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Digitalizing Historic Building Renovation: Technology Adoption in the Construction Phase

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Abstract

This study investigates the adoption of digital technologies during the construction phase of historic building renovation, with a focus on stakeholder communication, coordination, and real-time decision-making. Guided by the Technology Acceptance Model (TAM), the research collected qualitative data from semi-structured interviews with public clients, contractors, and consultants.

Findings show that adoption is shaped by perceived usefulness, ease of use, and external conditions such as contracts, team dynamics, and site complexity. Stakeholders evaluate digital technologies through role-specific priorities rather than uniformly. Beyond adoption, these technologies influence how decisions are made, information is shared, and heritage challenges are addressed on site.

It is also found that successful digitalization in historic renovation requires more than access to tools, it depends on organizational readiness, inclusive workflows, and alignment with preservation values. Digital technologies are most effective when used as collaborative frameworks that promote transparency, long-term knowledge, and respect for cultural significance. The findings could be helpful for future historic renovation projects where improving communication and decision-making is a concern.

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Sammanfattning

Denna studie undersöker användningen av digital teknik under byggfasen vid renovering av kulturhistoriska byggnader, med särskilt fokus på kommunikation, samordning och beslutsfattande i realtid mellan olika intressenter. Med stöd av Technology Acceptance Model (TAM) har kvalitativa data samlats in genom semistrukturerade intervjuer med offentliga beställare, entreprenörer och konsulter.

Resultaten visar att användningen av digital teknik påverkas av upplevd nytta, användarvänlighet och yttre förutsättningar såsom kontrakt, teamdynamik och platsens komplexitet. Intressenterna bedömer tekniken utifrån sina specifika roller och prioriteringar snarare än på ett enhetligt sätt. Utöver direkta effekter i själva användningen påverkar tekniken även hur beslut fattas, hur information delas och hur kulturarvsrelaterade utmaningar hanteras på plats.

Studien visar också att lyckad digitalisering inom kulturhistorisk renovering kräver mer än bara tillgång till verktyg; det förutsätter organisatorisk beredskap, inkluderande arbetsflöden och en anpassning till bevarandemässiga värden. Digital teknik är mest effektiv när den används som ett samarbetsverktyg som främjar transparens, långsiktig kunskap och respekt för byggnadens kulturella betydelse. Resultaten kan vara till hjälp för framtida renoveringsprojekt där förbättrad kommunikation och beslutsfattande är viktiga.

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1. Introduction

In this chapter, the background of this study is first described, and the current status and importance of historical building renovation and the application of digital technology in historical building renovation are briefly explained. Then the purpose of this study and the research questions are introduced. Finally, the research outline and delimitation of this paper is provided.

1.1 Background

Historic buildings, which have significant cultural, historical, or architectural value, are vital cultural assets that embody the collective memory and identity of societies, serving as tangible connections to the past. Historic buildings constitute an important part of the entire building stock worldwide (Yung & Chan, 2012) and the preservation of historic buildings is in line with the global Sustainable Development Goals (SDGs), especially SDG 11, which emphasizes sustainable cities and communities (United Nations., 2024). It is typical in many cities to find heritage preservation a predominant factor integrated in urban planning, which ensures the historic buildings are still used for their intended purposes, while ensuring the historic values are maintained.

The special nature of historic buildings goes beyond their physical structure, with complexity in both form and the information they retain (Charlton et al., 2020). Unlike new construction, the renovation of historic buildings is a complex process that involves many uncertainties and requires a balance between conservation, structural safety, modern functionality, and environmental performance (Kelly & Koo, 2024). Renovation projects related to historic buildings must also comply with strict heritage conservation regulations, which often dictate the types of materials and methods that can be used (ICOMOS, 2011a). Many historic buildings are not designed to meet contemporary energy efficiency or safety standards, so renovations must be carefully planned to avoid compromising their integrity (Gremmelspacher et al., 2021). Complexity is also created by the multitude of stakeholders involved within historic renovation projects (Penjor et al., 2024). Property owners, conservation agencies, architects, contractors, engineers, and local heritage groups all play vital roles, but their interests may not always align (Angrisano et al., 2024). Therefore, effective collaboration and communication is necessary to ensure everyone is aware of both the conservation priorities and requirements of modern buildings. Lack of alignment between owners and construction professionals can result in duplication of work, lead to cost overruns, and heighten the possibility for disagreements over design (Penjor et al., 2024).

The ongoing digital transformation across industries marks the fourth industrial revolution, driving important shifts in business models and performance (Lorenz et al., 2020). Nowadays, digital technologies, like Building Information Management (BIM), digital twins, robotics, virtual reality (VR), augmented reality (AR), sensor-based monitoring, and cloud-based project management have been used in various fields, including the construction industry(Wang et al., 2024). These technologies allow real-time data integration, predictive modelling, and automated documentation of delivery, thereby managing some of the uncertainty that abounds on projects and providing enhanced coordination of project teams.

Despite the growing recognition of these technologies, their implementation in historic renovations is not yet widespread across all projects. In Sweden, organizations such as the National Property Board of Sweden (SFV) are responsible for managing state-owned cultural properties and ensuring their long-term preservation (SFV, n.d.). Numerous historic renovation projects highlight that differing approaches vary in modern construction methods while keeping the inherent authenticity of the heritage building. However, the extent to which digital technologies are used in these projects varies. While some projects incorporate digital technologies such as BIM, digital twins, and sensor-based monitoring to enhance decision-making and risk management (García-León et al., 2023; Lovell et al., 2023), while other projects rely on more traditional documentation and site inspection methods.

Furthermore, while digital technologies have become common in new construction, their application in the construction phase of historic building renovation remains inconsistent. Existing research has mainly focused on the design phase, such as their application in construction or structural visualization simulation (Alshawabkeh et al., 2024), cost control (Sepasgozar et al., 2021), material selection (Vanhellemont et al., 2016), etc., but less attention has been paid to their role in stakeholder communication and real-time decision-making during the construction phase of historic projects.

As the construction industry moves toward greater digitalization, understanding how these technologies can improve collaboration and support decision-making become increasingly important. Investigating the barriers and drivers of digital technology adoption in historic renovations can provide valuable insights into improving project outcomes and heritage preservation efforts.

1.2 Purpose and Research Questions

The purpose of this study is to investigate the acceptance and adoption of digital technologies in the construction phase of historic building renovation projects, with a focus on stakeholder communication, coordination, and real-time decision-making. The study aims to have a better understanding of digital technologies use and explore its practical implications in specific complex historic building renovation background.

This study aims to answer the following research questions:

RQ1. What are the key factors influencing stakeholders' adoption and acceptance of digital technologies in the construction phase of historic building renovation projects?

RQ2. What are the implications of digital technology adoption for stakeholder communication, coordination, and real-time decision-making in the construction phase of historic building renovation projects?

1.3 Outline

The rest of this thesis is divided into 7 chapters, and the descriptions of each chapter are included *Table 1*, shown the outline of the study.

Table 1. The outline of the study

Chapter	Topic	Description
1	Introduction	Presents the background, purposes, research questions, outline and limitations of this study.
2	Literature overview	Provides the overview of previous research on historic building renovation, digitalization in construction phase and digital technology in historic building renovation.
3	Theoretical framework	Explains the Technology Acceptance Model and the application in this study.
4	Methodology	Presents the choice of method of this study, data collection and analysis.
5	Findings	Reflects the findings from semi-structured interviews.
6	Discussion	Presents the discussion of the results of the findings.
7	Conclusions	Presents the conclusions of this study.
	References	Lists the references of this study.
	Appendix	Presents the appendixes.

1.4 Delimitation

This study focuses on the adoption and use of digital technologies specifically within the construction phase of historic building renovation projects. The term “digital technologies” in this context refers to technologies such as BIM, laser scanning, photogrammetry, and other similar tools explicitly mentioned throughout the research. It does not include general digital resources such as internet search engines, generative AI tools like ChatGPT, or other digital platforms unrelated to construction site activities.

2. Literature Review

This chapter reviews literature relevant to the renovation of historic buildings and the role of digital technologies during the construction phase. In this section, the literature review is divided into three parts and presented: first, the characteristics and challenges of historic renovation; second, the digitalization of the construction industry; and third, the application of digital tools in historic renovation background.

2.1 Historic Building Renovation

Historic building renovation is shaped by evolving theoretical frameworks, practical challenges, and shifting expectations for how heritage should be preserved and reused in contemporary society.

2.1.1 The Evolution of Historic Building Conservation Principles and International Framework

The principles of historic building conservation have evolved from simple restoration to comprehensive conservation, and the establishment of an international framework has had a profound impact on global conservation practices. The theoretical basis upon which the renovation of historic buildings relies are the charters of international cultural heritage conservation. The Athens Charter of 1931 first proposed a scientific framework for the conservation of historic sites (ICOMOS, 2011b), while the Venice Charter of 1964 established the principles of "minimum intervention" and "reversibility", and has fundamentally changed the way the world conserves heritage (ICOMOS, n.d.). In recent years, various charters issued by ICOMOS have further expanded the scope of conservation and emphasized the protection of vernacular architecture and cultural landscapes. These documents constitute an international conservation framework that guides the conservation practices of historic buildings in various countries.

2.1.2 Systematic Analysis of Multidimensional Challenges

The protection of historic buildings faces challenges in multiple dimensions, including technical, social, economic and environmental, see Figure 1.

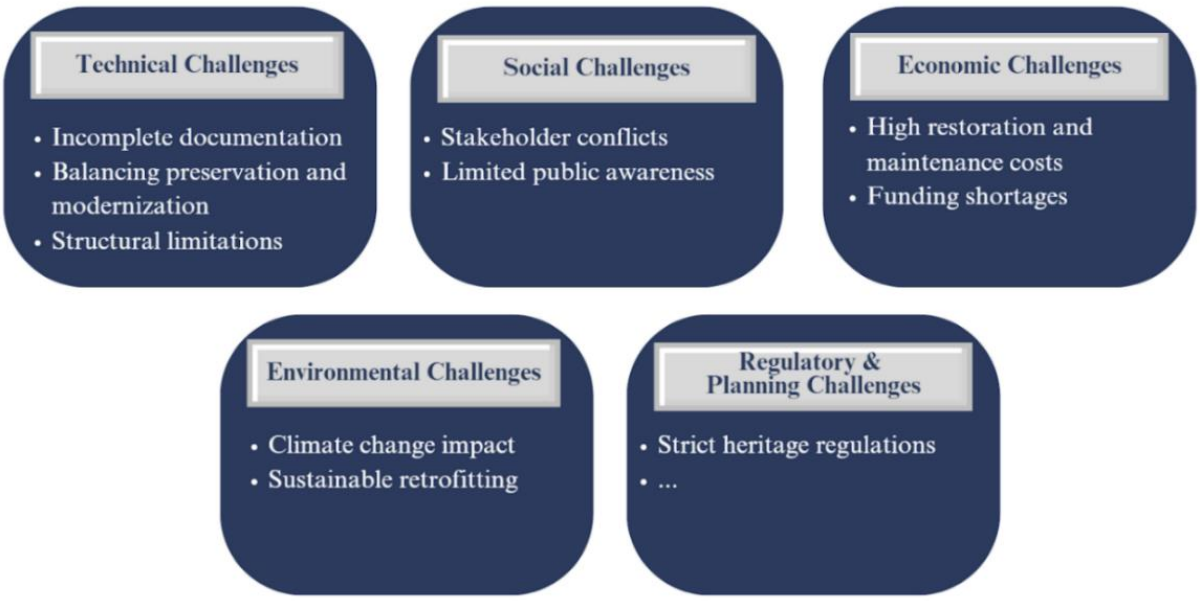

Figure 1. Multidimensional challenges in historic building renovation, compilated by author based on literature

On the technical level, many historic building renovations face inefficiencies, delays, and budget overruns due to the lack of information and missing documentation (Khan et al., 2022). The protection of historic buildings requires meeting modern functional requirements while maintaining the original structure and materials of the building, and this balance is often difficult (Koo et al., 2024). For example, many historic buildings lack space for modern heating, ventilation and air-conditioning systems, making it challenging to install these systems without destroying the integrity of the building. In addition, the structure of historic buildings may not be able to withstand the loads required for modern use, which requires structural reinforcement without affecting the historical value of the building (Arandelovic & Musil, 2023).

On the social level, a lack of public engagement and difficulties in coordination among stakeholders often hinder the delivery of protection processes (Penjor et al., 2024). Historical building conservation projects often involve multiple stakeholders, including government agencies, non-governmental organizations, local communities, and private owners, who may have different expectations and interests, leading to conflicts in the decision-making process (Angrisano et al., 2024). In addition, the public's lack of awareness of the importance of historical building conservation may lead to insufficient support for conservation efforts.

Economic challenges mainly include funding shortages and high maintenance costs. The restoration and maintenance of historical buildings is usually costly. In addition, the maintenance cost of historical buildings may be higher than that of modern buildings because special materials and technologies are required to maintain their historical authenticity (Panakaduwa et al., 2024).

With global climate change, the frequency and intensity of extreme weather events have increased, which poses a threat to the structure and materials of historical buildings. Changes in temperature and humidity may cause expansion and contraction of building materials, leading to structural problems (Cavalagli et al., 2019). In addition, climate change may also

lead to an increase in biological deterioration factors (such as fungi and insects), causing further damage to historical buildings. Environmental sustainability is receiving more consideration in order to sustain and lower the cost of renovations to older buildings, with particular tasks required to maintain energy efficiency while not compromising the historical integrity of the building (Panakaduwa et al., 2024).

In addition to the above, planning and regulatory requirements to ensure that the character and historical significance of the building are preserved may also pose challenges to the renovation of historic buildings (Arandelovic & Musil, 2023; Panakaduwa et al., 2024).

2.1.3 A Paradigm Shift from Static Protection to Dynamic Regeneration

Traditional historical building protection is mainly static protection, emphasizing the preservation of the original appearance of the building (ICOMOS, n.d.). However, with the development of society, simple static protection can no longer meet the needs of modern society. Historical building protection is transforming from static protection to dynamic regeneration, emphasizing the protection of historical values while giving buildings new functions and vitality (Heesom et al., 2021).

The field of historical building protection is undergoing profound changes from the evolution of protection principles and the establishment of an international framework, to systematic analysis of multi-dimensional challenges, and then to the paradigm shift from static protection to dynamic regeneration. These changes provide new ideas and methods for the sustainable protection and utilization of historical buildings.

2.2 Digitalization in the Construction Phase

The construction industry, traditionally characterized by low productivity and fragmented workflows, is undergoing a profound transformation driven by digitalization, but still remains one of the least digitized industries (Chen et al., 2024). However, the increasing complexity of construction projects, the growing demand for efficiency (quicker and cheaper), sustainability and collaboration, and advances in information technology have accelerated the industry's digital transformation. In the past decade, Industry 4.0 principles have further influenced the construction industry, integrating automation, real-time data analytics, cloud computing, and artificial intelligence (Oesterreich & Teuteberg, 2016; Wang et al., 2024). The transition from traditional paper-based processes to fully digital workflows is considered a critical driver for improving efficiency and sustainability in construction projects. However, digital adoption remains unbalanced across regions and project types (Oesterreich & Teuteberg, 2016).

2.2.1 Key Digital Technologies in Construction Phase

The construction phase of a project is highly dynamic and complex, requiring real-time coordination, decision-making, and resource management (Son, 2022). Digitalization in the construction phase is enabled by a variety of emerging technologies that improve efficiency (less time and high quality), collaboration, and project outcomes (Brozovsky et al., 2024). Today, more and more digital tools are being used in the construction industry, with more than 35 types (Brozovsky et al., 2024). Digital transformation of the construction industry is a way to reduce construction time, reduce waste of material, strengthen collaboration between different disciplines, and enhance quality control as well as safety and regulatory process

management (Wang et al., 2024). Table 2 lists the main digital technologies used nowadays in the construction stage.

Table 2. The main digital technologies in construction stage

Digital technology	Simple description
3D modelling	Use software to create digital representations of objects (Brozovsky et al., 2024)
Artificial Intelligence (AI) and Machine Learning (ML)	Computer intelligence based on training data (Brozovsky et al., 2024)
Building Information Modelling (BIM)	Detailed 3D computer model of the project that includes all information about the building and systems, also technical information, material and costs for construction, design, and maintenance purposes (Brozovsky et al., 2024)
Cloud technology	Store, share and process information and data (Brozovsky et al., 2024)
Digital twin	Digitally represent a physical asset based on big data (Brilakis et al., 2019)
Internet of Things (IoT)	Connect devices, materials and objects to a network which could enhance efficiency and precision (Brilakis et al., 2019)
Virtual Reality (VR) and Augmented Reality (AR)	Virtually visualize the progress of construction projects; view actual on-site status (Kwok & Chang, 2024)

2.2.2 Benefits of Digitalization in Construction Phase

Several studies have shown that the integration of digital technologies in the construction phase provides benefits to various stakeholders, including property owners, contractors, project managers, and design teams (Jahanger, 2024; Vaughan et al., 2013). It is often claimed that digitalization has the potential to improve efficiency, collaboration, and sustainability, which can lower costs and improve project quality (Oesterreich & Teuteberg, 2016; Prebanić & Vukomanović, 2021).

Study has shown that one of the advantages is improved project management and decision-making (Jahanger, 2024). Digital Construction Information Management (DCIM) systems provide real-time access to construction data, which allows property owners to better monitor progress, prepare for delays, and communicate with contractors (Jahanger, 2024). Digital systems reduce information silos and allow everyone to work with current relevant accesses.

For contractors, digital technologies have been noticed to optimize workflow coordination, cost control, and scheduling. Vaughan et al. (2013) found that digitalization helps contractors to manage materials, labor, and subcontractors better and decrease delays and waste. Additionally, digitalization can also help automate and use analytics for equipment distribution, risk

assessment, and productivity tracking, which provides project teams a way to improve the utilization of resources and reduce bottlenecks.

Another major benefit has been found is enhanced stakeholder engagement and communication. Prebanić and Vukomanović (2021) concluded that digital transformation improves stakeholder collaboration by enabling transparent information sharing, streamlining documentation processes, and reducing miscommunication. Cloud-based platforms, digital twin models, and collaborative BIM environments allow architects, engineers, and construction managers to work more cohesively, reducing design conflicts and ensuring that decisions are based on accurate data. Additionally, improved communication across project participants can promote trust, confidence, and create a stronger working relationship which will ultimately ensure project success.

From a security and risk management perspective, digitalization has been shown that it helps mitigate document ownership disputes, and decision-making challenges. Safa et al. (2019) found that digital technologies enhance data traceability, access control, and version tracking, ensuring that the right information is available to the right stakeholders at the right time.

Furthermore, digital adoption also improves safety and wellness of the workforce. Digitalized safety includes IoT-enabled sensors, wearables, and AI driven systems to monitor existing conditions on-site, which includes finding potential hazards, while also being able to alert workers to unsafe conditions (Oesterreich & Teuteberg, 2016). Digital safety training, including AR/VR simulations, allows workers to practice emergency responses in a controlled virtual environment, reducing the risk of accidents. Studies have shown that digital safety solutions lead to a decrease in workplace injuries and improved regulatory compliance (Oesterreich & Teuteberg, 2016).

Digitalization also plays a key role in sustainability and environmental impact reduction (Oesterreich & Teuteberg, 2016). BIM-driven material planning, waste tracking, and automated energy efficiency assessments help optimize resource use and minimize construction waste. Digital twin technology supports life cycle assessments, allowing for data-driven decisions on material reuse and sustainable construction techniques.

Table 3 shows the specific ways in which key stakeholders in the construction phase are affected by digital technology in terms of project management, process optimization, communication and collaboration, safety, sustainability, etc., highlighting the different values of digitalization for owners, contractors, and consulting teams.

Table 3. Benefits of using digitalization for key stakeholder groups during the construction phase, compilation based on the text reviewed

Benefit Category	**Property Owners**	**Contractors**	**Consultants (Engineers, Conservation Specialists, etc.)**
Project Management & Decision-Making	Real-time data for monitoring & decision-making	Progress tracking, delay anticipation, and process optimization	Improved planning accuracy and technical feasibility assessment
Workflow Optimization	Cost control & efficient budgeting	Automated scheduling, material tracking & resource allocation	Better integration with regulatory and engineering workflows
Stakeholder Communication	Improved coordination with different parties	Transparent communication with clients & subcontractors	Digital based technologies for collaboration and decision-making
Security & Risk Management	Document tracking & ownership clarity	Data handling & risk mitigation	Version control of project data & compliance tracking
Safety & Worker Well-being	Ensuring regulatory compliance & oversight	Hazard detection & safety monitoring	Safety training & site condition assessments
Sustainability & Environmental Impact	Life Cycle assessment & carbon footprint tracking	Waste reduction, energy-efficient workflows & material reuse	Sustainability analysis & conservation planning

2.2.3 Challenges and Barriers to Digitalization in Construction Phase

Despite the numerous advantages of digital technologies in the construction phase, many construction companies have yet to fully integrate these tools (Oesterreich & Teuteberg, 2016). One of the primary barriers is organizational resistance to change, which is common when new technologies require adjustments to existing workflows and processes (Oesterreich & Teuteberg, 2016). Fragmentation within the construction industry further complicates digital adoption, as said before, different stakeholders each prioritize their own objectives, making consensus on digital integration difficult (Alaloul et al., 2016).

Additionally, The cost of implementation, along with limited resources are also prohibitive factors in a firm's decision to adopt new technologies, especially among small and medium-sized enterprises (SMEs) (Chen et al., 2024). SMEs often lack the financial capacity, infrastructure, and technical expertise to support large-scale digital transformations. This challenge is exacerbated by unclear stakeholder benefits, inadequate knowledge management, and the long-term nature of digital investments, which require continuous maintenance and training (Oesterreich & Teuteberg, 2016).

Further challenges arise from the lack of standardized software, increasing technical demands of digital tools, and concerns over data security and privacy (Oesterreich & Teuteberg, 2016). Prolonged supply chains in construction projects mean that no single digital solution can address all existing inefficiencies (Kwok & Chang, 2024). In developing countries, digital adoption is further constrained by poor infrastructure, weak ICT-driven policies, and additional financial limitations for both clients and contractors (Ebekozien & Samsurijan, 2024).

Ultimately, while digitalization offers significant potential, addressing cost concerns, improving standardization, enhancing knowledge sharing, and ensuring clear stakeholder benefits are critical to overcoming these barriers and driving widespread adoption in the construction phase.

2.3 Digital Technology in Historic Building Renovation

Renovating historic buildings involves a combination of preservation requirements, structural constraints, and long-term maintenance responsibilities (Koo et al., 2024). The following discusses how digital technologies are being used and the challenges in historic renovation background.

2.3.1 Applications of Digital Technologies in Historic Building Renovation

Preserving heritage structures through advanced restoration techniques is essential for extending their lifespan (Hajirasouli et al., 2021). It is shown in the research that digital technologies provide significant advantages over traditional methods, improving documentation, monitoring, visualization, and condition assessments (Kivits & Furneaux, 2013). Digital models strengthen the potential for data integration and consistency in the management of information, leading to greater informed discussions about interventions, reuse of materials, and approaches to long-term operation. Studies have shown that these technologies facilitate mapping architectural components, managing spatial configurations, and tracking material conditions, supporting both conservationists and engineers (Volk et al., 2014).

Beyond documentation, digital technologies also contribute to energy efficiency improvements, predictive maintenance, and lifecycle management. Real-time monitoring can help demonstrate that it is possible properly retrofitting or upgrading the energy performance of heritage building systems and procedures while maintaining the values and principles of their architectural heritage (Volk et al., 2014). Predictive maintenance planning, supported by AI-driven diagnostics, helps identify structural weaknesses and plan interventions proactively (Edirisinghe et al., 2017). Additionally, as said before, digital platforms improve stakeholder collaboration, ensuring that architects, engineers, and heritage managers operate within a shared framework for data exchange and project coordination.

2.3.2 Challenges in Implementing Digital Technologies for Historic Renovation

Despite their potential, the adoption of digital technologies in historic renovations faces significant challenges related to organizational processes, technical limitations, and sector-wide constraints. Many heritage projects still rely on traditional workflows, and integrating digital tools requires overcoming both institutional resistance and skill gaps (Edirisinghe et al., 2017). There are challenges associated with the fragmentation of the construction industry in implementing a blended whole sector approach, as multiple stakeholders, including

conservation specialists, contractors, and engineers, often prioritize different objectives, making digital standardization difficult (Angrisano et al., 2024).

There are also limitations to the technology which include interoperability between digital platforms, modelling irregular or historically significant built forms, and affordability of scan and monitoring technology (Charlton et al., 2020). Unlike modern buildings, historic structures often lack detailed architectural records, requiring extensive data collection and validation before digital tools can be effectively applied (Charlton et al., 2020). Furthermore, the lack of standardized heritage data storage systems limits long-term knowledge management, making it difficult to track modifications over time (Lovell et al., 2023).

From an industry-wide perspective, budget constraints and limited investment in digital innovation remain major barriers to adoption. Many heritage institutions also prioritize conservation of elements instead of modernization leading to minimal implementation of digital-based workflows (Charlton et al., 2020). The heritage sector tends to have a conservative approach to technology, leading to a reliance on manual assessments rather than AI-driven diagnostics or automated monitoring (Charlton et al., 2020). Addressing these challenges will require greater institutional support, improved training programs, and clearer regulatory frameworks to encourage digital integration in historic building renovations.

2.4 Summary

In summary, despite the growing recognition of digital technologies in historic building renovation, their implementation during the construction phase remains inconsistent. While studies highlight the benefits of digital information management, real-time monitoring, and stakeholder collaboration, researches also underscore challenges related to adoption, communication inefficiencies, and decision-making under uncertainty. Existing literature largely focuses on pre-construction planning and post-renovation facility management, and how to solve the problems of reducing delays and cost control during the construction process, but there is still a gap in understanding how digital technologies influence on-site decision-making, coordination, and adoption choices during the construction phase.

To address this gap and analyze the factors more systematically, the next chapter introduces Technology Acceptance Model (TAM), which provides a framework for examining the adoption in the construction phase of historic renovation projects.

3. Theoretical Framework

In this section, Technology Acceptance Model (TAM) is presented as the theoretical framework, which provides a structured approach to understanding how users adopt digital technologies. Also, this section explains application of TAM to the present study, and discusses its limitations and necessary adaptations.

3.1 The Technology Acceptance Model

The Technology Acceptance Model (TAM) was proposed by Davis (1989) and has been widely recognized as a reliable model to evaluate the acceptance of information systems and technologies (Sepasgozar et al., 2021). The model suggests that adoption of a technology is based on two key perceptions: Perceived Usefulness (PU) and Perceived Ease of Use (PEU). PU refers to the extent to which someone believes that using the system will enhance their efficiency and productivity, while PEU describes the level of easiness someone perceives a certain technology has in terms of installation, learning, and operation without consuming too much effort (Okoro et al., 2023). In addition to PU and PEU, TAM incorporates external variables (EVs), which account for specific aspects of the technology or the context in which it is implemented. These external variables are assumed to indirectly influence user acceptance by shaping PU and PEU (Davis, 1989). Over time, TAM has evolved into extended versions, such as TAM2 and TAM3 with many more variables that could determine, which include additional factors influencing technology adoption. TAM2 expands the model by incorporating variables such as image, job relevance, output quality, and result demonstrability, while TAM3 further introduces factors affecting ease of use, including computer self-efficacy, perceived external control, computer anxiety, and perceived enjoyment (Sepasgozar et al., 2021). These extensions recognize that technology adoption is influenced by both functional and psychological factors, so the TAM has been used in many settings and many industries.

3.2 Application of TAM in This Study

Given its widespread use in information systems (IS) research, TAM provides an established framework for examining how users evaluate and adopt digital tools (Lin et al., 2011; Sepasgozar et al., 2021). In this study, TAM is applied to analyze stakeholders' decisions regarding digital technology adoption in the construction phase of historic building renovations. Since stakeholders in renovation projects (e.g., property owners, contractors, consultants, and preservation specialists) have different levels of familiarity with digital technologies, their acceptance of technology varies depending on their perception of its usefulness and ease of implementation.

The conceptual interpretation of this study is based on previous adaptations of TAM in construction-related contexts. In particular, this study draws on the work of Okoro et al. (2023), who tailored the TAM framework to the specific characteristics of construction project environments. In this study, Perceived Usefulness (PU) relates to whether stakeholders believe digital technologies enhance project efficiency, improve coordination, and support real-time decision-making. If stakeholders perceive digital twins, BIM-based collaboration, or real-time monitoring tools as improving construction outcomes, they are more likely to integrate them into renovation processes. Conversely, Perceived Ease of Use (PEU) focuses on concerns such as technical complexity, training requirements, and workflow disruptions. If a technology is

seen as difficult to learn, time-consuming to implement, or requiring significant adjustments in established work practices, resistance to adoption may increase.

Additionally, external variables (EVs) in this study include project-specific conditions, stakeholder roles, regulatory requirements, and financial constraints. For example, a project could be driven by the client requesting a digital twin requirement or by a government push to improve the use of BIM in heritage projects which may have a positive effect on stakeholders PU and drive the project team to continue using digital technologies during the project. Similarly, contractor experience with digital workflows, availability of training programs, and compatibility with existing systems can influence PEU. This study uses TAM in part, to consider what influences or limits digital adoption and hopefully lead to a better understanding of effectively integrating digital technologies in historic rehabilitation projects.

It is important to note that this study does not include the "Behavioral Intention to Use (BI)" component traditionally found in the original TAM framework (Okoro et al., 2023). The decision to exclude this from the research because it aims to focus on actual adoption and influencing perceptions, and implications in an ongoing construction context, rather than predict future behavioral intentions. The basic model for this study is shown in Figure 2.

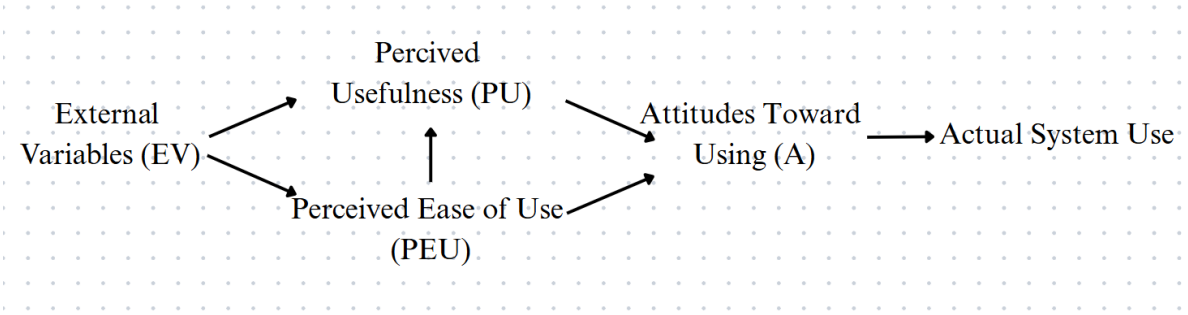

Figure 2. TAM for this study adapted from Okoro et al. (2023)

This study applies TAM as the theoretical framework to examine RQ1, which focuses on stakeholders' adoption and acceptance of digital technologies in historic renovation projects. While RQ2 does not directly emerge from TAM, it is theoretically linked to RQ1. It builds upon the findings from TAM-informed adoption analysis to explore the practical implications of digital technologies for communication, coordination, and decision-making. In this way, the second research question complements the first by translating adoption patterns into construction-phase outcomes.

While the original TAM framework usually analyzes the adoption of a single technology, this study applies the model to the broader perception of digital technologies used in the construction phase of historic building renovation. These include, but are not limited to, BIM, 3D scanning, and other site-based digital documentation tools. The application of TAM in this context aims to capture general stakeholder attitudes towards adopting integrated digital workflows, rather than a specific tool.

3.3 Limitations of TAM and Adaptations for This Study

While TAM has been widely used in multiple fields of study, many researchers have pointed several limitations in regards to using it. One major critique is that TAM primarily focuses on

external factors influencing PU and PEU, but does not sufficiently account for personal attitudes or the complex relationship between user attitude (UA) and intention to use the technology (Okoro et al., 2023). In many cases, self-reported data is used to measure technology acceptance, making the findings subjective and potentially unreliable (Liu et al., 2018). Additionally, the majority of TAM studies measure technology acceptance at a particular point in time, offering little illumination on how and/or if the user's perceptions change over time after extended use (Liu et al., 2018).

To minimize the impacts of the outlined limitations on the findings of this study, a structured research design is adopted. Rather than viewing technology adoption in separately, project presumption about use conditions must be considered. By clarifying whether digital adoption is mandated by project requirements or emerges as an internal optimization effort, the study ensures that TAM is applied within a well-defined project context rather than as a generic model.

Moreover, reflecting on either singular or individual stakeholder perspectives would be overly simplistic. Therefore, the study takes a cross-stakeholder view to highlight those particular stakeholders, be it contractors, property owners, consultants and specialists, may have their own ways of perceiving the understanding or use of digital technologies. By acknowledging these limitations and carefully defining the study’s context, presumptions, and stakeholder perspectives, TAM remains a valuable framework for analyzing how and why digital technologies are adopted in the construction phase of historic renovations.

4. Methodology

This section outlines the methodological approach used to investigate the adoption and impact of digital technologies in the construction phase of historic building renovations. Also, how to collect and analyze data, research quality and uncertainty, and ethical considerations will be explained.

4.1 Data Collection

Given the study's focus on stakeholder decisions, communication, and real-time problem-solving, a qualitative research design was chosen, which allows for an in-depth exploration of perceptions, motivations, and contextual factors (Saunders et al., 2023). A qualitative method is particularly well-suited for this study because digital technology adoption in heritage renovations is influenced by complex, context-specific factors rather than quantifiable metrics alone.

As Saunders et al. (2023) said, the explorative approach aims to explore the current state of the chosen research area. The exploratory approach is adopted as the limited existing research on digital adoption during the construction phase of historic building renovations. The exploratory nature of the study ensures that emerging themes, challenges, and best practices can be identified through both existing literature and industry insights. The data collection process consists of two primary methods: literature studies and semi-structured interviews.

4.1.1 Literature Studies

The study began with a thorough review of existing literature to inform the theoretical framework. This includes research on digital technology adoption in construction, heritage conservation, and stakeholder decision-making models such as the Technology Acceptance Model (TAM). Most literature was discovered using databases such as KTH Primo and Scopus. The search used keywords including "digital technology," "historic building renovation," "construction industry," "technology acceptance," and specific tools such as "BIM." A snowballing technique was also applied, tracing relevant references and citations from key publications. Peer-reviewed articles where prioritized in the search and updated literature from the past ten years, focusing on both foundational theories like the TAM and emerging applications of digital technologies in heritage conservation contexts.

The literature study was designed to achieve several key purposes. First, it identifies existing research gaps, allowing the study to refine its focus. Second, it helps establish a framework for understanding how digital technologies have been implemented in past projects. Last, the literature would inform a semi-structured interview guide by reporting on stakeholders' interview questions that were shaped by theoretical frameworks and the anticipated challenges brought about by the use of digital technologies in the industry. By synthesizing information from academic research, industry publications, and real-world case studies, the literature study creates a foundation for analyzing the findings from stakeholder interviews.

4.1.2 Semi-structured Interviews

Primary data was collected through semi-structured interviews with professionals involved in the construction phase of historic renovation projects.

The semi-structured interviews involved three main categories of groups: (1) respondents from public clients, (2) contractor involved in historic construction work, and (3) consultants and specialists in historic building renovation. All respondents were either currently involved in or had prior experience with the construction phase of historic building renovation projects.

The cases discussed spanned approximately six projects located in various Swedish cities, including Stockholm, Lund, and other municipalities, as well as two non-European projects. Several respondents were involved in more than one site and contributed perspectives shaped by different institutional environments and project scales. One prominent case in central Stockholm involved both client- and consultant-side respondents, allowing for multi-angled insight on a shared project.

The interview guide was developed using four primary parts. The first part included general open-ended questions of respondents as to their backgrounds and roles in historic renovation construction. The second part included questions on stakeholders' perceptions and acceptance level of digital technologies, which was based on the TAM. The third part discussed the implications of digital technologies use on communication, coordination, and decision-making. The final part invited respondents to offer their views, expectations, and recommendations related to the future use of digital technologies in historic renovation.

The general interview guide is included in Appendix 1. Minor adjustments to the guide were made depending on the professional role of the respondents. Table 4 provides an overview of the respondents, and their companies, and their role.

Table 4. The overview of respondents

Respondent	Company Type	Length	Date	Role
PC A	Public client	46 min	03/10/2025	Project Manager
PC B	Public client	47 min	15/04/2025	Project Manager
CT C	Contractor	57 min	19/04/2025	Production Manager
CS D	Consultancy	46 min	09/05/2025	Structural Engineer
CS E	Consultancy	37 min	04/03/2025	BIM Engineer
CS F	Consultancy	35 min	04/05/2025	Digital Consultant
HBPS G	Public client	43 min	22/01/2025	Historic building protection specialist

PC = Public client
CT = Contractor
CS = Consultant
HBPS = Historic building protection specialist

4.2 Data Analysis

All the interviews were recorded and transcribed for analysis. A thematic analysis was conducted to identify patterns in stakeholder perceptions, adoption barriers, and the perceived impact of digital technologies on historic renovation workflows. Then findings were compared

with existing literature to assess how real-world practices align with or differ from documented research. According to Saunders, et al. (2023) said, thematic analysis is commonly regarded as a comprehensive method for analyzing qualitative data. It enables researchers to systematically and logically interpret both large and small data sets. This approach not only provides a structured way to explore the research topic and guide respondents along key themes, but also remains flexible enough to uncover new insights and individually experienced barriers.

Following Braun and Clarke (2021), the study was analyzed as: (1) familiarization with the data by reading transcripts multiple times and noting initial impressions; (2) data coding; (3) identifying and grouping similar codes into preliminary themes; (4) creating and revising the themes; (5) detailed analysis of each theme. Also, it is necessary to adjust during the process, such as merge the similar ones and divide the large part. Table 5. shows an example of thematic analysis.

Table 5. An example of thematic analysis

Data	Code	Theme
"Most of our buildings don't bring income... we've always had a tight budget…"	Financial limitation, public ownership constraints, Limited digital investment	External Variables: Resources constraints

4.3 Reliability and Validity

It is important to establish clear reliability and validity when conducting qualitative research to ensure credible and meaningful findings. In this study, reliability refers to the consistency and dependability of the research process, while validity relates to the accuracy and relevance of the data in addressing the research objectives (Saunders et al., 2023). There were steps taken to ensure transparent, reduce bias and provide trustworthiness to the findings.

Reliability was enhanced by using a systematic approach to the selection of the literature, and in undertaking interviews. The literature review was based on journal articles, industry reports, and authoritative policy documents, ensuring that sources were credible and relevant to the study. In the interview, a semi-structured format was used to maintain consistency across discussions while allowing for flexibility in responses. An interview guide was developed to ensure that all respondents addressed key themes, while allowing space for spontaneous insights and context-specific discussions. Additionally, interviews were recorded and transcribed, reducing the risk of misinterpretation and ensuring an accurate representation of respondents' perspectives.

For validity, findings from literature, interviews were compared to identify recurring patterns and discrepancies. Also, researcher reflexivity was maintained throughout the study by acknowledging potential biases and preconceptions, particularly in interpreting stakeholder perceptions of digital technology adoption.

This allows future studies or practitioners in similar renovation projects to assess the applicability of the findings in their own contexts.

4.4 Ethical Considerations

This study considered a number of ethical issues in order to enhance the credibility of the research and treated respondents and those involved in the historic buildings with respect. Informed consents were obtained from all stakeholders, as emphasized by Saunders et al. (2023), ensuring they understand the purpose of the research and how their data would be used. Privacy and data protection are critical, particularly with sensitive data and stakeholder information, which were anonymized and securely stored. Eldh et al. (2020) emphasize the importance of proper quotations, and all contributions from respondents and external data sources were clearly cited to ensure transparency and accountability. Additionally, it is significant that all stakeholder perspectives were equally considered.

The research used AI tools to help with transcribing, improve translations of some responses to English and check for grammatical issues.

4.5 Limitations

This study is based on a relatively small number of semi-structured interviews, which limits the extent of perspectives across different project types and organizational structures. However, due to the exploratory and in-depth nature of the research, the selected respondents represent diverse stakeholder roles and offer detailed insights grounded in real project experience. Although only one contractor was interviewed, his involvement in multiple historic renovation projects provided a wider project-based perspective that helps reduce potential bias from having a single contractor viewpoint. The purpose of this research is not to generalize across all contexts but to understand underlying patterns and challenges in the adoption of digital technologies during the construction phase of historic building renovation. Therefore, the limited sample size doesn’t have a negative impact on the validity or relevance of the research findings. Two of the respondents were based outside of Sweden and contributed perspectives from a different regulatory and institutional context. While these viewpoints reflect varying national settings, the focus of this study remains on the construction-phase experience of historic building renovation. All responses were analyzed in relation to the respondent's project involvement and role, rather than their geographic or cultural background. Therefore, their inclusion does not compromise the validity or thematic consistency of the findings.

5. Findings

This part presents the key findings from the semi-structured interviews with stakeholders involved in the construction phase of historic building renovation projects. The results are structured according to the research questions, focusing on stakeholders' adoption and acceptance of digital technologies and the implications of such adoption for communication, coordination, and real-time decision-making. Distinctions between clients, contractors, consultants and other stakeholders are highlighted to show different perspectives across stakeholder groups.

5.1 Stakeholders' Adoption and Acceptance of Digital Technologies

The adoption and acceptance of digital technologies among stakeholders involved in the construction phase of historic building renovation projects varies based on their roles, organizational context, and project demands. As explained in the theoretical framework, this study focuses on broader perceptions of digital technologies rather than evaluating a single platform or software, but respondents referenced a range of digital tools in their responses. These included BIM, 3D scanning, digital maps, collaborative platforms for communication and document sharing, and integrated databases. In several cases, comprehensive platforms combined multiple functionalities, such as BIM, 3D scanning, structural tracking, progress tracking, issue resolution, and visual inspection. An overview of the types of projects and examples of digital technologies they mentioned through the interviews are shown in Table 6.

Table 6. Overview of types of projects and examples of digital technologies mentioned in the interviews

Respondent	Type of project	Digital technology respondents referred to
PC A	Industry building (Large-scale Refurbishment)	Digital platform combining multiple functionalities.
PC B	Theater (Large-scale Refurbishment) Theater (Local Refurbishment)	Digital platform combining multiple functionalities, 3D scanning, Virtual Reality, Cloud technology, etc.
CT C	School and several other types of projects (Large-scale Refurbishment)	Digital platform combining multiple functionalities, Digital platform for reuse materials, 3D scanning, Virtual Reality, etc.
CS D	Theater, commercial, school and other types of projects (Large-scale Refurbishment)	Digital platform combining multiple functionalities, BIM, Cloud technology, etc.
CS E	Several projects (Large-scale Refurbishment)	BIM, Digital platform combining multiple functionalities, etc.
CS F	Museum (Large-scale Refurbishment)	BIM, IoT.
HBPS G	Museum, office and many other types of projects (Both Large-scale Refurbishment and Local Refurbishment)	BIM

The following sections present stakeholder-specific findings according to the Technology Acceptance Model (TAM), covering perceived usefulness, perceived ease of use, and relevant external factors.

5.1.1 Perceived Usefulness

Perceived usefulness in this study refers to the extent to which stakeholders believe digital technologies improve their performance or help achieve project goals.

Client Perspectives

All the interviewed public clients agreed that digital technologies provided transparency, coordination, and heritage protection during the construction phase of renovation projects. Respondents viewed tools like Building Information Modeling (BIM), 3D scanning, digital mapping, and integrated platforms were enabling clients to follow site activities with less reliance on physical inspections. As PC A explained, *"it became easy to follow up (through the digital platform) … Each task, you can block it off,"* to highlight how structured systems made inspection simpler.

Both PC A and PC B agreed that digital technologies like BIM and platforms provided the potential to track problems and act upon them earlier in the process. Clients were able to intervene more quickly and reduce the likelihood of heritage loss by visualizing site conditions and deviations from the original plan. In PC B's words, *"If there is a deviation, the contractor prepares to do something not entirely according to the plan… this way we can assess and intervene before work continues."* The ability to evaluate options before irreversible work was carried out was seen as a major benefit in projects involving protected materials or limited access.

In addition to recognition of short-term control, the value of digital technologies and specifically short-term for longer term management, whether it is the GIS data or the 3D scans and 360-degree photos or inventory databases journalists used to get onboard and share knowledge throughout project phases. These functions were specifically marketed to larger, multi-year projects with multiple stakeholders. *"We think we will have so much out of the digital that it will cost less in the end",* PC B said, in relation to opportunities to create future maintenance that is more stream lined, along with reuse of documented information.

However, both respondents pointed out that these systems must be used in the same way by everyone to realize their full value. If contractors do not update models or respond through designated platforms as instructed, the benefits of traceability and coordination were wasted in practice. As PC A noted, *"A tool is just a tool. Its usefulness depends on how well it's used… it depends on who you are working with."* This comment could be observed to more closely agree with as exploration of a broader issue, that underpins the success of the systems in relation to the provider's digital maturity and the participation of everyone involved.

To summarize, for interviewed clients, digital technologies mentioned above were perceived as highly useful when properly maintained and integrated into site operations.

Contractor Perspectives

The interviewed contractor offered a much more operational view of usefulness, and during the production phase, perceived usefulness is closely related to operational efficiency (quicker and cheaper), traceability, and problem-solving in the construction stage.

Digital technologies like systems or platforms were viewed as especially useful in managing subcontractors, tracking progress, and ensuring accurate documentation of tasks completed outside the original scope of work. As CT C explained, *"You can have maybe 5,000 tasks extra… and even still be able to go back in time and check everything, who ordered them, who did them, and what the impact was"*, which was seen as critical in controlling costs, managing claims, and reducing disputes.

The interviewed contractor also emphasized that digital records provided a form of protection against future disagreements with clients or consultants. Documentation of communication, approvals, and delivery milestones allowed contractors to demonstrate accountability. As CT C said, *"We have everything written, everything is recorded… In case of problems in the future, you just go back and find everything recorded. It's very easy and beneficial actually."*

However, the interviewed contractor also emphasized that the perceived usefulness greatly depended on the simplicity and speed of accessing information, for example, if the tools were too slow or disconnected from site realities, they were perceived as burdens rather than aids.

Consultant/Specialist Perspectives

Interviewed consultants and specialists showed strong adoption of digital technology during the construction phase when those technologies clearly supported project-specific goals, especially in managing uncertainty, preserving historical materials, and improving precision in complex environments.

For them, perceived usefulness was often linked to the ability of digital technology to provide technical clarity and reduce irreversible damage in heritage-sensitive areas. For example, one consultant provided an example with digital paint layer overlays where they were able to evaluate and select which surfaces needed to be protected prior to removing beams, in a way that traditional documentation would never have made this evaluation in advance. As CS F said, this approach *"allowed the historic specialists to 'predict' where sanding might cause damage",* and prevented unnecessary loss of original materials. Also, CS D described how they had conducted structural investigating in a digitized way. They had directly linked the investigations into the project model. This meant that all design decisions were referencing the most up-to-date contextual and site-specific data, thus potentially minimizing technical errors in the construction phase of the project: *"...you can put in and you've tested it, and then you could put in a comment or anything..., which that wall can take this kind of load. "*

According to the respondents, the value of digital technology was not immediately recognized at the start. Consultants had to demonstrate, often through simulations or side-by-side comparisons, how these technologies could reduce errors, avoid rework, or support with maintenance planning. As CS D described how they were able to show a client a visualization of a structural deformation that would occur if they do not deal with a beam that was damaged. The client initially resisted, but the simulation convinced them to revise their repair strategy. As CS F said, *"The turning point was when they saw the digital model predict long-term impact."*

They also mentioned that usefulness was defined not only by technical accuracy, but by whether digital processes helped align construction decisions with heritage protection principles. As HBPS G emphasized, *"The question is not whether the model works, but whether the repaired object can still be accepted and reintegrated into its historical setting."* For many specialists,

the use of digital technologies was considered meaningful only when it supported the accurate preservation of historical character, by enabling informed decisions that respected original materials and contexts, rather than introducing changes that could compromise the building's authenticity.

5.1.2 Perceived Ease of Use

Perceived ease of use is understood here as how intuitively stakeholders can integrate digital technologies into their daily construction workflows.

Client Perspectives

Despite the complexity of their large-scale renovation projects, PC A reported relatively little resistance from stakeholders when adopting digital technologies. Most of this acceptance stemmed from the integrated workflows structured in the digital system. By integrating all project communications and documentation into a single interface with consistent practices, users relied on repetition and structure to reinforce practice. *"If something was unclear, we could trace back everything in one place… That makes it easier, especially over time",* said PC A. While not everyone was digitally advanced, the team could maintain a shared understanding without relying on external tools or extensive manual follow-up.

However, PC B shared a less balanced experience with perceived ease of use, which is primarily due to different levels of digital knowledge across different internal roles. Architecture and design stakeholders adjusted quickly, because they were used to similar modeling tools to the BIM software being used, but project managers, administrators, and heritage consultants tended to require more support and training than their more digitally advanced teammates. *"Almost everyone is very interested. But I won't do that more confident in the technology. And among all our other authorities and company managers and so on. It's more on a person-based interest. And I don't think that everyone is going to use it",* admitted PC B, highlighting generational and experiential gaps within their internal teams.

PC B also acknowledged that ease of use could indirectly relate to the level of digital competence of contractors. While the digital technology itself had high functionality, perceived ease of use at the project level relates directly to whether contractors and collaborators were engaging with it, and when contractors were not frequently updating documents or models, the utility and ease-of-use collapsed.

For the interviewed clients, the perceived ease of use is less about their personal interaction with digital systems and more about the overall digital standardization and participation across stakeholders.

Contractor Perspectives

According to the interview with CT C, the general attitude toward digital technologies usability among contractors was positive, particularly among younger staff or who previously experience. The interviewed contractor expressed that the systems on the site were often easy to use, and were not technically difficult to handle. CT C pointed out, *"I've never had any problem with those programs",* and highlighted that even with teams with mixed experience (senior engineers that are less used to digital workflows will sometimes still avoid or delay responding) that were actually still able to just get the informal peer support on site quickly with any minor problems.

However, usability was not universal. The interviewed contractor observed that some senior engineers were not that comfortable with to digital workflows and might avoid or delay responses, especially when some technologies like platforms replaced more familiar communication methods, such as to call someone directly instead. *"Some people just say they missed the notification",* CT C noted, suggesting that behavioral factors, more than technical ones, can still affect digital technology's adoption. Nevertheless, when the technologies enabled real-time tracking, photo documentation, and clear task assignments, even skeptical users tended to recognize their value over time.

Importantly, the use of checking drawings through mobile devices (e.g., iPads) on-site was reported as a major improvement compared to paper-based methods, as they had access to updated drawings and task lists much more quickly, and did not have to carry around paper copies, which allowed contractors to *"just go around with an iPad and check the drawings here instead."* This shift was not only more efficient but also seen as environmentally preferable.

Consultant/Specialist Perspectives

The situation around ease of use was more complex for the interviewed consultants and specialist. Interviewed consultants possessed competent digital literacy, but when using the technologies in practice on-site the expectation was to simplify them into a physical version. Consultants are not encouraged to engage all workers with models directly, they were looking for hybrids such as a printed 3D visual representation with notes or daily updates on a mobile device. These changes reduce barriers for people who are not familiar with digital technologies.

While digital maturity is often assumed to vary by age like CT C said, CS D emphasized that openness to new working methods was more important. Some professionals at one company were both younger and familiar with model based work while some older professionals were willing to accept new working practices because they clearly communicated what, was changing, why, and how. *"I thought this was like an age thing... but now I see it's more of a state of mind."*

Ease of use also depended on how well the technologies or tools matched actual workflows. Interviewed consultants found that when digital technology helped to mitigate repeat works, such as linking model components to progress forms, teams were more likely to use them. However, there was still some resistance, because some professionals were more comfortable using traditional formats. As CS E noted, *"They expect PDFs, not databases",* which reflects the slow cultural shift required in moving from document-based habits to data-driven environments.

The perceived ease of use is an obvious point by most of the respondents, but is also hindered by technical complexity, data integration challenges, and ambiguous status of vague sector standards in the heritage sector.

5.1.3 External Variables

External variables played a decisive role in shaping the adoption of digital technologies during the construction phase of historic building renovation projects. These factors are found as followed.

Client Perspectives

One major driver was the use of contracts to formalize digital processes from the beginning. In some cases, this was inherent in the procurement process, and left little scope for deviation. As PC A explained, *"We decided from the beginning. If it's in the contract, then it's no problem",* specifically referring to the client-side decision to include mandatory use of digital technology in the initial contract with contractors, which indicated that formal requirements fostered compliance and enabled smoother onboarding. In some of the other projects, digitalization was not mandatory, and instead encouraged through internal initiatives that were aligned to longer-term modernization trajectories. However, without clear obligations, the pace of adoption varied, often depending on individual project teams and their motivation and capacity.

The historic renovation complexity itself was another strong external influence. Compared to routine construction projects, historic buildings often require more detailed planning, stricter documentation, and closer monitoring. One respondent noted, *"This type of building is not something we usually work with... we needed a more detailed system to manage it",* also emphasizing it is scale and uniqueness making a digital system more essential. In such cases, digital adoption was not just about finish something quicker and faster, but also about ensuring compliance with preservation standards and maintaining accurate records for future maintenance and public accountability. But clients also pointed out that digital technology itself is not enough, it also needs to be combined with personal on-site assessment: *"several challenges could hinder digital integration, which often require on-site assessments instead of relying solely on pre-modeled data."*

Decisions were further embedded in institutional context. In some organizations, digital documentation had been limited in the past due to financial constraints and the non-commercial nature of many historic assets. As one client said, *"Most of our buildings don't bring income... we've always had a tight budget…",* which reflected the perceived return on investment affected technology planning.

Moreover, generational gaps and differences of digital competency level across teams also presented barriers. *"...We haven't had the knowledge or capability…",* another CS Explained, adding that the transition depended heavily on education and internal leadership.

Overall, for clients, external variables such as contractual structures, organizational policies, project complexity, and resource availability are key to whether and how digital technologies are accepted and adopted. In terms of motivations across client organizations, there was a strong emergent consensus from those interviewed regarding a need for these technologies anywhere where clients and workers are faced with the unknown complexities collectively posed by the historic renovations.

Contractor Perspectives

Similar to the clients' perception, the interviewed contractor acknowledged that digital technologies were often mandated through their contracts. CT C emphasized that the decision to adopt digital technologies and the specific systems used was almost always made by the client. *"It's usually the customer who decides... what kind of tools we will be using in the project."* This means that contractors must adapt to many alternate digital environments across

projects, which are sometimes more well standardized than others, but cannot control the select the platforms they will use.

It is shown that in certain instances the budget also played an important role. The interviewed contractor acknowledged that digital technologies can save money in the long term, but *"the investment might not be efficient for smaller projects",* especially if the client is not willing to support the cost. *"Contractors often operate in a highly competitive bidding environment, it is rarely to have the ability to propose digital innovations independently without risking price disadvantages",* as CT C said.

Furthermore, the interviewed contractor did indicate that the historical buildings can also add a layer external complexity. In many cases, they often lacked reliable original documentation, or certain materials or conditions could not be identified until after demolition or exposure. This meant that full integration with digital models was sometimes limited if everything could not be modeled due to unforeseen circumstances of the historic structures. *"You don't usually know all the products that are inside the walls",* CT C said, while illustrating the limits of modeling in a heritage context.

Despite these constraints, the interviewed contractor expressed a positive attitude toward long-term digital adoption, especially if they could reuse data from prior projects. There was strong recognition that digital records help retain project knowledge across time and teams, which is particularly valuable in renovations where similar buildings may be addressed in the future.

Consultant/Specialist Perspectives

As with other stakeholder groups, consultants noted that several external conditions, particularly government regulations, played a prominent role when it comes to encouraging digital adoption, particularly in historic/heritage projects. In relation to the different external conditions, several consultants attributed a stronger immediate push towards adoption from government agencies that demanded full digital documentation for reasons of transparency, archival purposes, and future maintenance. However, interviewed consultants also pointed that successful implementation was about embedding the policies into the ongoing projects daily needs. As CS F explained, *"Just doing it for submission (to comply with contractual or regulatory requirements) isn't enough. We used the documentation to serve future repair and risk assessment."* In other words, external need created the trigger for adoption, but meaningful use based on internal motivation and discussed or felt benefits.

Project size, complexity, and budget were also seen as key factors influencing the adoption of digital technologies according to the interviewed consultants. CS D mentioned that smaller projects often rely on traditional documentation, as the cost of digital setup it made substantially more difficult to justify. Larger projects, on the other hand, usually benefit from digital technologies due to their complexity and longer timelines. *"In smaller projects, it's easier and more efficient to do it the traditional way… But if the project is big, you can see that you will win it back."* Consultants discussed the importance, relevance and effectiveness of the digital model in larger or more complex buildings, especially when they are composed of mixed materials or are structurally irregular. Likewise, smaller or simpler buildings are unlikely to find sufficient value in the integration of fully developed digital systems. *"Not all sites need full BIM or 3D systems",* said one consultant.

It is worth mentioning that cultural expectations around heritage also shaped the role of digital technology in those projects. HBPS G emphasized the need to consider that technology should always remain secondary to meaning when dealing with heritage conservation. He posed questions such as, *"Will this intervention, once completed, be accepted by the community as part of the original?"* This reflects a broader view that successful digital adoption is not just about faster and cheaper, but respecting and being informed about the past.

5.1.4 Summary

The results from this analysis illustrate the ways in which the stakeholders interviewed incorporate and embrace digital technologies while engaged in the construction activities in renovation projects for historic buildings. The analysis based on the TAM framework shows that perceived usefulness and perceived ease of use can be influenced by a number of external variables, including contractual driven, project complexity, heritage demands, resource constraints, and organizational practices etc. These factors influence stakeholder attitudes and ultimately affect the actual use of digital systems on site.

Figure 3 summarizes these relationships, illustrating how external conditions interact with stakeholder perceptions to shape digital adoption outcomes. The model is adapted from Okoro et al. (2023) and tailored to the specific context of this study.

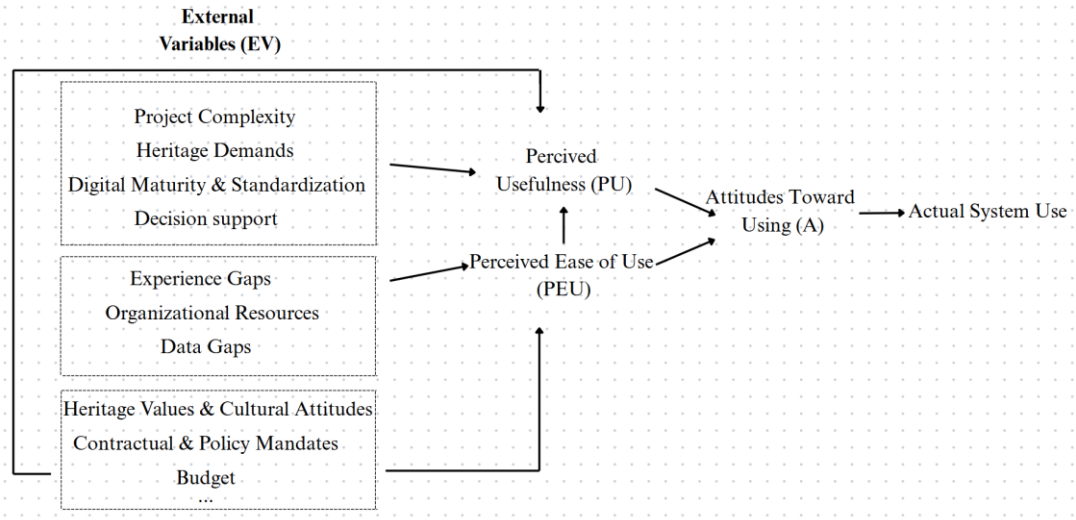

Figure 3. Adapted TAM in the construction phase of historic building renovation, based on Okoro et al. (2023)

5.2 Implications of Digital Technology Adoption

While the previous section examined the factors that influence stakeholders' adoption of digital technologies, this section focuses on the implications of their use during the construction phase. The analysis explores how digital technologies affect communication structures, stakeholder coordination, and the quality of real-time decision-making in complex historic renovation projects. Rather than analyzing motivations, this section highlights the operational and collaborative outcomes that emerge once these technologies are in place.

5.2.1 Client Perspectives

From the perspective of the interviewed clients, digital technologies were mainly identified as streamlining communication structures, coordination structures and the overall quality of real-time decision-making that occurred during renovations of complicated historic buildings, especially in multi-stakeholder environments where transparency, control, and traceability were required.

Visual Feedback

One of the most recognized advantages was the visibility and clarity that were being added during the ongoing communication. Consider visual communication features such as color-coded task feature indicators, and workflow-integrated documentation, allowed the client to keep track of things without always having to be there. As PC A said, *"You can see what's done and what still needs to be signed off… everything is visible, even photos and measurements."* It showed that descriptions and real time feedback really enabled an informed and timely decision.

Communication Structure and Control

In addition to visual feedback, digital technologies contributed to structured communication flows, which were especially important in managing large consultant and contractor networks. Clients were able to define whether the communication was to go through a hierarchy (for example, providing all consultant responses through internal review before the contractor saw it), and this ensured cohesiveness subordinate to project interests and mostly consistent messages. As PC A explained, *"We always read what the consultants write before it's passed on. If we need to change it, we do."* Through this process control, clients can maintain a coherent communication across parties and minimize the risk of miscommunication.

Traceability and Accountability

Digital technology also strengthened accountability with detailed records of technical questions, design changes, and administrative actions. Clients emphasized that having a single, searchable environment reduced reliance on informal communication and reduced the possibility of forgetting something. One respondent mentioned, *"You don't want to rely on memory or email threads… Everything we said is there, and you can go back and check."* This traceability was valuable for clarifying disputes or when examining previous decisions

Quality Control and Acceptance Process

Real-time monitoring and quality control were additional areas where digital technologies had a meaningful impact. Through structured digital platforms, all inspections, sign-offs, and compliance checks could be logged, verified, and referenced at later stages. As one client described, *"We could see every check, every approval… It's all there when we need to verify it."* It was particularly useful for ensuring that heritage protection standards were obeyed across various construction phases.

Remote Collaboration and Limited On-site Access

When physical access to the building was limited, some due to ongoing public use or preservation concerns, digital technology offered an effective alternative for remote coordination. Digital models in the form of high-resolution scans, and over-recorded interactive versions, allowed teams to comprehend spatial conditions and responses to the project without introducing the need for site visits. As PC B noted, *"We couldn't always enter the building, but with the digital walk-through, we knew what was happening."*

Decision Support

Finally, digital technology supported decision making regarding historical materials, allowing teams to document, track, and manage sensitive components with accuracy. These systems ensured that decisions related to removal, reuse, or conservation were made based on full historical and regulatory context, thus improving accountability and reducing the risk of accidental loss or non-compliance.

In summary, from the clients' point of view, the advantages of digital technology extended far beyond data storage or general productivity improvements. They enabled clarity, control, and collaboration in a highly complex and regulated project environment. More importantly, they helped create a shared digital memory of the project, which promoted the day-to-day coordination, as well as long-term governance of historic assets.

5.2.2 Contractor Perspectives

Streamlined Problem Resolution and Daily Communication

For the interviewed contractor, digital technologies provided the greatest changes to how they communicated and coordinated onsite. One of the clearest impacts was greater clarity when communicating with their clients and subcontractors, particularly when reacting to the unplanned. In complex restoration environments, the interviewed contractor mentioned that they often faced daily surprises, from undocumented structural elements to unplanned technical requirements. Digital technologies provided a means to document these situations instantly and share them with the relevant actors for input or approval.

The interviewed contractor described how they handled problems by sending out marked-up drawings and photos to specific people responsible for resolving them. *"...when I do that, they will get a notification. And when they solve the problem, they can take a picture and send it to me, and then I have to accept it."* This approach not only streamlined daily communication but also helped maintain accountability, as all actions were tracked and connected to specific actors.

Inclusive Decision-Making across Stakeholders

The ability to involve multiple parties, such as conservation consultants, designers, and clients, in the decision-making process was also seen as a major benefit. In historic building renovation, contractors cannot act independently as decisions often require coordination across institutions. *"Using digital, you can ensure that all the interests of the building are involved in the important decisions",* said CT C. This approach of inclusiveness allowed them to achieve a balance between technical practicality and historical sensitivity and less risk of inadvertent change or omissions.

Health, Safety, and Environmental Risk Management

As CT C pointed out, digital technologies were also useful in managing health, safety, and environmental risks during the construction phase. When potentially hazardous materials were suspected, consultants could mark specific locations and attach test results directly within the digital system. In addition, digital documentation contributed to environmentally informed decision-making. For example, material databases would allow the team to track the environmental performance of products used on-site. As CT C noted, *"Like for environment..., we have all the materials that have been used in this project, if it's not that good environmentally, then we have to try to figure out if there is anything else that we can use instead",* which enabled them to make more intentional replacements, supported their sustainable materials when carrying out the capital works, and kept track of the products they used.

5.2.3 Consultants/Specialist Perspectives

Shared Visual Language

For the interviewed consultants and historic building protection specialist, the adoption of digital technologies in the construction phase brought both operational benefits and deeper collaborative shifts in how decisions were made and communicated across disciplines. While some experiences were similar to those of the interviewed clients and the interviewed contractor, consultants also highlighted how digital technology bridged expert divides, and supported heritage-specific judgment processes.

Visualized Decision Support

One of the biggest changes was the emergence of a shared visual language that enabled all stakeholders to engage with the same complex situation. As CS F said, *"We were not just exchanging messages, we were all looking at the same model, the same beam, and discussing whether to keep it or replace it."* The opportunity to collaboratively engage with a visual object was particularly significant when the consultants were evaluating whether they could continue to meet their structural concerns and conservation objectives, particularly when physical access was limited, for instance, in cases of fragile elements.

Heritage-Specific Reflection and Judgment

Consultants highlighted how digital technologies provided a new way of engaging in detailed decisions that ultimately connected with exploratory alternatives that would have been difficult to assess. HBPS G reflected, *"It's not about choosing the fastest way. It's about understanding what each choice means for the building's story."*

However, limitations were also recognized. One was the continued reliance on consultants as "digital translators", those who processed model data, created visuals, and maintained information flows. CS E noted, *"...the opportunities are endless, but that requires that they can describe we need this information for this purpose at this time, in this file format and in this structure…"* Another limitation was the challenge of balancing real-time decision-making with the slower pace of heritage reflection. As HBPS G reminded, *"Fast decisions aren't always better, some require space to reflect, especially when dealing with irreversible change."*

5.2.4 Summary

To better understand how digital technologies shape stakeholder practices during the construction phase of historic building renovation, Table 7 presents a comparative matrix that summarizes key implications from the perspectives of the interviewed clients, contractor, and consultants/specialist. The table illustrates how each stakeholder group interprets and applies digital technologies in response to these constraints, revealing not only points of similarities (e.g., traceability, remote coordination) but also role-specific functions, such as consultants' interpretive mediation or clients' institutional control. The comparative format helps clarify how digital practices in historic background are shaped as much by regulatory, spatial, and material complexity as by technological capacity.

Table 7. Comparative Matrix of Digital Technology Use During Historic Building Renovation

	Client	**Contractor**	**Consultant / Specialist**
Real-time Communication & Feedback	Structured messaging and controlled communication chains	Used annotated photos/drawings/models to report issues and track responses	Used models to create shared discussion
Decision-making under Uncertainty	Visualized options before irreversible decisions	Coordinated quick decisions on unexpected site conditions	Simulated heritage/structural-sensitive alternatives
Coordination in Complex Teams	Controlled info flow through internal reviews	Ensured input from clients and consultants via digital platforms quickly	Translated between disciplines and digital formats
Accountability & Traceability	Archived all interactions; accessible records	Logged site actions and changes for dispute prevention and record-keeping	Visual logs helped justify heritage interventions
Heritage-specific Risk Management	Used digital walk-throughs when site entry restricted	Consulted specialists remotely when hazardous areas found	Balanced conservation vs. structural needs visually
Access Limitations (Legal/Physical)	Digital support acknowledged but field inspection remained essential	Shared conditions visually when real-time access was impossible	Assessed site state remotely, advised based on virtual representation
Limitations	Acknowledged need for field validation beyond models	Not all hidden conditions could be captured; on-site expertise remained essential	Cautioned against over-reliance on digital speed for complex heritage contexts

In summary, the integration of digital technologies during the construction phase of historic renovation projects brought tangible effects on project execution. These technologies supported clearer communication, more structured coordination processes, and better-informed decisions

in time-sensitive and heritage-sensitive scenarios. While adoption itself was shaped by multiple internal and external factors, the actual implications were reflected in improved clarity, traceability, and responsiveness across stakeholder groups.

6. Discussion

In this section, the findings will be compared with the literature study, the reflection and future research suggestions will be presented as well.

Although the stakeholders indicated that they used different digital technologies and tools depending on their organizational preferences and specific project setups, their reflections had clear similarities. In spite of the different digital technologies used, there were consistent themes around improved coordination, traceability and heritage-informed decision-making emerging from their reflections.

6.1 Stakeholder Adoption and Acceptance of Digital Technologies

6.1.1 Perceived Usefulness

The literature has consistently emphasized that digital technologies facilitate documentation and data integration, monitoring, visualization, and assessing conditions (Kivits & Furneaux, 2013). This was a good alignment with public clients' perception of the value of digital technologies. Clients highlighted that visual feedback, such as measuring progress through tracking and use of photographs documented how they could respond earlier of mitigate risk of irreversible mistakes. However, the usefulness was not simply embedded in the technology itself but emerged from how systematically the technologies were applied. Edirisinghe et al. (2017) recognized the positive role of digital systems in improving heritage preservation workflows. This study contributed the qualification that these positive roles come with a stipulation that models be continuously updated and transparently engaged with by stakeholders, their digital systems showed as PC A mentioned, *"everything is visible, even photos and measurements"* if it is properly updated.

The interviewed contractor had a similar view of usefulness. While much of the literature on BIM related to construction discussion focuses on long-term benefits of lifecycle data integration (Volk et al., 2014), the interviewed contractor in this study demonstrated that they also placed emphasis on short-term value of functionality. For a contractor, the activity of digitally documenting extra tasks, confirming orders, and defending against disputes enhanced project work. Usefulness here is more about protection, control, and documentation under conditions of risk. Compared to clients, contractors are typically responsible for short-term execution rather than long-term ownership. Their focus on immediate, actionable benefits reflects this role. The digital technology with low cost and limited risk of exposure provided assurances for managing costs, accountability, and complexity at site.

For consultants and specialists perceived usefulness was directly relative to leveraged tasks and consequential risk of irreversible damage within historic environments, which is consistent with Charlton et al. (2020). The position of digital outputs to historical authenticity brought clarifying positions on attributable usefulness, *"whether the repaired object can still be reintegrated",* which illustrates more situated usefulness in historic contexts.

In summary, the perceived usefulness of digital technology is not embedded in the tools or technologies themselves, it is the demonstration and participation of their use by different actors or designers. When systems are actively updated and fully embedded in daily workflows they deliver real value. Conversely, passive or inconsistent use can limit their impact even if the

tool/platform is highly recognized. This suggests that usefulness should be considered relationally based, context dependent, and in fact contingent on the extent to which project roles, organizational commitments, and stakeholder engagement interdependently contribute to the successful delivery of project outcomes.

6.1.2 Perceived Ease of Use

Across stakeholder groups, findings indicated that ease of use was influenced less by elements of technical interface complexity and more by habits of use, team interactions, and context related expectations. This finding contrasts with much of the traditional TAM literature in which ease of use is gauged based on overarching attributes of technology, e.g. easy to learn or easy to become skilled in (Liu et al., 2018; Okoro et al., 2023), the data here show that project roles, generational familiarity, and adaptation mindsets were the more highly variable factors impacting ease of use.

Clients generally viewed digital technologies as easy to use, but not necessarily because they themselves interacted intensively with the systems. It was the perceived consistency and reliability of a standardized digital workflow that allowed for better coordination. Clients or project leaders experience ease of use based on whether or not the other project actors (particularly contractors and consultants) utilized and updated the common digital system regularly. When project actors do not routinely engage with the platform, the ideal usability of the system would sometimes deteriorate.

The interviewed contractor observed differences within his team: while younger or more digitally familiar team members easily adapted to mobile-based systems and digital drawings, some were reluctant to move away from traditional habits such as calling or relying on printed documents. The nature of these behaviors shaped the level of consistency in utilizing the systems/ platform, which sometimes influenced the timing of project changes or updates getting missed. So even very intuitively designed tools did not create ease of use as actors were asked to adopt and utilize a system consistently.

Consultants often found they were connected to bridging a gap between technical systems, and non-digitally based project actors. They adapted digital outputs into more accessible formats, such as annotated printouts or simplified mobile summaries, especially for on-site use. This kind of role-specific filtering made the system easier to work with for others, but also reflected the limited digital integration across all project levels. Ease of use could not rely on just one platform being easy in this case, but represented the ability of some actors to re-interpret and re-distribute information effectively.

Overall, ease of use was not determined by the technology itself, but about how ideally the digital working practices align with the working habits and groups' capacities. In historic construction projects, where stakeholders come from diverse technical and cultural backgrounds (Penjor et al., 2024), ease of use could be better understood as a relational outcome, it is shaped by communication style, willingness to adapt, and the ability to mediate across digital and non-digital working methods.

6.1.3 External Variables

Some external factors including contractual structures, institutional priorities, and the physical characteristics of historic buildings were important in shaping the adoption of digital technologies during the construction phase.

The information deficiencies experienced when managing projects for historic buildings, including undocumented changed, unidentified materials, or hidden conditions, are well established in the literature (Khan et al., 2022; Koo et al., 2024), and findings from this study confirm those challenges. Several respondents in this study emphasized that unexpected discoveries during demolition or inspection could easily invalidate pre-modeled assumptions. These disruptions limited the full application of digital technologies and often required re-coordination outside the model. Therefore, digital systems in historic contexts must be flexible enough to accommodate change, instead of just documenting plans.

Another external consideration was the limited availability of resources in some client organizations, which affected their ability to invest in digital technologies. Unlike commercial developments, many historic renovations are funded by state budgets or managed by non-profit organizations with limited budgets. These factors will affect choices regarding digital technology, who gets trained, and whether licenses can be provided to all stakeholders. This observation aligns with Charlton et al. (2020), who highlight that limited investment and preservation-first priorities often hinder the fast pace of digital innovation in heritage conditions. Similarly, Panakaduwa et al. (2024) note that high maintenance costs and funding shortages are common barriers in historic building projects. In this sense, digital adoption is not just about meeting a form of readiness, but also about the broader economic and political environment of public heritage management.

Finally, cultural expectations surrounding historic buildings influenced how digital decisions were evaluated. For consultants and specialists, where the intervention's success was impacted not simply when the technical quality of the work matched the expectations of the regulatory approval, it was also important that the product could be accepted as part of the site's historic identity. This is in line with Arandelovic & Musil (2023), who emphasize that interventions in historic buildings must preserve cultural identity and contextual significance, not just comply with regulatory standards. Similarly, ICOMOS (n.d.) underscores the principle that heritage work must maintain historic integrity, highlighting that successful outcomes are often culturally and socially negotiated. It reflects that in historic renovation, external variables are not just about regulation, but also about interpretation, meaning, and long-term acceptance.

In summary, external variables influencing digital adoption are often interrelated. As discussed, factors such as contractual structures, project-specific uncertainties, institutional capacities, cultural values and others did not exist as stand-alone variables. They constituted experiences and expectations that shaped and enhanced accountability expectations. Understanding these interrelations is essential for navigating the complexities of digital implementation in historic renovation projects.

6.2 Implications

6.2.1 Structured Communication in Multi-Stakeholder Historic Projects

In historic building renovation projects, communication is not just about information exchange, it is also about managing responsibility, interpretation, and risk. Unlike new construction where roles and technical scopes may be clearer, the renovation of protected or aging structures where time itself has altered specifications, can involve fluid authority and a surprise discovery, and always takes serious coordination, which is in consistent with literature by Penjor et al. (2024) and Angrisano et al. (2024). Digital technology played a key role in managing these dynamics through visual tools, shared databases, mobile communication, structured approval chains, etc.

The perceived benefit of digitalization was the ability to point to where someone said something, when, and where on the building that was, which lessened disputes and enabled responsibility especially when circumstances required reviewing decisions made. Unlike verbal or email-based exchanges, digital communication was a structured, searchable record that multiple participants could reference. This was seen as important in multi-phase projects, where actors changed over time and memory was unreliable. This assessment is consistent with findings of Jahanger (2024).

In agreement with Brozovsky (2024), the finding of the research on forms of visual communication recognized by participants (annotated drawings, 3D/physical views, rendered photos of changes/revisions from site) as they are good methods of representation for reducing conflicts and/or misunderstandings between actors with different expectations. These forms were seen as useful not only for technical teams but also for specialists such as heritage consultants or project administrator, where detailed understanding of raw construction information was problematic or an unknown. In this way, digital technology supported a kind of shared visual language, enabling more inclusive participation in decisions.

More importantly, the flows of information through digital communication allowed the team to determine their own communication/hierarchies, which had not been found in the current literature. Clients could simply filter consultant information or whether to share it with contractors, or contractors could ask specifically a designer or regulator about a question without interrupting through the absolute chain of project. It protected the potentially sensitive flow of decision making in certain values particularly concerning aspects of historic fabric, regulation compliance, and personal safety risks.

Overall, communication in historic renovation projects benefited from digital technologies not because of any one specific tool or platform, but by virtue of blending forms of visual structured, role-sensitive and traceable means of communicating that helped delineate responsibilities, coordinate relative differences and/or distance, and support decisions in complex, fragile, and with many voices and with potential for interruptions or derailing from voices fragmented in previous dialogue.

6.2.2 Real-Time Decision-Making under Uncertainty

Uncertainty is a constant feature of construction work on historic buildings (Arandelovic & Musil, 2023; Charlton et al., 2020; Khan et al., 2022). The unanticipated is often revealed when demolition begins, or when areas of the building that were previously unseen are exposed. With

uncertainty, the ability to make decisions quickly and based on reliable information becomes critical. Digital technologies provided important support for these responses, but also provided the benefit of allowing conservation work to work at a slower and more methodical pace.

Consultants and clients also identified that not all decisions should be made quickly. Certain decisions will require some reflection, particularly when historic materials are threatened. The team was able to evaluate numerous scenarios based on digital simulations and layered visualizations, as reflected in Volk et al. (2014). This was especially valuable when balancing technical feasibility with conservation principles. In these cases, the technology did not speed up decisions, but made them more informed.

Instead of forcing fast decisions, digital technologies gave teams the opportunity to slow down and reflect when needed. They supported both immediate responses and longer discussions. This flexibility was important for balancing the need to save time and costs with the careful handling of historic materials and the coordination of construction processes.

6.3 Practical Considerations in Historic Building Renovation Contexts

While the adoption of digital technology in construction has become common, the renovation of historic building presents particular constraints that challenge full integration. These constraints are not only technical but also institutional, cultural, and physical.

First, as CS D mentioned, digital technologies cannot fully replace physical presence and on-site expertise, also pointed out by Charlton et al. (2020). Although virtual walk-throughs, 3D scans, and annotated models provide useful references, decisions about historic materials often require real inspection. Clients and consultants emphasized that visual data alone may not capture aging, or structural fragility. In many cases, digital representations had to be validated through direct observation.

Second, the longevity and governance structure of historic projects demands a longer-term perspective on data use. Rather than exclusively thinking about the delivery of the project, clients began to view a digital system as an environment of project memory, which is in line with Volk et al. (2014). Documentation of approvals, repairs, and discussions served not only immediate needs but also future maintenance and regulatory audits. The expectation of what a digital system could mean for a historic building construction project represented a shift from the usual process of understanding the construction logic of hand over.

Third, stakeholders adopted different levels of digital integration depending on their roles and project pressures in historic renovation projects. This is partially reflected in the prior studies, which highlighted the various differences based on role responsibility in the adoption (Edirisinghe et al., 2017). While some users worked directly within digital models, others only accessed filtered outputs such as printed visuals or checklists. This unbalanced adoption was not necessarily a failure of training, but a reflection of real site dynamics and role-specific needs. Consultants often acted as translators, ensuring that important information made its way to the appropriate project members who may have less digital engagement in a meaningful way.

7. Conclusion

This chapter provides a summary of the study by answering the research questions, highlighting practical implications, and presenting a final reflection on the role of digital technologies in historic building renovation.

7.1 Answering the Research Questions

RQ1. *What are the key factors influencing stakeholders' adoption and acceptance of digital technologies in the construction phase of historic building renovation projects?*

The findings show that adoption is driven by stakeholders' perceptions of usefulness and ease of use, both of which are strongly influenced by external variables, such as contractual obligations, organizational structure, project complexity, resource availability etc. Rather than seeing digital tools as universally beneficial, stakeholders evaluate their value in relation to role-specific priorities. Clients prioritize traceability and institutional control; contractors focus on operational clarity and documentation; consultants emphasize preservation accuracy and risk mitigation. Thus, acceptance is not only a function of the tool's quality but also of the environment in which the technology is applied and the stakeholder's responsibilities within the project.

RQ2. *What are the implications of digital technology adoption for stakeholder communication, coordination, and real-time decision-making in the construction phase of historic building renovation projects?*

While this question builds directly on the adoption dynamics explored in RQ1, it extends the analysis from "why technologies are used" to "how they function once in use." Importantly, the implications of adoption are not the reflection of perceived usefulness. Instead, they manifest in new organizational practices: structured communication flows, shared visual references for decision-making, and enhanced remote collaboration in sensitive environments. Stakeholders pointed out that when digital technologies are embedded into daily routines, they improve accountability and transparency, reduce misunderstandings, and support more inclusive and informed decision-making. While digital technologies improved coordination between stakeholders and decision-making, they did not replace the need for professional judgment or on-site assessment. The technologies worked best not as automated systems, but as collaborative frameworks supporting human expertise and contextual interpretation.

7.2 Implications for Practice and Research

This study shows that in historic building renovation, digital technologies cannot be evaluated purely on a technical basis. This involves the level of integration within project governance, team collaboration, or heritage protection strategies to evaluate the level of use they appear to provide.

The adoption of digital technologies is not a neutral or automatic process. It involves decisions about who controls information, how communication is structured, and which project values are prioritized. Successful digitalization involves not only functional tools, but also clear workflows, mutual expectations, and leadership that supports inclusive and informed use.

Furthermore, in heritage projects, the application of digital technologies should remain in service to the cultural and historical meaning of the building. Technology should support preservation ethics instead override them. The most effective uses of digital technologies in this study were those that enhanced collective understanding, encouraged reflection and respected material sensitivities of the renovation process.

Based on the scope and findings, several directions for future research can be identified. First, future studies could broaden the empirical base by involving a larger number of projects and stakeholders across different institutional and geographic backgrounds, which help examine how varying regulatory frameworks, procurement models, and resource constraints shape digital adoption practices in historic renovation in construction phase. Besides, while this study focused on the construction phase, future studies could examine how digital records developed in the construction phase are utilized in the building lifecycle within related processes of facility management, heritage reporting, or adaptive reuse. This continuity may provide insights into the long-term value of construction phase digital documentation. Such future research could contribute to a more comprehensive understanding of how digital technologies function not only as project tools but as part of conservation processes within the historic built environment.

7.3 Final Reflection

Digital technologies hold great promise for improving the construction phase of historic building renovations. However, their full value emerges not from novelty, but from thoughtful implementation aligned with cultural, practical, and ethical dimensions. Under these circumstances, technologies should be seen not as ends in themselves, but as mediators of trust, memory, and shared knowledge. Used properly, critically and collaboratively, they can support the task of preserving the past while enabling action in the present, and build the bridge for the future.

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Appendixes

Appendix 1 General Interview Guide

1. Introduction

- Self-introduction & Explain the purpose of my research
- Could you briefly describe your role in historic building renovation projects?
- Have you been involved in any historic renovation projects where digital tools were used during the construction phase? (What kind of experience do you have with digital technologies)

2. Stakeholders' perception

1. Perceived Usefulness (PU)

- What were the key factors influencing the decision to adopt digital technologies during the construction phase of XX?
- How did different stakeholders (e.g., project managers, architects, contractors) perceive the integration of digital tools in this project?
- Are there specific outcomes (e.g., quality, cost, speed, risk reduction) that digital tools can help achieve in heritage projects?
- Do different stakeholders (e.g., government, contractors, design teams) have consistent views on digital technology? Are there any particular supporters or opponents?

2. Perceived Ease of Use (PEU)

- How easy or difficult was it to integrate these digital tools into existing workflows? Are there any specific examples?
- Did stakeholders face challenges in adopting, learning, or using these technologies? If so, how were these addressed?
- Do construction teams and project managers have barriers to using digital technology? (e.g. learning costs, skills gap, data compatibility, etc.)

3. External Variables (EV)

- Was the adoption driven by internal initiatives (contractors/consultants optimizing processes) or external mandates (city requirements, regulations, or funding conditions)? / In your experience, what external factors (e.g., regulations, heritage requirements, budget, organizational culture) influence whether or not digital tools are used during renovation? + Are there any project-specific aspects (e.g., size, complexity, level of heritage protection) that tend to influence perceptions of digital tools?
- To what extent do clients or heritage agencies influence digital adoption decisions?
- Were any additional training programs, technical support, or process adjustments required?

3. Implications for communication, coordination, and decision-making

- In XXX projects, how have digital technologies helped improve communication between stakeholders?
- Have these tools helped avoid misunderstandings or information gaps during the construction phase?
- How do digital platforms support coordination in multi-actor settings with different roles (e.g., contractor, client, heritage authorities)?
- Can you share any examples where digital tools helped with fast or informed decision-making on-site?

- How helpful are digital tools when unexpected challenges arise, especially in protected or older structures?
- Do you think digitalization allows for more agile problem-solving during renovation?

4. Further questions

- Looking ahead, do you think digital adoption in historic renovation projects will become more standardized or remain project-specific?
- Based on your experience with XXX, how do you see digital technologies shaping the future of historic building renovations?
- What recommendations would you offer to other professionals considering the integration of digital technologies in similar projects?
- Do you see any policy changes or funding incentives that could encourage broader adoption?

To Clients:

- Do digital tools give you better oversight or control of the construction process?
- How do you evaluate whether the use of digital tools was worth the investment?

To Contractors / Site Managers

- How do digital technologies help you manage daily tasks, subcontractors, and communication on-site?
- What are the challenges of using digital tools in heritage-sensitive construction environments?

To Consultants / Digital Advisors / Specialist

- How do you support the integration of digital tools in heritage projects?
- What advice would you give to clients or teams hesitant about digital adoption?

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