Figure 6.12 shows the radar chart of HBIM informational (I) priorities across the three-development stages. In the pre-retrofit stage (DS1), the highly prioritize items is structural data (I6), historical evidential (I2) and surveying (I4). For the implementation stage (DS3), higher priorities are allocated for structural (I6), historical evidential (I2) and pathology (I3) whereas the post-retrofit stage (DS4) shows that the highest in ranking is structural (I6), followed by energy performance (I5) and pathology (I3). The radar chart represents the options and recommendations in determining the best options for HBIM informational (I) in implementing the HBIM-retrofit framework to enhance the performance of heritage building conservation projects in Malaysia.

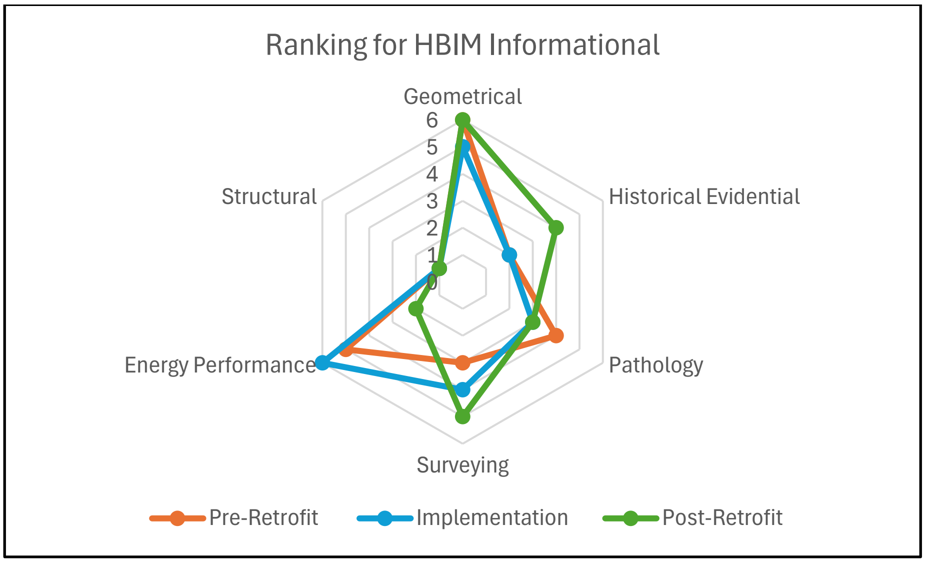

Figure 6.12 The Ranking of HBIM Informational in Three Development Stages

Table 6.31 and Figure 6.12 show that structural (I6) data emerged as the highest-ranked HBIM informational (I) indicator during the pre-retrofit stage, followed by historical evidential (I2) and surveying (I4). This highlights the importance of detailed structural information during early retrofit planning and assessment. During this stage, project teams are required to conduct whole-building investigations, significance assessments, and risk evaluations to determine appropriate retrofit strategies. Lee et al. (2020) and Edwards (2021) emphasised that the pre-retrofit stage involves detailed surveys and whole-building analysis, while Historic Scotland (2021) stressed the importance of technical investigations during early retrofit assessment. The findings also reflect the role of HBIM structural data in supporting evidence-based planning. Volk et al. (2014) highlighted that BIM structural data provides information on load-bearing capacity, material degradation, and structural weaknesses. Similarly, Mol et al. (2020) demonstrated that HBIM structural lifecycle data supports condition monitoring and intervention planning, while Valero et al. (2019) integrated structural and surveying data to identify deterioration patterns in historic masonry structures.

Structural data (I6) remained the highest-ranked HBIM informational (I) indicator during the implementation stage (DS3) followed with historical evidential (I2) and pathology (I3). This highlights the importance of accurate structural information during retrofit execution. During this stage, retrofit works involve direct physical interventions and integration of new systems, requiring continuous monitoring of structural conditions to minimise damage to the original fabric. Gigliarelli et al. (2022) highlighted that HBIM enables integration of diagnostic and structural data to support coordinated retrofit execution and technical decision-making during intervention works. Similarly, Bouzas et al. (2022) demonstrated that HBIM structural models can support structural health monitoring and assessment of physical behaviour during retrofit implementation. Mol et al. (2020) further explained that HBIM structural lifecycle data assists in monitoring deterioration and supporting maintenance and intervention decisions in historic structures.

Furthermore, structural data (I6) also remained the highest-ranked HBIM informational (I) indicator during the post-retrofit stage (DS4), followed by energy performance (I5) and pathology data (I3), highlighting the importance of continuous HBIM-based structural monitoring after retrofit completion. During this stage, retrofit projects require long-term evaluation of structural performance and maintenance conditions to ensure continued compatibility with heritage values and operational performance. Leijonhufvud et al. (2021) demonstrated that iterative monitoring supports adaptive management of heritage retrofit interventions, while Pocobelli et al. (2018) highlighted that reliable building information is essential for post-retrofit optimisation and maintenance activities. Murphy et al. (2013) further explained that HBIM structural data supports continuous documentation and management of historic building conditions throughout the building lifecycle.

Therefore, the findings indicate that structural data remains critical throughout the retrofit lifecycle to support retrofit planning, execution, and long-term conservation management of heritage buildings.

6.9.6 The HBIM Process Lifecycle for HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.32 presents the ranking of HBIM process lifecycle (PL) indicators across the pre-design (DS1), implementation (DS3), and post-retrofit stages (DS4). Overall, the ranking patterns highlight how each stage prioritises different aspects of the HBIM process lifecycle (PL). These results provide a useful reference for practitioners, helping them identify and select the most suitable options when planning and managing HBIM-enabled retrofitting projects.

Table 6.32
Ranking of HBIM Process Lifecycle in the Three Development Stages *(Author)*

Rank	**Pre-Retrofit Stage (DS1)**	**Implementation Stage (DS3)**	**Post-Retrofit Stage (DS4)**
1	PL3 - Simulation and Analysis	PL1 - Data Acquisition	PL1 - Data Acquisition
2	PL4 - Design Visualization	PL3 - Simulation and Analysis	PL3 - Simulation and Analysis
3	PL1 - Data Acquisition	PL4 - Design Visualization	PL4 - Design Visualization

Figure 6.13 presents the radar chart of HBIM process lifecycle priorities across the three development stages. In the pre-retrofit stage, the top priorities are simulation and analysis, design visualization, and data acquisition. During implementation, data acquisition, simulation and analysis, and design visualization remain most important. In the post-retrofit stage, data acquisition ranks highest, followed by simulation and analysis and design visualization. The chart guides the selection of optimal HBIM lifecycle options for implementing the HBIM-retrofit framework in Malaysian heritage buildings.

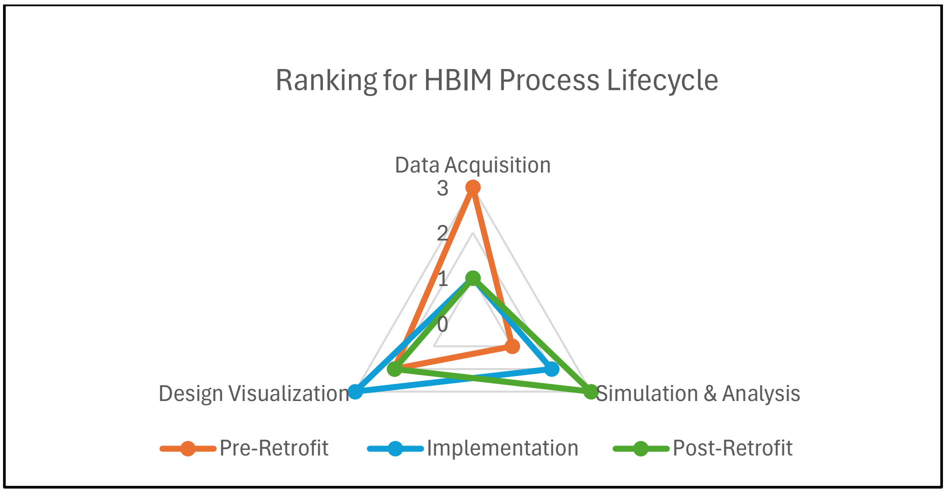

Figure 6.13 The Ranking of HBIM Process Lifecycle in Three Development Stages

Table 6.32 and Figure 6.13 show that simulation and analysis (PL3) emerged as the highest-ranked HBIM process lifecycle (PL) indicator during the pre-retrofit stage (DS1) followed by design visualization (PL2) and data acquisition (PL1), this highlights the importance of analytical assessment during early retrofit planning and decision-making. During this stage, retrofit projects require whole-building investigations, risk assessment, and technical diagnostics to determine appropriate retrofit strategies. Lee et al. (2020) and Edwards (2021) emphasized the need for comprehensive building analysis during pre-retrofit planning, while McCaig et al. (2018) stressed the importance of technical investigations during early retrofit assessment. The findings also reflect the role of HBIM simulation and analysis in supporting evidence-based retrofit planning. Carvalho et al. (2019) highlighted that building energy simulation (BES) and building performance simulation (BPS) are significant components of HBIM analysis in historic retrofit projects. Similarly, Gigliarelli et al. (2017), Karlapudi (2018), and Ouellette et al. (2022) emphasised that HBIM simulation tools enable accurate and real-time analysis of historic building performance. Ansah et al. (2019) further explained that BIM-based simulation supports energy and operational performance analysis during retrofit planning.

Data acquisition (PL1) emerged as the highest-ranked HBIM process lifecycle (PL) indicator during the implementation stage (DS3), followed by simulation and analysis, and design visualization, highlighting the importance of accurate building data during retrofit execution. During this stage, retrofit works require continuous validation of existing building conditions to ensure conservation-compatible interventions. Troi and Bastian (2015) and McCaig et al. (2018) emphasised the importance of monitoring and conservation supervision during implementation activities. The findings also reflect the importance of integrated HBIM data acquisition workflows, where Puerto et al. (2024) highlighted that technologies such as laser scanning, photogrammetry, and point-cloud processing improve the accuracy and reliability of heritage documentation and retrofit management, while Wang et al. (2025) demonstrated that semantic point-cloud integration enhances evidence-based HBIM workflows for heritage conservation.

Data acquisition (PL1) remained the highest-ranked HBIM process lifecycle (PL) indicator during the post-retrofit stage (DS4), followed by simulation and analysis (PL3), and design visualization (PL4), highlighting the importance of continuous building data collection and monitoring after retrofit completion. During this stage, retrofit projects require ongoing evaluation and maintenance monitoring to ensure long-term compatibility with heritage values and building performance. Historic Scotland (2021), and Leijonhufvud et al. (2021) emphasised the importance of post-retrofit monitoring and feedback processes in supporting adaptive conservation management. The findings also reflect the importance of integrated HBIM data acquisition workflows in long-term heritage management. Brumana et al. (2020) highlighted that integrated digital surveying techniques improve the accuracy of heritage documentation, while

Pocobelli et al. (2018) emphasised that reliable building information is essential for post-retrofit monitoring and maintenance management. Similarly, Gigliarelli et al. (2022) demonstrated that HBIM integration with sensors and monitoring systems supports continuous evaluation and evidence-based conservation management in heritage retrofit projects.

Overall, the findings indicate that HBIM process lifecycle priorities evolve across the retrofit development stages, where simulation and analysis are prioritised during the pre-retrofit stage to support early assessment and decision-making, while data acquisition becomes more critical during the implementation and post-retrofit stages to support accurate documentation, monitoring, and long-term conservation management of heritage buildings.

6.9.7 The HBIM Technical for HBIM-Retrofit Framework for Heritage Building Conservation Projects in Malaysia

Table 6.33 presents the ranking of HBIM technical (T) indicators across the pre-design (DS1), implementation (DS3), and post-retrofit stages (DS4). Overall, the ranking patterns highlight how each stage prioritises different aspects of the HBIM technical (T). These results provide a useful reference for practitioners, helping them identify and select the most suitable options when planning and managing HBIM-retrofitting projects.

Table 6.33
Ranking of HBIM Technical in the Three Development Stages *(Author)*

Rank	**Pre-Retrofit Stage (DS1)**	**Implementation Stage (DS3)**	**Post-Retrofit Stage (DS4)**
1	T2 - Hardware Infrastructure	T4 - Data Exchange	T3 - Standards
2	T3 - Standards	T2 - Hardware Infrastructure	T4 - Data Exchange
3	T1 - Software	T3 - Standards	T2 - Hardware Infrastructure
4	T4 - Data Exchange	T1 - Software	T1 - Software

Figure 6.14 presents the radar chart of HBIM technical (T) priorities across the three development stages (DS). In the pre-retrofit stage (DS1), the top priorities are hardware infrastructure (T2), standards (T3), software (T1) and data exchange (T4). During implementation (DS3), the highest priority is the data exchange (T4), followed

by hardware infrastructure (T2), standards (T3) and software (T1). In the post-retrofit stage (DS4), standards (T3) rank the highest, followed by data exchange (T4), hardware infrastructure (T2) and software (T1). The chart guides the selection of optimal HBIM technical (T) options for implementing HBIM-retrofit framework.

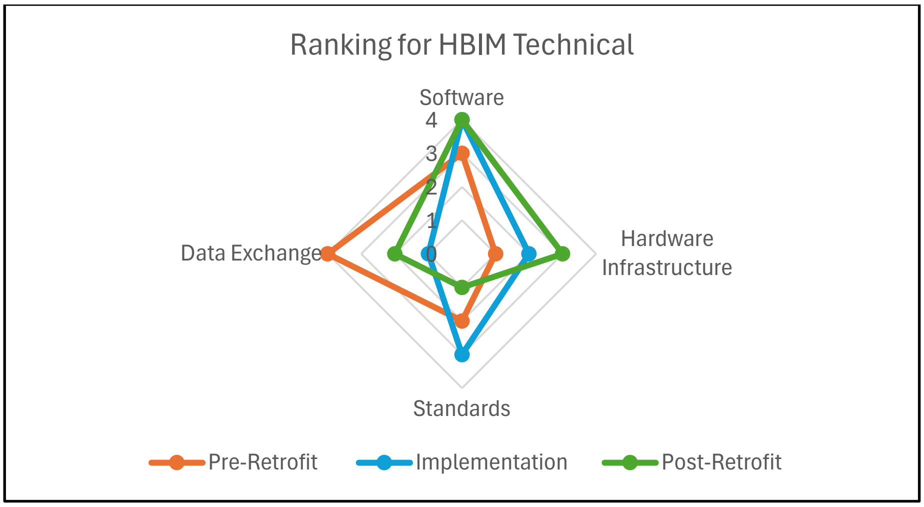

Figure 6.14 The Ranking of HBIM Technical in Three Development Stages

Table 6.33 and Figure 6.14 show that hardware infrastructure emerged as the highest-ranked HBIM technical (T) indicator during the pre-retrofit stage (DS1) followed by standards (T3) and software (T1), highlighting the importance of adequate survey and computational infrastructure during early retrofit planning and assessment. During this stage, retrofit projects require comprehensive building investigations, technical diagnostics, and performance evaluations to support evidence-based decision-making. Lee et al. (2020) and Edwards (2021) emphasised that pre-retrofit activities involve extensive assessment and documentation processes to identify technical risks and conservation constraints prior to intervention. The findings also reflect the importance of hardware infrastructure in supporting HBIM-retrofit implementation. Bruno and Roncella (2019) and Alshawabkeh et al. (2021) highlighted that 3D laser scanning and photogrammetry technologies significantly improve the accuracy of heritage documentation and HBIM development. Similarly, Brumana et al. (2019) emphasised that robust computational infrastructure is essential for efficient point-cloud processing, HBIM modelling, and retrofit analysis.

Data exchange (T4) emerged as the highest-ranked HBIM technical indicator during the implementation stage (DS3) followed by hardware infrastructure (T2) and standards (T3), highlighting the importance of interoperability and coordinated information sharing during retrofit execution. During this stage, retrofit projects require continuous coordination to ensure conservation-compatible interventions and minimise technical errors. National Park Service (2013) and Leijonhufvud et al. (2021) emphasised the importance of monitoring and multidisciplinary coordination throughout retrofit implementation. The findings also reflect the significance of interoperable HBIM workflows in supporting reliable information exchange. Parente et al. (2020) highlighted that HBIM supports structured exchange of conservation information across the project lifecycle, while Logothetis et al. (2015) and Brumana et al. (2019) demonstrated that IFC-based workflows improve data transfer and reduce information loss during retrofit implementation. Baharuddin et al. (2024) further identified weak interoperability as a continuing challenge in heritage conservation projects.

Standards (T3) emerged as the highest-ranked HBIM technical (T) indicator during the post-retrofit stage (DS4) followed by data exchange (T4) and hardware infrastructure (T2), highlighting the importance of standardized information management and conservation compliance in supporting long-term heritage management. During this stage, retrofit projects require continuous monitoring and operational evaluation to ensure long-term compatibility with heritage values and building performance. Leijonhufvud et al. (2021) emphasised the importance of systematic post-retrofit monitoring and evaluation in adaptive conservation management. The findings also reflect the significance of HBIM standards in ensuring consistent post-retrofit information management. Pocobelli et al. (2018) highlighted that HBIM-retrofit requires specialized standards to manage complex heritage information, while Lie et al. (2023) emphasised the importance of LOD and LOIN standards in supporting retrofit assessment and operational management. Similarly, Bruno and Roncella (2019) demonstrated that standardized HBIM libraries and heritage documentation standards improve interoperability and long-term conservation management.

Overall, the findings indicate that HBIM technical (T) priorities evolve across the retrofit development stages, where hardware infrastructure are prioritised during the pre-retrofit stage to support early assessment and decision-making, while data exchange becomes more critical during the implementation and HBIM standards is critical in the post-retrofit stages to support documentation, monitoring, and long-term conservation management of heritage buildings.

6.10 Summary of Chapter

This chapter presented the findings for all three research objectives by integrating empirical analyses with expert insights to develop a practical and procedural aspects of HBIM-retrofit framework to enhance and guide the Malaysian heritage building conservation projects. The results were interpreted in relation to the literature, demonstrating alignment, consistency, and support for the overall objectives of the study. Through the combination of quantitative modelling and AHP-based expert prioritization, the chapter establishes a structured understanding of how retrofit characteristics and HBIM functionalities operate across different project development stages. Collectively, the findings confirm the framework's relevance, clarify its core components, and reinforce its value as a systematic decision-support tool for enhancing the planning and implementation of HBIM-enabled retrofit projects. The next chapter presents the study's conclusion, research contributions, and recommendations for future research.

CHAPTER 7
CONCLUSION AND RECOMENDATIONS

7.1 Introduction

This concluding chapter consolidates the key insights gained throughout the research process. It begins with a recapitulation of the research, followed by recommendations that address its contributions to the body of knowledge, methodological implications, and practical applications. A detailed explanation of the research conclusions is also presented. Subsequently, the limitations of the study are outlined, highlighting opportunities for future research. The chapter ends with a final concluding statement that encapsulates the overall thesis.

7.2 Achievement of Research Objectives

As explained in Chapter One, the aim of this study was to develop an HBIM-retrofit framework in enhancing the performance of heritage building conservation projects in Malaysia. The study addressed several critical issues within the Malaysian heritage-built environment sector, including the increasing deterioration risks of heritage buildings, sustainability pressures on historic assets, limitations in current retrofit-conservation practices, and the low adoption of HBIM in heritage retrofit implementation. Consequently, the research focused on addressing the lack of clear HBIM-retrofit concepts and characteristics, limited understanding of the relationship between HBIM-retrofit and project performance, and the absence of a structured HBIM-retrofit framework in Malaysia.

Objective One was successfully achieved through the identification and validation of the underlying concepts and characteristics of HBIM-retrofit influencing the performance of heritage building conservation projects in Malaysia. The findings established that heritage retrofit performance is influenced by interconnected heritage aspect, development stages, design criteria, method of approach, organizational, informational, lifecycle and technical factors, demonstrating the multidimensional nature of HBIM-retrofit. As a result, the study established a conceptual framework with two higher-order constructs, namely Historic Building Retrofit Characteristics (HRC) and HBIM-Retrofit Functionality (HRF), supported by eight significant variables representing the key domains of heritage retrofit and HBIM implementation.

Objective Two was achieved through the PLS-SEM analysis, which established statistically significant relationships between the HRC and HRF domains towards the performance of heritage building conservation projects in Malaysia. Out of forty-six (46) indicators initially developed, forty-three (43) indicators were validated and established as significant factors influencing the proposed HBIM-retrofit framework. The findings demonstrated that effective heritage retrofit implementation is not solely dependent on digital technology adoption, but on the alignment between retrofit requirements and HBIM functional capabilities. This finding further supports the applicability of the Task-Technology Fit (TTF) theory within the heritage retrofit context (Goodhue & Thompson, 1995).

Objective Three was achieved through the formulation of the final HBIM-retrofit framework using the validated variables and indicators established from the PLS-SEM analysis. Through the Analytical Hierarchy Process (AHP), the variables and indicators were constructed into a hierarchical model and further prioritized across the pre-retrofit, implementation, and post-retrofit stages. The findings demonstrated that the priorities of the indicators evolved according to the specific conservation, technical, organizational, informational, and operational requirements within each development stage. This indicates that HBIM-retrofit implementation should be interpreted as a dynamic and lifecycle-oriented process rather than a static technological approach. Consequently, the proposed framework establishes a structured and adaptive approach that supports systematic decision-making, multidisciplinary coordination, and improved conservation project performance throughout the retrofit lifecycle.

Overall, the three research objectives were successfully achieved through the exploratory identification, validation, and formulation of a structured HBIM-retrofit framework for enhancing the performance of heritage building conservation projects in Malaysia. The findings demonstrated that effective HBIM-retrofit implementation requires the integration of conservation requirements, organizational coordination, informational management, lifecycle processes, and HBIM technological capabilities.

7.3 Research Contributions

The framework developed in this study incorporates both direct and indirect influences to establish the relationship between the HBIM-retrofit framework and the performance of heritage conservation projects in Malaysia. The findings contribute valuable insights to the existing body of knowledge and offer methodological as well as practical implications. In addition, the study provides important recommendations for implementing agencies, policymakers, academicians, and conservation practitioners, highlighting the strategic key measures and decision-making factors necessary for the successful adoption of HBIM-retrofit in Malaysian heritage conservation projects.

7.3.1 Research Contribution to Knowledge

This research contributes to knowledge by addressing the major gaps identified in Chapter One and Chapter Two, namely the lack of clear HBIM-retrofit concepts and characteristics, the limited empirical understanding of the relationship between HBIM-retrofit and project performance, and the absence of a structured HBIM-retrofit framework for heritage building conservation projects in Malaysia.

Firstly, the study establishes a more comprehensive understanding of HBIM-retrofit by integrating Historic Building Retrofit Characteristics (HRC) and HBIM-Retrofit Functionality (HRF) into a unified framework. The study validated eight domains comprising heritage aspects, development stages, retrofit design criteria, method of approach, organizational, informational, process lifecycle, and technical dimensions. This contribution addresses the fragmented understanding of HBIM-retrofit implementation within heritage conservation projects.

Secondly, the study contributes empirical knowledge by testing and validating the relationship between HBIM-retrofit characteristics and project performance using PLS-SEM analysis. The findings confirmed significant relationships between the HBIM-retrofit constructs and project performance dimensions including time, cost, quality, design, environmental, relationship, and communication performance. A total of forty-three indicators were established, strengthening the empirical foundation of HBIM-retrofit research in the heritage conservation field.

Thirdly, the study extends the application of Task–Technology Fit (TTF) theory into the heritage conservation and retrofit context. The findings demonstrate that project performance improvement depends on the alignment between HBIM technological capabilities and heritage retrofit task requirements. This advances the understanding of HBIM-retrofit as a performance-driven and task-oriented system rather than solely a digital documentation tool.

Finally, the study contributes operational knowledge through the development of a structured and validated HBIM-retrofit framework. By incorporating AHP analysis, the framework provides prioritized and lifecycle-oriented decision-making support across pre-retrofit, implementation, and post-retrofit stages. This contribution addresses the lack of a practical and structured framework for heritage retrofit implementation in Malaysia.

7.3.2 Research Contribution to Methodology

This study contributes methodologically by providing a systematic and empirically validated approach for investigating HBIM-retrofit implementation in heritage conservation projects. The methodological structure enabled fragmented HBIM-retrofit knowledge to be operationalized and validated into a structured framework.

The study applied Partial Least Squares Structural Equation Modelling (PLS-SEM) to examine the relationships between historic building retrofit characteristics (HRC), HBIM-retrofit functionalities (HRF), and project performance constructs. The approach strengthened the empirical reliability and validity of the framework through the validation of multidimensional constructs and indicators.

In addition, the integration of the Analytical Hierarchy Process (AHP) contributed a structured multi-criteria decision-making approach for prioritizing retrofit indicators and implementation stages. This enabled the framework to be translated into a more practical and operational decision-support structure for heritage conservation projects in future.

Furthermore, the combined use of literature synthesis, content analysis, PLS-SEM, and AHP provides a replicable methodological reference for future studies related to HBIM implementation, heritage retrofit, and conservation digitalization.

7.3.3 Research Contribution to Industry

This study contributes to the heritage conservation industry by providing a structured HBIM-retrofit framework capable of addressing issues related to fragmented practices, limited HBIM adoption, poor coordination, and inconsistent retrofit decision-making in Malaysian heritage conservation projects.

The framework supports practitioners, consultants, policymakers and implementing agencies by integrating retrofit requirements, HBIM functionalities, organizational coordination, technical considerations, and lifecycle processes into a unified decision-support structure. This improves the management and implementation of heritage retrofit projects throughout the conservation lifecycle.

Additionally, the incorporation of AHP enables prioritized retrofit indicators and structured ranking mechanisms across pre-retrofit, implementation, and post-retrofit stages. This supports more systematic and evidence-based decision-making, while improving coordination, communication, and project delivery performance within conservation projects.

The study also supports Malaysia's heritage digitalization agenda by providing a practical reference for future HBIM adoption, guideline development, and digital workflow implementation within the heritage conservation sector.

7.4 Research Limitations

With reference to the topic of the research, the findings of the current study must be interpreted by taking some of the research limitations into consideration, although the present study has included support for the hypothesized relationships between the exogenous and endogenous variables. The research limitations are stated below:

i. The use of TTF confines the study to performance-related outcomes rather than utilisation behaviours. This was intentional, as HBIM adoption in Malaysia remains low, rendering utilisation measures less meaningful. However, this theoretical boundary limits deeper examination of behavioural and organisational factors influencing HBIM uptake.
ii. The absence of real project-based validation limits the ability to assess the framework's practical applicability in real-world conservation settings. This limitation is further compounded by the limited HBIM experience among

practitioners, which reduces opportunities to incorporate operational insights into the framework.

iii. Although the AHP successfully generates indicator priorities to the framework, the rankings are not yet aligned with existing national or local authority conservation policy, guidelines or workflows. Without such integration, the direct applicability of the framework within Malaysia's regulatory practices remains incomplete.

iv. The study's sample is dominated by conservators, with insufficient representation from contractors and builders. This constrains understanding of HBIM-retrofit from the execution and construction-management perspective, where many practical constraints arise.

v. The study's scope focuses primarily on HBIM within the retrofitting project execution phase and does not extend to long term asset management, maintenance and digital twin integration. As a result, the full lifecycle potential of HBIM in heritage conservation remains outside the research boundaries.

7.5 Recommendations for Future Research

Building on the limitations identified in this study, several avenues for future research are proposed. To extend the current knowledge. There are various questions directly connected to the nature of this study which continue unanswered as explained below.

i. Future studies may incorporate utilization-focused theories to capture behavioral, organizational, and cultural factors influencing HBIM-retrofit adoption. This will become increasingly meaningful as HBIM usage grows within the Malaysian heritage conservation sector.

ii. The real-world pilot projects are needed to validate the HBIM-retrofit framework in practical conservation settings. Such project-based studies would allow researchers to examine practical applications, workflows, on-site constraints, and actual performance improvements, thereby strengthening the empirical robustness of the framework.

iii. Future researchers may integrate the AHP-derived indicator rankings with existing national or local authority conservation procedures and guidelines. This alignment would enhance practical and technical applicability and support the development of operational standards for HBIM-retrofit implementation.

iv. Expanding the respondent base to include contractors, builders, and technical specialists, such as the B3 contractors would enrich understanding of HBIM-retrofit from the construction execution perspective. Mixed-method studies combining surveys, interviews, and site observations could provide deeper insights into operational barriers.

v. Future research should extend the HBIM-retrofit focus beyond project execution to encompass long-term asset management, maintenance, monitoring, Artificial Intelligence (AI), machine learning and digital twin technologies. This would support the development of a lifecycle-oriented HBIM framework capable of sustaining heritage assets more holistically over time.

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APPENDICES

APPENDIX 1

Questionnaire Survey

UNIVERSITI TEKNOLOGI MARA

Invitation Letter

To : Dato/Datin/Mr/Mrs
Subject : Invitation for research participation

I am conducting academic research entitled: ***"Historic Building Information Modelling (HBIM)-Enabled Retrofit Framework in Enhancing the Performance of Heritage Building Conservation Projects Malaysia"***. The purpose of my research is to develop an appropriate HBIM-retrofit framework in improving the performance of heritage building conservation practitioners in Malaysia. This questionnaire survey consists of five (5) sections (Sections A - E) as follows.

Section A:	General Information and Demographics
Section B:	Historic Building Retrofit Characteristics
B1:	Heritage Aspect
B2:	Development Stages
B3:	Retrofit Design Criteria
B5:	Method of Approach
Section C:	HBIM-Retrofit Model Characteristics
C1:	Organizational
C2:	Informational
C3:	Process Lifecycle
C4:	Technical
Section D:	HBIM-Enabled Retrofitting Influence on the Performance of Historic Building Conservation Process in Malaysia.
Section E:	Closing

Attached herewith is the consent form for further details. After thoroughly reading the consent form, please sign it to indicate your agreement. The purpose of this consent form is to ensure that you understand the nature of the study, your rights as a participant, and the confidentiality of your responses. The survey will require only 10-20 minutes of your time, thus I would greatly appreciate your participation. Kindly read all instructions pertaining to each section carefully and respond to every question sincerely. Do keep in mind, there are no right or wrong answers.
All responses will be kept strictly confidential and used solely for academic research purposes. Thank you very much for your kind cooperation.

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Coding:				

Historic Building Information Modelling (HBIM)-Retrofitting Framework in Enhancing the Performance in Heritage Building Conservation Projects in Malaysia

Section A: General Information

Please provide the following general information about your organisation. Please tick (/) all the boxes that apply.

1. Where is the location of your organisation?

☐ Selangor	☐ Kuala Lumpur	☐ Penang	☐ Johor
☐ Perak	☐ Kedah	☐ Perlis	☐ Negeri Sembilan
☐ Melaka	☐ Pahang	☐ Kelantan	☐ Terengganu

2. What is the primary type of business of your organisation?

☐ Architectural design consultancy
☐ Heritage building conservation consultancy
☐ Engineering consultancy
☐ Project management consultancy
☐ Other (please specify): ____

3. What is your job title in the company?

☐ Director / Associate Director
☐ Project Manager
☐ Architect
☐ Engineer
☐ Conservator
☐ BIM Manager
☐ Surveying Consultant
☐ Other (please specify): _______________________________________

4. How long have you been involved in heritage/historic building conservation related projects?

☐ Less than 5 years
☐ 6-10 years
☐ 11-20 year
☐ Above 20 years

5. List the types of heritage/historic building conservation projects you have been involved in? *(You can select more than one)*

☐ Adaptive Reuse /Adaptation
☐ Refurbishment
☐ Rehabilitation
☐ Retrofitting
☐ Renovation
☐ Other (please specify):________________________________

6. Are you familiar with the concept of Heritage-Building Information Modelling (HBIM)?

- ☐ Yes
- ☐ No

7. If yes, where did you learn about Heritage-Building Information Modelling (HBIM)?

- ☐ Seminar and conference
- ☐ Industry academic publications / reading materials
- ☐ Colleagues / professionals
- ☐ Education / courses
- ☐ Others (please specify): ___________________________________

8. How well do you understand about Heritage Building Information Modelling (HBIM)?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Well
- ☐ Very Well

9. Does your project organization use Heritage-Building Information Modelling (HBIM) in heritage/historic building conservation projects?

- ☐ Yes
- ☐ No
- ☐ Not sure

10. If yes, to what extent does your organisation use HBIM in your projects?

- ☐ Not at all
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Always

11. Would you be willing to attend a course or training on HBIM if given the opportunity?

- ☐ Yes
- ☐ No

Section B: Historic Building Retrofitting Characteristics

12. Please provide your view on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) by ticking the appropriate number in the scale provided at the top.

No.	B1. The **HERITAGE ASPECT** attributes that should be taken into consideration to ensure retrofits respect and sustain historic building's significance.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	HISTORIC BUILDING TYPOLOGY (state or nationally defined classification framework organizing historic buildings by functions, values and characteristics to guide conservation and retrofit)					
2.	HERITAGE VALUES & SIGNIFICANCE (the recognition of tangible and intangible heritage values guiding retrofit decisions of historic buildings)					
3.	REGULATIONS (the compliance with policy, statutory, legal, and regulatory frameworks that govern heritage preservation while promoting sustainable retrofitting)					
4.	PRINCIPLES OF CONSERVATION (the adherence to the key principles in historic building conservation, eg. compatibility, reversibility, respect to authenticity, etc.)					
5.	MULTIDISCIPLINARY STAKEHOLDERS (the integration of diverse expertise to balance heritage values, technical performance, and sustainability in historic building retrofits)					

13. If you have any other opinions apart from the above, please specify:

____

No.	B2. The **DEVELOPMENT STAGES** attributes essential in the management of retrofitting in historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	PRE-RETROFIT PHASE (the phase that encompasses preliminary research, surveys, project definition, and planning to guide appropriate retrofit strategies.)					
2.	RETROFIT DESIGN PHASE (which includes retrofit design development and detailed assessment of design objectives)					
3.	IMPLEMENTATION PHASE (which involves executing physical retrofit works, repair, upgrading, and integration aligned with conservation principles, supervision, and design specifications.)					
4.	POST-RETROFIT PHASE (which ongoing monitoring, evaluation, feedback, and maintenance ensuring retrofit effectiveness and heritage preservation.)					

14. If you have any other opinions apart from the above, please specify:

____

No.	B3. The significance of **RETROFIT DESIGN CRITERIA** that can be associated with the retrofitting of historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	BUILDING FABRIC (retrofit measures on thermal and energy performance of envelopes including walls, floors, roofs, windows, doors and materials.)					
2.	BUILDING SYSTEMS AND EQUIPMENT (efficiency of HVAC, lighting, and appliances through smart, adaptable, and low-carbon technologies ensuring reduced energy use while preserving heritage integrity)					

3.	BUILDING STRUCTURE (interventions to evaluate structural integrity, safety, and resilience ensuring stability, durability, and adaptability in retrofit strategies)					
4.	USER BEHAVIOUR (assessment of occupants' energy-use patterns, comfort expectations, and management practices influencing retrofit performance in historic building)					
5.	COLLECTIONS (strategies to safeguard valuable objects (eg. artifacts) from environmental risks, pollutants and climatic fluctuations in historic building)					
6.	ECONOMIC FACTORS (evaluates project feasibility, funding, and cost-effectiveness of retrofit measures while sustaining heritage and energy performance)					

15. If you have any other opinions apart from the above, please specify:

____

No.	B5. The **METHOD OF APPROACH** associated in the assessment for retrofitting historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	ENVIRONMENTAL MONITORING AND ANALYSIS (provide microclimatic monitoring and assessment of indoor and outdoor conditions of historic buildings)					
2.	IN-SITU MEASUREMENT (the condition measurement and assessment of original and natural state of historic buildings)					
3.	LABORATORY TESTING (controlled assessments of historic materials' mechanical, thermal, and hygrothermal properties to validate retrofit compatibility)					
4.	BUILDING PERFORMANCE ANALYSIS (dynamic computational tools to assess energy and hygrothermal performance for optimizing compatible historic retrofit interventions)					
5.	ENERGY PERFORMANCE CERTIFICATE ASSESSMENT (standardized certification tools assessing energy and environmental performance to guide sustainable historic retrofits (eg. GBI)					
6.	RISK ASSESSMENT (the evaluation of potential impact and benefits associated in the retrofitting of historic buildings)					
7.	HISTORICAL DOCUMENTATION (involving the analysis of records, photos, and drawings to guide accurate and heritage-preserving retrofits)					

16. If you have any other opinions apart from the above, please specify:

____

Section C: The HBIM-Retrofit Model Characteristics

17. Please provide your view on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) by ticking the appropriate number in the scale provided at the top.

No.	C1. The **ORGANIZATIONAL** attributes to be considered in HBIM-enabled retrofitting of historic buildings in Malaysia	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	ROLES & RESPONSIBILITY (establish clear organizational roles to ensure accountability, coordination, and effective collaboration in multidisciplinary HBIM retrofit projects.)					
2.	TRAINING AND EDUCATION (the development and support of HBIM-retrofit to build capacity of knowledge, skills and competency)					

3.	BIM PROTOCOL (establish standardized frameworks for data integrity, legal clarity and collaboration agreement for HBIM-retrofit)					

18. If you have any other opinions apart from the above, please specify:

____

No	C2. The **INFORMATIONAL** attributes to be associated in the management of HBIM-enabled retrofitting of historic buildings in Malaysia.	Strongly Disagree			Strongly Agree	
		1	2	3	4	5
1.	GEOMETRICAL DATA (comprehensive 2D and 3D modelling of a building's form, fabric, and parametric data for accurate HBIM documentation)					
2.	HISTORICAL AND EVIDENTIAL DATA (the HBIM documentation of historical archives and records, chronologies, ownership, land matters and photos information)					
3.	PATHOLOGY DATA (encompasses HBIM-integrated surveys documenting structural deficiencies, material decay, and environmental deterioration)					
4.	SURVEYING DATA (capturing data that integrates photogrammetry, 3D laser scanning (LiDAR), and Unmanned Aerial Vehicle (UAV)-based methods to support HBIM accuracy)					
5.	ENVIRONMENTAL PERFORMANCE DATA (encompasses HBIM information on energy, material properties, thermal and environmental performance)					
6.	STRUCTURAL DATA (comprehensive HBIM information related to building's structural integrity, configuration and material composition)					

19. If you have any other opinions apart from the above, please specify:

____

No.	C3. The **PROCESS LIFECYCLE** involved in documenting HBIM-enabled retrofitting of historic buildings in Malaysia.	Strongly Disagree			Strongly Agree	
		1	2	3	4	5
1.	DATA ACQUISATION (the HBIM techniques and process of existing site and building capturing for retrofitting of historic buildings)					
2.	3D MODELLING (The techniques and process of geometrical, numerical, parametrical, and documentary modelling of historic buildings)					
3.	DATA SIMULATION AND ANALYSIS (which includes the whole lifecycle building performance evaluation in historic buildings, eg. energy, cost, time, sustainability)					
4.	DESIGN VISUALIZATION (which include the visualization techniques and process such as Augmented Reality (AR), Virtual Reality (VR) and Extended-Reality)					

20. If you have any other opinions apart from the above, please specify:

____

No.	C4. The **TECHNICAL** attributes to be associated in the HBIM-enabled retrofitting of historic buildings in Malaysia.	Strongly Disagree				Strongly Agree
		1	2	3	4	5
1.	SOFTWARE (The initial investment and operational cost of HBIM software and applications)					
2.	HARDWARE AND INFRASTRUCTURES (The initial and operational investment of physical tools and equipment related to HBIM-retrofit such as 3D laser scanners, PC, VR technology)					
3.	STANDARDS (Guide HBIM information accuracy, modelling practices, and semantic consistency through frameworks such as Level of Detail (LOD) and BIM object standards)					
4.	DATA EXCHANGE (which includes technical manual for HBIM-retrofit data compatibility, sharing and interoperability)					

21. If you have any other opinions apart from the above, please specify:

____

Section D: HBIM-Enabled Retrofit Influence on the Performance of Historic Building Conservation Process in Malaysia.

22. Please provide your view on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree) by ticking the appropriate number in the scale provided at the top.

No.	D1. In adopting HBIM-enabled retrofitting, I believe the design management **PERFORMANCE** in conserving historic buildings was grounded in..	Strongly Disagree						Strongly Agree
		1	2	3	4	5	6	7
1.	The design project TIME can be significantly reduced.							
2.	The associated COST to the project were substantially reduced.							
3.	The accuracy and QUALITY of the design output was successfully achieved.							
4.	The overall ENVIRONMENTAL impact can be significantly reduced or accomplished.							
5.	The flexibility in historic building retrofit DESIGN can be successfully attained.							
6.	Effective and positive RELATIONSHIP among the project team members/stakeholders can be increasingly satisfied.							
7.	The COMMUNICATION and understanding among the project collaborators were significantly facilitated and enhanced.							

23. If you have any other opinions apart from the above, please specify:

____

Section E: Closing

24. Do you wish to make any comments? If so, please give your comments below:

____

____

____

APPENDIX 2

Analytical Hierarchy Process (AHP) Questionnaire

Information Sheet

This PhD research, entitled ***"Historic Building Information Modelling (HBIM)-Retrofit Framework in Enhancing the Performance of Heritage Building Conservation Projects in Malaysia"***, aims to develop and validate a HBIM integrated retrofitting framework for heritage building conservation projects. Prior to this, the research variables and indicators were earlier identified through a survey questionnaire, and the data were analyzed using the Partial Least Squares Structural Equation Modelling (PLS-SEM) method. The results of the PLS-SEM analysis were then further developed into a hierarchical structure for this research (see Figure 1).

To achieve the goal of HBIM-retrofit framework for heritage conservation projects, the hierarchical structure is organized into levels determined by clusters (pre-retrofit stage, implementation stage, and post-retrofit stage). These clusters are further examined in relation to their interdependence with sub-clusters, namely: heritage aspects, retrofit design criteria, method of approach, HBIM organizational, HBIM informational, HBIM process lifecycle, and HBIM technical.

Your expert judgements are therefore requested through the questionnaire below; this involves responding with pairwise comparisons of the identified criteria. Your input will guide the researcher in assigning appropriate weights and priorities to each criterion under consideration using the Analytic Hierarchy Process (AHP), a method within Multi-Criteria Decision Making (MCDM).

You are invited to participate in this survey as part of the expert group contributing to the development of the HBIM-retrofit framework for heritage building conservation projects in Malaysia. Participation in this research is entirely voluntary, and you are free to withdraw at any time. The survey questions have been designed to avoid causing distress, and beyond the time required to complete the questionnaire, hence no risks or inconveniences are anticipated.

Should you wish to withdraw your submitted questionnaire, you may do so by informing the researcher within seven (7) days of submission. Your responses will be kept strictly confidential and used solely for the purpose of this research. We kindly request your valuable input to be completed by **13 October 2025**. This will ensure sufficient time for the analysis of the Analytic Hierarchy Process (AHP) results. Your cooperation is greatly appreciated.

The analyzed results will form part of a PhD dissertation in Built Environment at Universiti Teknologi MARA (UiTM), Malaysia, and may also be published in academic journals or presented at conferences. Please be assured that no personal details of respondents will be disclosed in any report or publication. If you wish to receive a copy of the final results of the study, kindly contact the researcher using the details provided below.

This research is conducted by Ts. Khairool Aizat Ahmad Jamal, under the supervision of Associate Professor Ts. Dr. Shahrul Yani Binti Said (main supervisor) and Ts. Dr. Mohamed Rizal Bin Mohamed (co-supervisor).

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If you would like to discuss any concerns regarding this study with someone not directly involved, you may contact the UiTM Research Ethics Committee (REC) at recsecretariat@uitm.edu.my.

Thank you very much for your valuable contribution.

Consent Form

Below is the informed consent for this study. Please review the statement below and select if you wish to participate in this study. Please select "I agree with the statements above and I agree to participate in this study".

1. I have been explained the information about the project on 'HBIM-Retrofit Framework in Enhancing the Performance of Heritage Building Conservation Projects in Malaysia'.
2. I have had been explained the purposes of the project and what will be required of me, and any questions I have had have been answered to my satisfaction.
3. I agree with the arrangements described in the Subject Information Sheet in so far as they relate to my participation.
4. I understand that participation is entirely voluntary and that I have the right to withdraw from the project at any time, and that this will be without detriment.
5. This application has been reviewed by the Universiti Teknologi MARA (UITM) Research Ethics Committee and has been given a favorable ethical opinion for conduct.

Please make your choice below before proceeding further:

☐ I agree with the statements above and I agree to participate in this study
☐ I disagree and I do not want to take part in this study

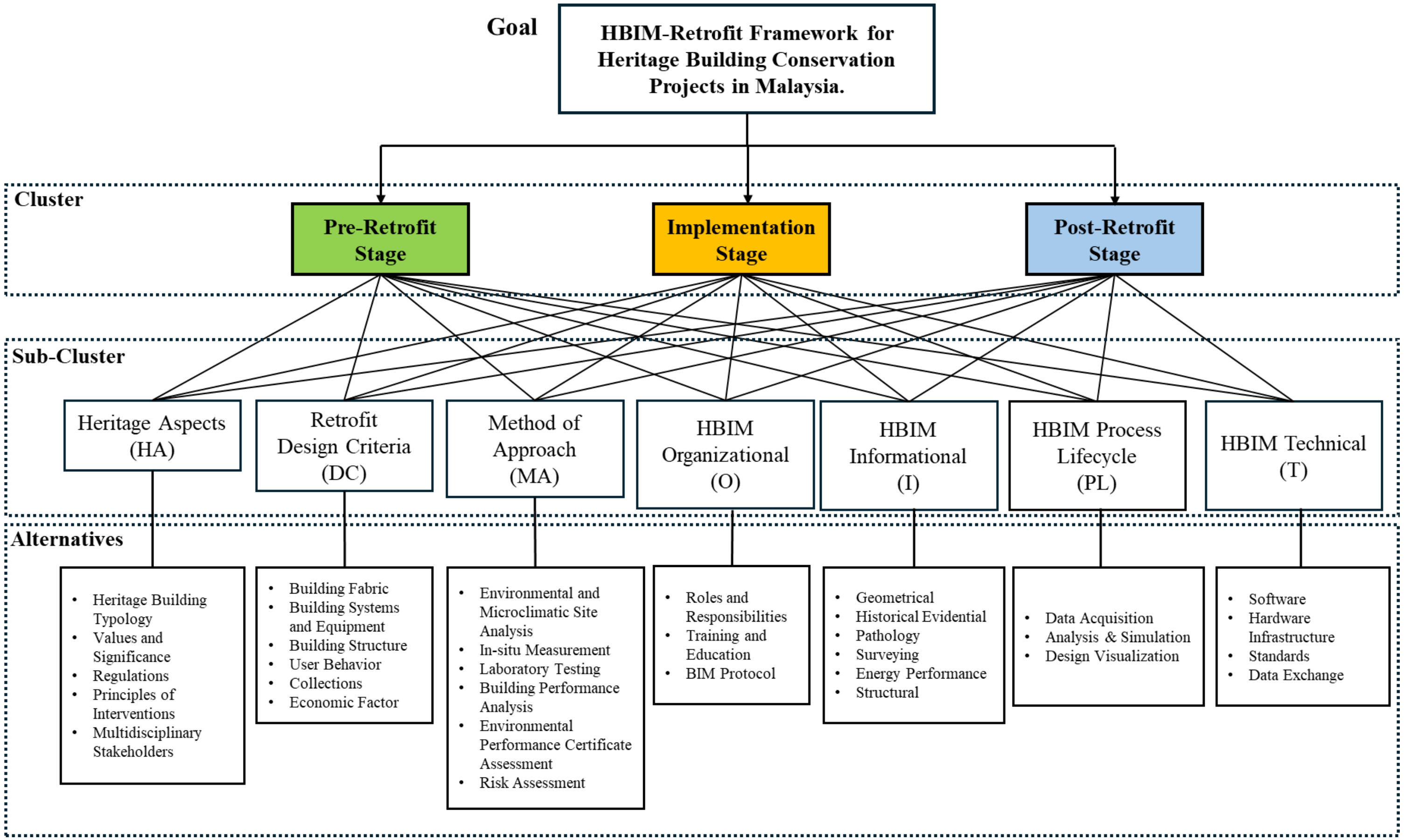


Figure 1. Hierarchy of Structure

RESPONDENT'S PROFILE

Highest Educational Qualification: Click or tap here to enter text.

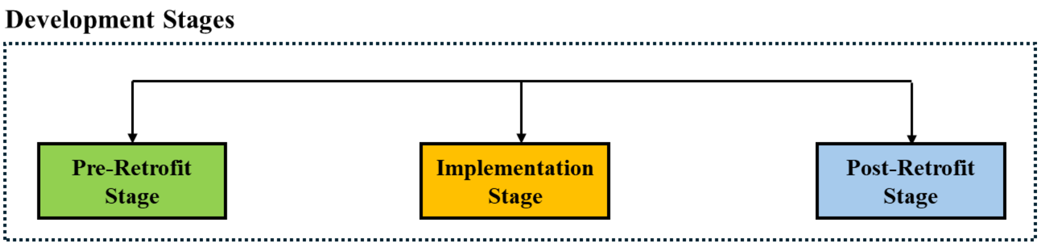
Current Position: Click or tap here to enter text.

Organization Name: Click or tap here to enter text.

Total Years of Experience: Click or tap here to enter text.

Definition of Cluster and Nodes

Cluster



Criteria:

Cluster	Detail
Pre-Retrofit Stage	The phase that encompasses preliminary research, surveys, project definition, and planning to guide appropriate retrofit strategies.
Implementation Stage	Involves executing physical retrofit works, repair, upgrading, and integration aligned with conservation principles, supervision, and design specifications.
Post-Retrofit Stage	The phase involves ongoing monitoring, evaluation, feedback, and maintenance ensuring retrofit effectiveness and heritage preservation.

Definition of Sub-Clusters and Nodes

Sub-Cluster 1

Heritage Aspect (HA): Consideration of the heritage aspects to ensure retrofits respect and sustain historic building's significance.

Criteria:

Code	Cluster	Detail
HA1	Heritage Building Typology	State or nationally defined classification framework organizing historic buildings by functions, values and characteristics to guide conservation and retrofit

HA2	Values and Significance	Recognition of tangible and intangible heritage values guiding retrofit decisions of historic buildings
HA3	Regulations	Compliance with policy, statutory, legal, and regulatory frameworks that govern heritage preservation while promoting sustainable retrofitting.
HA4	Principles of Interventions	The adherence to the key principles in historic building conservation, eg. compatibility, reversibility, respect to authenticity, etc.
HA5	Multidisciplinary Stakeholders	The integration of diverse expertise to balance heritage values, technical performance, and sustainability in historic building retrofits

Sub-Cluster 2

Retrofit Design Criteria (DC): The retrofit design criteria and benchmarks ensuring energy retrofit enhance performance while preserving heritage building's integrity.

Criteria:

Code	Cluster	Detail
DC1	Building Fabric	Retrofit measures on thermal and energy performance of building envelopes including walls, floors, roofs, windows, doors and materials.
DC2	Building System and Equipment	Efficiency of HVAC, lighting, and appliances through smart, adaptable, and low-carbon technologies ensuring reduced energy use while preserving heritage integrity.
DC3	Building Structure	Interventions to evaluate structural integrity, safety, and resilience ensuring stability, durability, and adaptability in retrofit strategies.
DC4	User Behavior	Assessment of occupants' energy-use patterns, comfort expectations, and management practices influencing retrofit performance in historic building.
DC5	Collections	Retrofit strategies to safeguard valuable objects (eg. artifacts) from environmental risks, pollutants and climatic fluctuations in historic building.
DC6	Economic Factor	Evaluates project feasibility, funding, and cost-effectiveness of retrofit measures while sustaining heritage and energy performance.

Sub-Cluster 3

Method of Approach (MA): The method of approach using tools, techniques, and whole-building strategies to guide coherent, heritage-sensitive retrofit decisions

Criteria:

Code	Cluster	Detail
MA1	Environmental and Microclimatic Site Analysis	Provide microclimatic monitoring and assessment of indoor and outdoor conditions of historic buildings
MA2	In-situ Measurement	The condition measurement and assessment of original and natural state of historic buildings
MA3	Laboratory Testing	Controlled assessments of historic materials' mechanical, thermal, and hygrothermal properties to validate retrofit compatibility.
MA4	Building Performance Analysis	Dynamic computational tools to assess energy and hygrothermal performance for optimizing compatible historic retrofit interventions.
MA5	Energy Performance Certificate Assessment	Standardized certification tools assessing energy and environmental performance to guide sustainable historic retrofits (eg. GBI).
MA6	Risk Assessment	The evaluation of potential impact and benefits associated in the retrofitting of historic buildings

Sub-Cluster 4

HBIM Organizational (O): The organizational attributes that should be taken into consideration in the management of HBIM-enabled retrofitting of historic buildings in Malaysia.

Criteria:

Code	Cluster	Detail
O1	Roles and Responsibilities	Establish clear organizational roles to ensure accountability, coordination, and effective collaboration in multidisciplinary HBIM retrofit projects.
O2	Training and Education	The development and support of HBIM-retrofit to build capacity of knowledge, skills and competency.
O3	BIM Protocol	Establish standardized frameworks for data integrity, legal clarity and collaboration agreement for HBIM-retrofit.

Sub-Cluster 5

HBIM Informational (I): The informational attributes to be associated in the management of HBIM-enabled retrofitting of historic buildings in Malaysia.

Criteria:

Code	Cluster	Detail
I1	Geometrical	Comprehensive 2D and 3D modelling of a building's form, fabric, and parametric data for accurate HBIM documentation.
I2	Historical Evidential	The HBIM documentation of historical archives and records, chronologies, ownership, land matters and photos information.
I3	Pathology	Encompasses HBIM-integrated surveys documenting structural deficiencies, material decay, and environmental deterioration.
14	Surveying	Capturing data that integrates photogrammetry, 3D laser scanning (LiDAR), and Unmanned Aerial Vehicle (UAV)-based methods to support HBIM accuracy.
15	Environmental Performance	Encompasses HBIM information on energy, material properties, thermal and environmental performance.
16	Structural	Comprehensive HBIM information related to building's structural integrity, configuration and material composition.

Sub-Cluster 6

HBIM Process Lifecycle (PL): The lifecycle process underpinning the implementation of HBIM-enabled retrofits for historic buildings in Malaysia

Criteria:

Code	Cluster	Detail
PL1	Data Acquisition	The HBIM techniques and process of existing site and building capturing for retrofitting of historic buildings
PL2	Simulation and Analysis	Which includes the whole lifecycle building performance evaluation in historic buildings, eg. energy, cost, time, sustainability.
PL3	Design Visualization	Which include the visualization techniques and process such as Augmented Reality (AR), Virtual Reality (VR) and Extended-Reality

Sub-Cluster 7

HBIM Technical (T): The technical attributes to be associated in the HBIM-enabled retrofitting of historic buildings in Malaysia.

Criteria:

Code	Cluster	Detail
T1	Software	The initial investment and operational cost of HBIM software and applications
T2	Hardware Infrastructure	The initial and operational investment of physical tools and equipment related to HBIM-retrofit such as 3D laser scanners, PC, VR technology.
T3	Standards	Guide HBIM information accuracy, modelling practices, and semantic consistency through frameworks such as Level of Detail (LOD) and BIM object standards.
T4	Data Exchange	Which includes technical manual for HBIM-retrofit data compatibility, sharing and interoperability.

Scale of Measurement

The criteria will be displayed side by side (on the left and right sides of the table) with Saaty‘s scale of judgement (1-9) displayed below. Score of 1 represents equal importance between two criteria, 3 represents moderately important of one criterion over another, 5 represents strongly important, 7 represents very strongly important and 9 represents extremely important. The weight assigned to a criterion will be determined by the degree of influence of the criterion when compared to another with respect to another criterion.

Please click ☒ on the check box based on your preferred scale option below.

Scale	Extremely Important	Very Strongly Important	Strongly Important	Moderately Important	Equal	Moderately Important	Strongly Important	Very Strongly Important	Extremely Important	
Criteria	**9**	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	**Criteria**

An example on how to use the scale.

If you clicked (select) the box (5) on the left, this shows that,

Regulations are **strongly more important** than Principles of Intervention

← Level of Importance →		
HA3– Regulations	☐ 9 ☐ 7 ☒ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Intervention

If you clicked (select) the box (9) on the right, this shows that,

Principles of Intervention are **extremely more important** than Regulations

← Level of Importance →		
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☒ 9	HA4– Principles of Intervention

Question 1: Comparison of cluster in development stage in **Pre-Retrofit Stage** to sub-clusters.

Comparison of Sub-cluster in **Heritage Aspect (HA)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
HA1–Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA2–Values & Significance
HA1–Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA3–Regulations
HA1–Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4–Principles of Intervention
HA1–Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5–Multidisciplinary Stakeholders
HA2–Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA3–Regulations
HA2–Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4–Principles of Intervention
HA2–Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5–Multidisciplinary Stakeholders
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4–Principles of Intervention
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5–Multidisciplinary Stakeholders
HA4–Principles of Intervention	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5–Multidisciplinary Stakeholders

Comparison of Sub-cluster in **Retrofit Design Criteria (DC)** with related criteria, which criteria is more important and up to what extent?

← **Level of Importance** →		
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC2– Building Systems & Equipment
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC3- Building Structure
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC3- Building Structure
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC4 – User Behavior	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC4 – User Behavior	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC5- Collections	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor

Comparison of Sub-cluster in **Method of Approach (MA)** with related criteria, which criteria is more important and up to what extent?

← **Level of Importance** →		
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA2- In-situ Measurement
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA3- Laboratory Testing

MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA3- Laboratory Testing
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA4- Building Performance Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA4- Building Performance Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA5- Energy Performance Certificate Assessment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment

Comparison of Sub-cluster in **HBIM Organizational (O)** with related criteria, which criteria is more important and up to what extent?

← **Level of Importance** →		
O1– Roles and Responsibility	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O2– Training and Education
O1– Roles and Responsibility	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O3– BIM Protocol
O2– Training and Education	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O3– BIM Protocol

Comparison of Sub-cluster in **HBIM Informational (I)** with related criteria, which criteria is more important and up to what extent?

← **Level of Importance** →		
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I2 - Historical Evidential
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I3- Pathology
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance

I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I3- Pathology
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I4- Surveying	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I4- Surveying	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I5 - Environmental Performance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural

Comparison of Sub-cluster in **HBIM Process Lifecycle (PL)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
PL1– Data Acquisition	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL2– Simulation and Analysis
PL1– Data Acquisition	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL3– Design Visualization
PL2– Simulation and Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL3– Design Visualization

Comparison of Sub-cluster in **HBIM Technical (T)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T2– Hardware Infrastructure
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T3– Standards
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange
T2– Hardware Infrastructure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T3– Standards
T2– Hardware Infrastructure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange

T3– Standards	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange

If you have any other opinions, please specify:

Click or tap here to enter text.

Question 2: Comparison of cluster in development stage in **Implementation Stage** to sub-clusters.

Comparison of Sub-cluster in **Heritage Aspect (HA)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA2– Values & Significance
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA3– Regulations
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Intervention
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders
HA2– Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA3– Regulations
HA2– Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Intervention
HA2– Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Intervention
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders
HA4– Principles of Intervention	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders

Comparison of Sub-cluster in **Retrofit Design Criteria (DC)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC2– Building Systems & Equipment
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC3- Building Structure

DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC3- Building Structure
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC4 – User Behavior	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC4 – User Behavior	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC5- Collections	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor

Comparison of Sub-cluster in **Method of Approach (MA)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA2- In-situ Measurement
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA3- Laboratory Testing
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA3- Laboratory Testing
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis

MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA4- Building Performance Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA4- Building Performance Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA5- Energy Performance Certificate Assessment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment

Comparison of Sub-cluster in **HBIM Organizational (O)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
O1– Roles and Responsibility	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O2– Training and Education
O1– Roles and Responsibility	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O3– BIM Protocol
O2– Training and Education	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O3– BIM Protocol

Comparison of Sub-cluster in **HBIM Informational (I)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I2 - Historical Evidential
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I3- Pathology
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I3- Pathology
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I2 – Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying

I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I4- Surveying	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I4- Surveying	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I5 - Environmental Performance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural

Comparison of Sub-cluster in **HBIM Process Lifecycle (PL)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
PL1– Data Acquisition	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL2– Simulation and Analysis
PL1– Data Acquisition	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL3– Design Visualization
PL2– Simulation and Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL3– Design Visualization

Comparison of Sub-cluster in **HBIM Technical (T)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T2– Hardware Infrastructure
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T3– Standards
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange
T2– Hardware Infrastructure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T3– Standards
T2– Hardware Infrastructure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange
T3– Standards	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange

If you have any other opinions, please specify:

Click or tap here to enter text.

Question 3: Comparison of cluster in development stage in **Post-Retrofit Stage** to sub-clusters.

Comparison of Sub-cluster in **Heritage Aspect (HA)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA2– Values & Significance
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA3– Regulations
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Conservation
HA1– Heritage Building Typology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders
HA2– Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA3– Regulations
HA2– Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Conservation
HA2– Values & Significance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA4– Principles of Conservation
HA3– Regulations	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders
HA4– Principles of Conservation	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	HA5– Multidisciplinary Stakeholders

Comparison of Sub-cluster in **Retrofit Design Criteria (DC)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC2– Building Systems & Equipment
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC3- Building Structure
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC1– Building Fabric	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC3- Building Structure
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior

DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC2– Building Systems & Equipment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC4 – User Behavior
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC3- Building Structure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC4 – User Behavior	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC5- Collections
DC4 – User Behavior	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor
DC5- Collections	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	DC6 – Economic Factor

Comparison of Sub-cluster in **Method of Approach (MA)** with related criteria, which criteria is more important and up to what extent?

	← **Level of Importance** →	
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA2- In-situ Measurement
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA3- Laboratory Testing
MA1– Environmental and Microclimatic Site Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA3- Laboratory Testing
MA2- In-situ Measurement	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA3- Laboratory Testing	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA4- Building Performance Analysis
MA4- Building Performance Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA5- Energy Performance Certificate Assessment

MA4- Building Performance Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment
MA5- Energy Performance Certificate Assessment	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	MA6- Risk Assessment

Comparison of Sub-cluster in **HBIM Organizational (O)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
O1– Roles and Responsibility	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O2– Training and Education
O1– Roles and Responsibility	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O3– BIM Protocol
O2– Training and Education	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	O3– BIM Protocol

Comparison of Sub-cluster in **HBIM Informational (I)** with related criteria, which criteria is more important and up to what extent?

	← Level of Importance →	
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I2 – Historical Evidential
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I3- Pathology
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I1– Geometrical	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I3- Pathology
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I2 - Historical Evidential	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I4- Surveying
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I3- Pathology	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural
I4- Surveying	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I5 - Environmental Performance
I4- Surveying	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural

I5 - Environmental Performance	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	I6- Structural

Comparison of Sub-cluster in **HBIM Process Lifecycle (PL)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
PL1– Data Acquisition	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL2– Simulation and Analysis
PL1– Data Acquisition	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL3– Design Visualization
PL2– Simulation and Analysis	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	PL3– Design Visualization

Comparison of Sub-cluster in **HBIM Technical (T)** with related criteria, which criteria is more important and up to what extent?

← Level of Importance →		
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T2– Hardware Infrastructure
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T3– Standards
T1– Software	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange
T2– Hardware Infrastructure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T3– Standards
T2– Hardware Infrastructure	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange
T3– Standards	☐ 9 ☐ 7 ☐ 5 ☐ 3 ☐ 1 ☐ 3 ☐ 5 ☐ 7 ☐ 9	T4- Data Exchange

If you have any other opinions, please specify:

Click or tap here to enter text.

General comments:

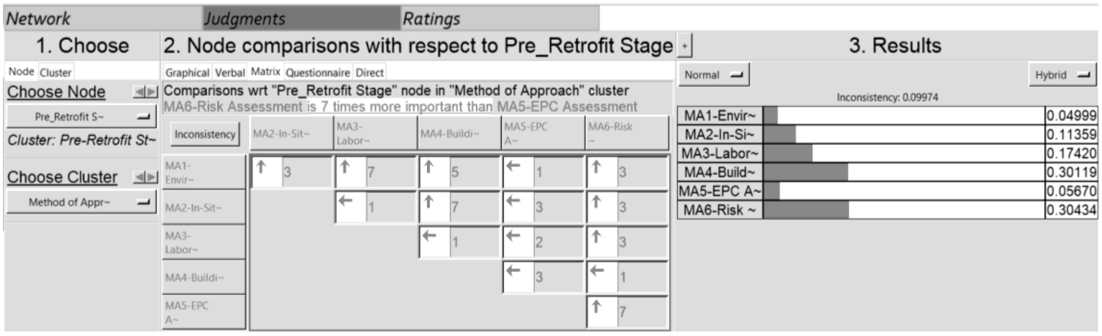
If you have any further comment, please describe below.

Click or tap here to enter text.

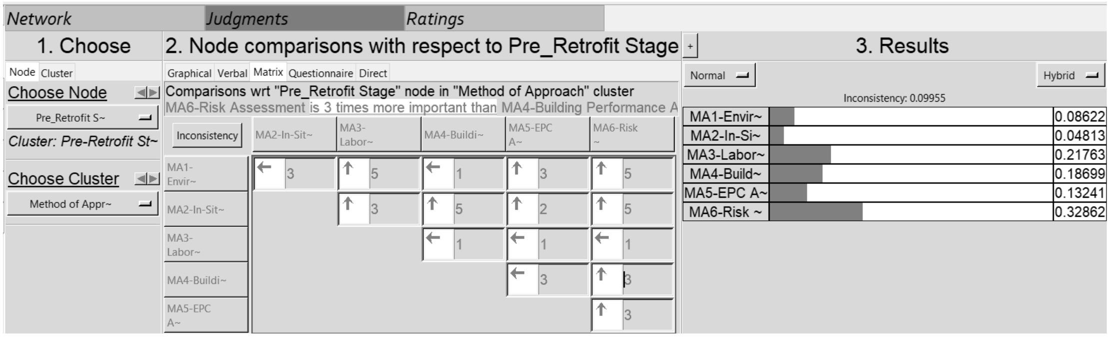
APPENDIX 3

AHP Consistency (Method of Approach)

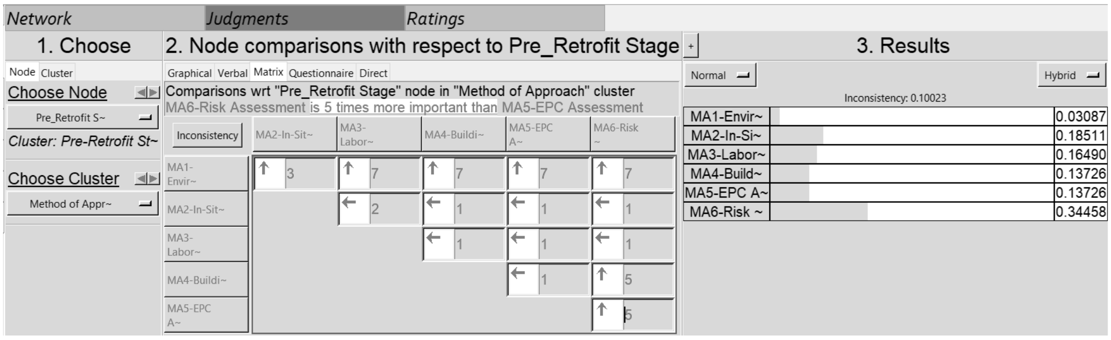
Expert 1



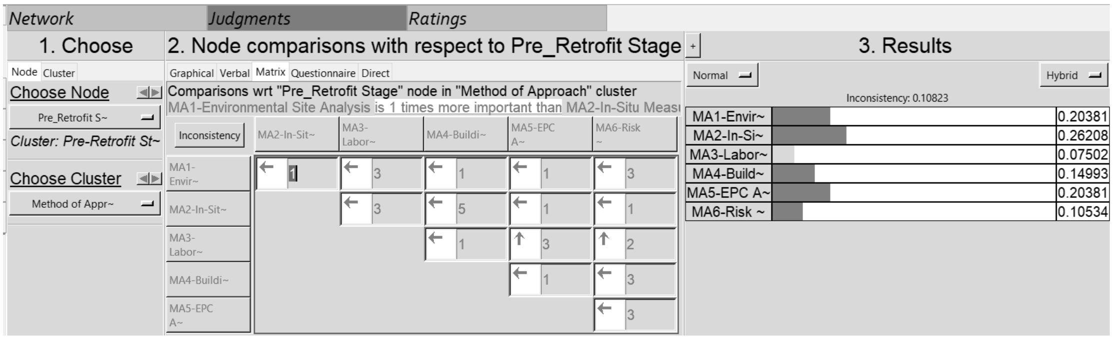
Expert 2



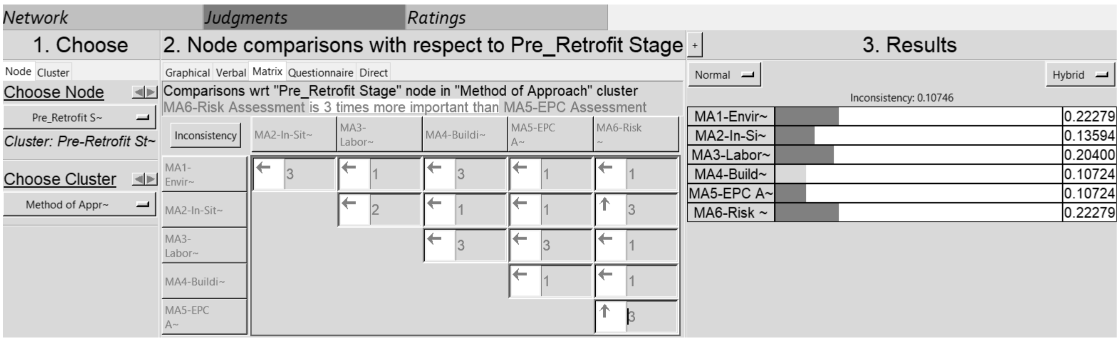
Expert 3



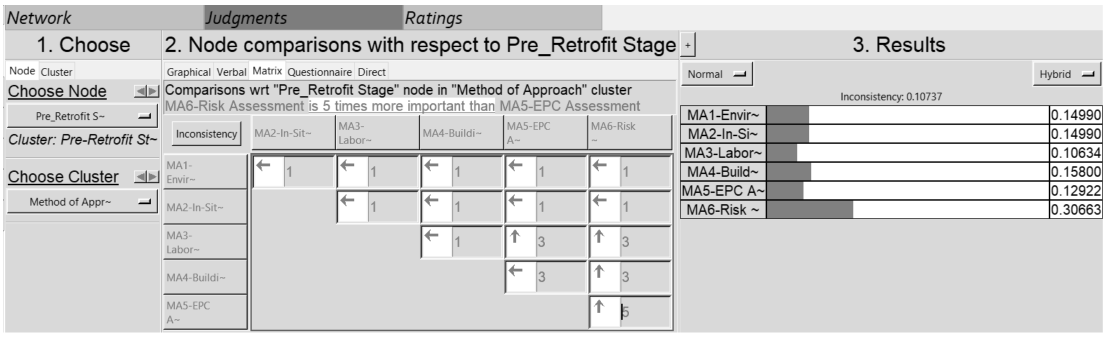
Expert 4



Expert 5



Expert 6



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List of Publication:

Jamal, K. A. A., Said, S. Y., Harun, S. N., Zainazlan, A. F., & Khiyon, N. A. (2026). The Review of HBIM-Retrofit Framework for Enhancing the Performance of Heritage Building Conservation Projects in Malaysia. In *Sustainable Construction and Heritage Conservation in the Digital Age* (pp. 71-106). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-5278-7.ch003.

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