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A Digital Record System for Heritage Buildings in Saudi Arabia

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Abstract

In this research, an approach for creating a holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia is presented. Many heritage buildings in Saudi Arabia are in poor condition due to negligence and lack of conservation (UNESCO World Heritage Centre, 2020), and the lack of scientific research focusing on the digital recording of heritage buildings' information exposes them to loss. Research, application, and experiments in digital recording of heritage buildings are needed in Saudi Arabia. So, the purpose of this research is to establish a framework to improve the recording process of heritage buildings' data, conserve and promote Saudi's Islamic, Arab, and National heritage locally and internationally, and support Saudi's Vision 2030 in developing recording and scientific research in the field of national heritage (Vision2030.gov.sa, 2020, pp. 2-54).

The aim is to establish a new framework for the intense digitalization of heritage buildings in Saudi Arabia as part of a holistic digital platform for voluntary public records. Such a framework and platform are supported through a pragmatic research approach and the use of mixed research methods considering novel fieldwork techniques: laser scanning and digital photogrammetry in combination with documentary research acquired from governmental and private parties. The framework findings resulted in the most holistic digital record system generated in Saudi Arabia recording intangible and tangible information by utilising several digital recording methods, integrating different recording systems, and saving and disseminating the data digitally in an open-access platform.

The delivery of this system and the resulting published information highlights the essential research needed regarding technology practical application and system accuracy between Historic Building Information Modelling Systems (HBIMs) and Geographic Information systems (GISs) and developing training skills strategies in using technical tools, data accessibility, acquisition, and processing, and stakeholder interactions with platforms for digital documentation and dissemination, and future management and decision-making.

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Acknowledgement

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My special thanks to my beautiful family my mother, brothers, and sisters for their endless encouragement, support, and prayers to achieve this ambition.

The Messenger of Allah (ﷺ) said, " “When a man dies, his good deeds come to an end except three: ongoing charity, beneficial knowledge, and righteous offspring who prays for him.” So, a special thanks to the biggest supporter in my scientific and practical career, who I hoped would see this work before he departs this life, and who I ask Allah Almighty to write the reward of the beneficiaries of this work in the balance of my good deeds and the good deeds of my father Taha Ahmad Albouraee, may Allah have mercy on him.

Declaration

I confirm that this thesis presented for the degree of Doctor of Philosophy in Design has:

i) been composed entirely by myself
ii) been solely the result of my own work
iii) not been submitted for any other degree or professional qualification.

Parts of this work have been presented at conferences, entitled:

1- "An Open Interactive Digital Record System of a Heritage Building in Jeddah Historical City, Saudi Arabia." at the conference CONNECTIONS: EXPLORING HERITAGE, ARCHITECTURE, CITIES, ART, MEDIA held at the University of Kent, June 29-30, 2020. https://architecturemps.com/wp-content/uploads/2020/06/Walaa_Albouraee_Creating-an-Open-Interactive-Digital-Record-System-i-Jeddah_Abstract_Canterbury_20.pdf

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Chapter 01: Introduction

This thesis documents a digital record system for heritage buildings in Saudi Arabia by creating a holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia. This chapter provides the background of the research. It describes the motivation behind conducting this research (1.1). It also highlights the research challenges for understanding and investigation (1.2). It explains the targeted scope of the study to give the reader an insight into what the study is aimed at and what should be expected (1.3), Then, it illustrates the timeline of the research including describing, in brief, the development process of the literature review, the research question and objectives, methods and methodology, data acquisition and processing, writing and drafting the dissertation, and finally it clarifies the training courses and talks that were attended during all years to help to conduct this research (1.4). It also gives the readers a quick outline of the research thesis structure to assist them in accessing the content (1.5).

1.1. Motivation

First, the dissertation has international and regional interests; Internationally, international organisations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) has an interest in concerning the safeguarding of historic areas. It is noted that a number of historical areas around the world were exposed to irrational demolishing and inappropriate reconstruction work, which caused damage to this historic heritage. In order to conserve this historical heritage from the dangers of deterioration or even total destruction to which it is exposed, each country must adopt a comprehensive system for the protection of historical heritage areas. In addition, it is noted that the digital recording of heritage buildings is an ongoing challenging topic that attracts engineers, designers, architects, conservationists, archaeologists, and those interested in heritage throughout the world to conserve these irreplaceable assets.

Therefore, until now, studies have been conducted on the development of methods, techniques, and systems for conserving heritage objects appropriately, such as historical buildings with antique and complex elements. Regionally, there is interest from the government of the Kingdom of Saudi Arabia, especially in the historical Jeddah area. The heritage aspects of this region are being developed, organized, and conserved under the umbrella of the Jeddah Municipality and the Heritage Commission in order to create replicable results for digital heritage. During the study phase of this research, the thesis topics were accepted at several conferences with oral presentations and peer-reviewed scientific papers.

1.2. The Research Challenges

The absence of specialists, experts, and researchers in conservation practices in Saudi Arabia has resulted in a lack of information about its historic sites and buildings. Consequently, many heritage buildings in Saudi Arabia are in poor condition due to negligence and lack of conservation (UNESCO World Heritage Centre, 2020). In light of this, and to help conserve the country's heritage, there is a need to accurately document the kingdom's historic sites and buildings' tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) information. Indeed, recording, documenting, and conserving these sites and buildings are interrelated. In enabling people to understand the value and importance of their historic buildings and their relationship to the country's cultural heritage, recording, documenting, and disseminating heritage information can serve an important educational role – in museums, universities, schools, etc… A better understanding and appreciation of the significance of these sites can help ensure their future conservation.

1.3. Scope of the Study

This research is not a computing PhD but adopts a digital humanities approach in collecting some data, which includes the systematic use of digital resources in the disciplines of the humanities, as well as the analysis of their application (University of Reading, 2022). During the increased interest in conserving heritage buildings worldwide, many heritage buildings in Saudi Arabia are in poor condition due to negligence and lack of conservation (UNESCO World Heritage Centre, 2020). Therefore, this research aims to create a holistic digital record system that integrates information about the tangible and intangible aspects of heritage buildings in Saudi Arabia.

In addition, this research should not be viewed as a technical PhD, in photogrammetry terms, it undertook a practice-based approach for capturing historic buildings in 3D, by effectively adopting a citizen science framing, which involves individuals taking part in scientific research to help expand the scientific understanding. This happens when people participate and contribute to programs that monitor and collect data (National Geographic Education, 2024). This is conducted in this research by establishing a new replicable framework for the intense digitalization of heritage buildings in Saudi Arabia as part of a holistic digital platform for voluntary public records in order to make the digital record information replaceable for citizens to recreate in **chapter 06**.

For instance, this study is limited to five heritage buildings in Jeddah's historical city, which are located within the area that has been classified as UNESCO World Heritage. The digital recording was conducted using mixed methods in action research design, including digital metric survey techniques, documented research sources, and case studies.

This recording process period lasted for three months and ended when the five heritage buildings were digitally recorded. Each building was studied to identify the most appropriate recording method to capture tangible and intangible information about a heritage building for helping citizens create and replicate a holistic digital record in other heritage regions.

1.4. The Timeline of the Research

When creating a timeline section for this research, it was essential to provide a clear and detailed plan that outlines the key milestones and activities the researcher intends to accomplish throughout her doctoral journey. The timeline section reflects the structure and progression of her research, demonstrating that she has a well-thought-out plan to complete her PhD. Figure 1.1 illustrates the main points that are included in the PhD timeline section.

Figure 1. 1: *The Timeline of the Research.*
(The Author, 2024)

1.4.1. The Literature Review: October 2018 - October 2019

In October 2018, the researcher started her PhD studies. During the first year and second year, the literature review in **chapter 02** focused on discussing arguments about the meaning, value, and classification of cultural heritage, as well as the definitions of heritage buildings. It then looked more deeply into the importance of heritage buildings, heritage buildings recording for documentation, methods used in heritage buildings recording, best practices in heritage buildings recording internationally, and previous studies in heritage buildings recording in Saudi Arabia. As a result of the literature review, the research question and objectives were developed.

1.4.2. Research Questions and Objectives: January 2019 – March 2020

The researcher initially looked at: How to preserve heritage buildings digitally for educational purposes. Based on the initial literature review, her research question was developed to be: How to record heritage buildings digitally? Then subsequently, she narrowed the research question further to focus more specifically on: How to create a digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia. Based on this question, her research objectives developed to be:

1- Determine what type of information will be included in the digital record and why.
2- Identify the most appropriate recording method to capture information about a heritage building.
3- Understanding the relationships between tangible and intangible information.
4- Establish and experiment with process-based methods of integrating tangible and intangible information.
5- Verify the effectiveness of the integration of information and stakeholder interactions.

As a result of the literature review, the research question, and objectives, the research methodology and methods were developed.

1.4.3. The Research Methodology and Methods: April 2019 - December 2020

The research methodology in **chapter 03** initially looked at different types of research paradigms, including positivism, interpretive, and pragmatism. Based on this initial examination, the researcher focused more on pragmatism philosophy because its ontology, epistemology, methodology, and methods can help to answer her research question and meet the research objectives.

Following this, the research methodology examined the research philosophy and the research design, including the advantages and disadvantages of the selected research tools. Besides, it examined research methods and their capability to produce effective results that meet the aims and objectives of this study and concluded with a discussion of the advantages and disadvantages of each method. As a result, the pragmatism research philosophy, the mixed methods in action research design including qualitative and quantitative methods, and the mixed research methods, including a combination of several scientific research tools, such as measuring tools (fieldwork) as well as documentary research and case study as methods, were chosen in this research.

The research methods in **chapter 03** were based on research methodology, this research used mixed research methods, including a combination of two main resources. Firstly, the primary resources depend on data collection from diverse resources for a deeper understanding of the research issues that need to be solved to meet the objectives of this research through fieldwork for capturing and then extracting the building element dimensions, materials, condition, and appearance by using digital metric survey techniques including digital photogrammetry and laser scanning to determine the most appropriate recording method to capture information of a historic building. Also, secondary sources in the form of documentary research presented in inventories from government institutions, computer-aided design (CAD) drawings from academic sources, a literature survey of previous studies, and historical records from local studies to obtain diverse textual and/or visual information via both online and/or offline documents.

1.4.4. Data Acquisition and Processing: October 2019 – October 2021

Initially, before the completion of the upgrade and the researcher's accreditation as a PhD candidate, the researcher worked to fill out the Ethical Approval Form to obtain the data from Saudi Arabia and was reviewed and audited by her supervisors, and then it was submitted 10th of March 2020 to the competent authority at the university for approval. Fortunately, approval was obtained very quickly in only eight working days. She was prepared to travel to Saudi Arabia to collect data, however, suddenly, Saudi Arabian Airlines stopped due to the COVID-19 restrictions. She attempted to communicate with the Saudi Cultural Bureau to request an evacuation to travel to Saudi Arabia.

While waiting for the Saudi Cultural Bureau to accept the evacuation request, she took advantage of this period by communicating with the target institutions in Saudi Arabia remotely to collect data for the research. Also, she participated and submitted a paper and a presentation remotely under the title *"An Open Interactive Digital Record System of a Heritage Building in Jeddah Historical City, Saudi Arabia"* in a CONNECTIONS: EXPLORING HERITAGE, ARCHITECTURE, CITIES, ART, MEDIA conference, which held at the University of Kent, June 29-30, 2020.

When back to Saudi Arabia, the data acquisition process was divided into two parts, using digital metric survey techniques in fieldwork and the collection of documented research of heritage building information, which was suggested in the research methodology, and was conducted as planned.

In the fieldwork, five heritage buildings were selected according to their important values, unique architecture, accessibility, and data availability. After that, devices for capturing the elements of the heritage buildings were chosen based on the availability, cost, and accuracy of capturing the tangible elements of the heritage buildings. However, many difficulties arose during the data capture process of the tangible elements of the heritage buildings, which are discussed in **chapter 05**. In addition to the impacts and restrictions of COVID-19, the very sudden death of her father has naturally significantly affected her and her family. These two major factors have seriously slowed down the progress of her fieldwork in Jeddah. In turn, documented research of heritage building information was obtained from different resources and institutions, which are discussed in **chapter 04.**

After conducting the data acquisition process, whether from measuring tools (fieldwork) and documented research, the researcher started classifying, processing, and analysing data based on its type, whether it was tangible data (physical: dimensions, materials) or intangible data (cultural: methods, skills, history) to help reach the research objectives.

1.4.5. Writing and Drafting: March 2021 – March 2023

After conducting the data acquisition and processing, the researcher started by writing in-depth **chapter 04** titled: Study Area General Information. The chapter was sent to supervisors to get their recommendation for further editing. Then the supervisors' comments were obtained to amend some sections. Rewriting, modification, and addition of some data were carried out to help improve the research. For instance, it was needed to add some graphs to make reading the search easier, simpler, and faster to reach the information. Also, a table has been added specifying the tangible and intangible data obtained in detail. In addition, a table for the nomination of heritage buildings in Jeddah has been added based on four essential criteria for selecting the appropriate buildings to be studied in this research based on previous literature reviews, which are significant value, unique structure, accessibility of the site, and availability of data.

As for the middle of the second year, the writing of **Chapter 05** had begun, which is about data acquisition and processing of selected case studies. Thus began a flurry of back-and-forth emails and meetings between the researcher and supervisors until we reached the final amendments to help improve the chapter.

At the beginning of the third year, the preparation of writing **chapter 06** began, which is about the creation of a holistic digital record for heritage buildings for documentation and dissemination. The researcher and her supervisors discussed the chapter backwards and forwards via emails and tutorials for several months because it is the main chapter that can provide answers to the research question and achieve the research objectives.

Following that, **chapter 07** was written at the beginning of the fourth year, which is about the overall conclusion, the overview of the research aim and objectives, research findings, original contribution to knowledge, limitations of the study, and recommendations for further studies. Then, the chapter was sent to supervisors for reviewing and obtaining feedback.

Also in the same year, the researcher participated in person at the conference “(In)Tangible Heritage(s)” in collaboration with the University of Kent, on 15-17 June 2022. At the same conference, she published a conference paper in collaboration with Stuart Walker, and Paul Cureton entitled: "Towards a Holistic Digital Record System of a Heritage Building in Jeddah Historical City, Saudi Arabia."

As for **chapter 01**, after meeting and discussing with the supervisors about the contents of this chapter, the main points that it could contain were reached, which are the research motivation, the research challenges, the scope of the study, research questions and objectives, and the research thesis structure.

When it comes to the literature review in **chapter 02**, which was mentioned earlier, it was reviewed and developed to include a detailed overview of cultural heritage, heritage buildings, the importance of heritage buildings, heritage buildings recording for documentation, methods used in heritage buildings recording, best practices in heritage buildings recording internationally, and previous studies in heritage buildings recording in Saudi Arabia.

As for the research methodology and methods in **chapter 03,** which are previously discussed, several meetings and engaging in discussions with the supervisors were held regarding developing the chapter's content, we arrived at a common understanding of the key points it should include, specifically research question and objectives, and research methodology including research philosophy, research design, and research methods.

1.4.6. Training Courses and Talks: May 2020 – September 2021

Several online courses and talks were attended to add knowledge and experience and to build the researcher's ability to conduct her research, see table 1.1 below:

	Talk/ Course Title	***The Organization Responsible for Holding***	***Location: Where it is Held***	***Date: When it was Held***
An Online Design Talk	"From Laser Scanning to BIM"	ArchiNect, which is the Architects and Interior Designers Network	In the Kingdom of Saudi Arabia	May 16, 2020
An Online Course	"My Way to a Professional 3D Visualization"	Namaa Platform in Madinah City	The Kingdom of Saudi Arabia	June 11, 2020
An Online Course	"Packaging Design"	The Deanship of Community Service and Continuing Education	Taibah University in Madinah City, The Kingdom of Saudi Arabia	July 5, 2020

An Online Design Talk	"The Third Exit: Designing a Better Future"	ArchiNect, which is the Architects and Interior Designers Network	The Kingdom of Saudi Arabia	September 3, 2020
An Online Course	"Corona Render Engine"	Abdulaziz Mahsoon, a 3D visualization trainer	Jeddah City, The Kingdom of Saudi Arabia	September 06-13, 2020
An Online Course	"Harnessing Technologies in the Service and Development of Scientific Research"	The Deanship of University Development in partnership with the College of Family Sciences at Taibah University	Madinah City, The Kingdom of Saudi Arabia	December 3, 2020

An Online Design Talk	"Beginning, Practice, and Thought "	ArchiNect, which is the Architects and Interior Designers Network	The Kingdom of Saudi Arabia	March 20, 2021
An Online Design Talk	"Craft Thinking in Talking Design "	ArchiNect, which is the Architects and Interior Designers Network	The Kingdom of Saudi Arabia	March 27, 2021
An Online Design Talk	" Cultural Identity in Interior Design"	ArchiNect, which is the Architects and Interior Designers Network	The Kingdom of Saudi Arabia	June 20, 2021
An Online Design Talk	" Identity between Heritage and	ArchiNect, which is the Architects and Interior	The Kingdom of Saudi Arabia	June 24, 2021

	Modernity in Interior Design"	Designers Network		
An Online Course	" Introduction to the Art of Digital Photography"	Edraak, is a Massive Open Online Course (MOOC) platform, that is an initiative of the Queen Rania Foundation (QRF)		September 28, 2021

Table 1. 1: *Online courses and talks attended.*
(Author, 2021)

1.5. Research Thesis Structure

This thesis consists of seven chapters; starting from the introduction in **chapter 01** to the conclusion in **chapter 07**. The following is a brief of each chapter:

Chapter 01 provides an overall background of the research. The motivation behind conducting this research is described. The research challenges for understanding and investigation are highlighted. The targeted scope of the study and the timeline of the research are explained. An outline of the research thesis structure is also provided.

Chapter 02 presents general information about cultural heritage. Arguments about the meaning, value, and classification of cultural heritage are discussed. Then, definitions of heritage buildings are mentioned. The importance of heritage buildings, heritage buildings recording for documentation, methods used in heritage buildings recording, mapping, and modelling, best practices in heritage buildings recording internationally, and previous studies in heritage buildings recording in Saudi Arabia are discussed.

Chapter 03 defines the research question and objectives based on the literature review chapter. It then focuses on explaining the research methodology, including the research philosophy and design. It discusses the research methods and their capability to produce effective results that meet the aims and objectives of this study. The chapter concludes with a discussion of the advantages and disadvantages of each method used in this research.

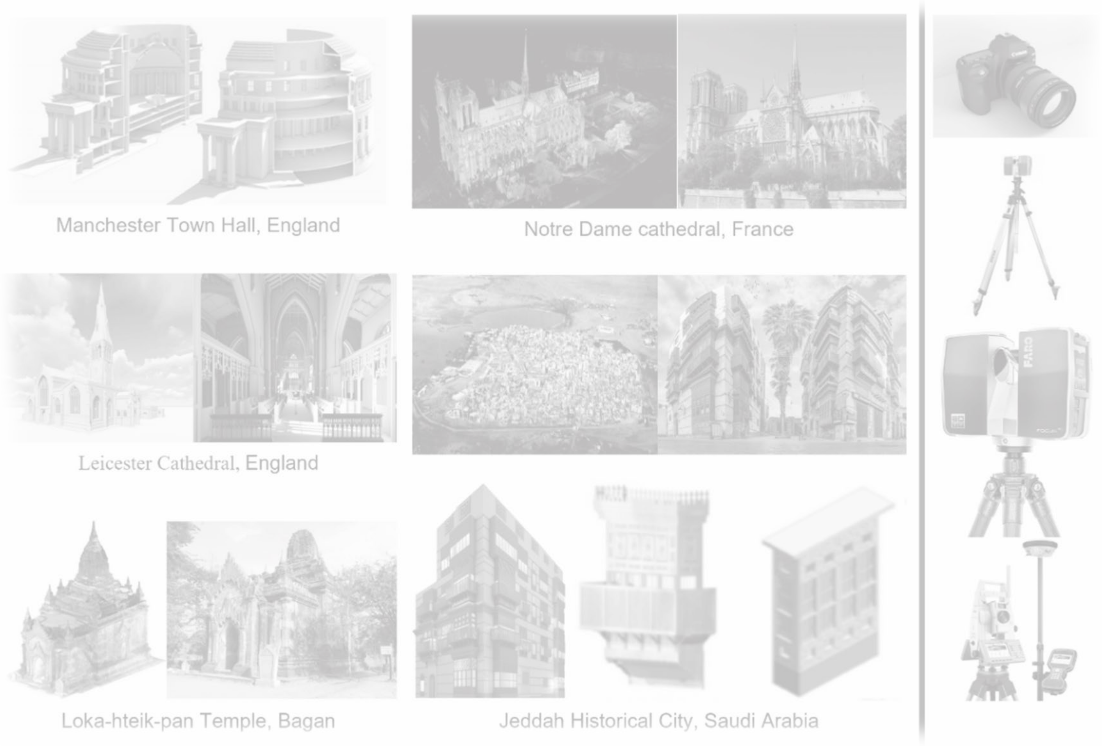
Chapter 04 begins with general information about the Kingdom of Saudi Arabia and its policy and governance, heritage and timelines for the protection and documentation of historic buildings in an international comparison. It elaborates on the vernacular characteristics of its historic buildings. It then focuses on exploring the historic buildings of Jeddah City and explaining the criteria for selecting a suitable sample of five buildings to be studied in detail in this research. Finally, it explains the process and information used to select the five historic buildings.

Chapter 05 explains the Structure from Motion (SFM) approach. The general workflow of Sharif Gate, the Jadid Gate, Makkah Gate, Ribat Banajah, and the Shafei mosque are introduced, which is followed by an explanation of the data acquisition processes and data processing stages of each building. This process examined the capability of varied digital devices to generate a three-dimensional (3D) model for identifying the most appropriate recording method to capture tangible and intangible information about a heritage building for creating a holistic digital record. Then, the data acquisition and processing stages of the used method and tools in recording heritage buildings are explained. Finally, the discussion findings of the whole chapter are clarified.

Chapter 06 briefly explains the origin of the Historic Building Information Modelling System (HBIM) and its importance for heritage building documentation. Then, it provides the best practices used by HBIM in the digital documentation of heritage buildings. The implementation processes of digital documentation for a heritage building in the Jeddah historical district are illustrated. The chapter then introduces a brief of the development stages of the disseminating process. It explains the importance of the digital dissemination of heritage buildings. It presents the methods used and best practices in the digital dissemination of heritage buildings. It then illustrates the implementation of digital dissemination for the Shafei Mosque's Minaret, which is a heritage building in Jeddah. It ended with the creation of a framework for a holistic digital record of the Shafei Mosque's Minaret that integrates its tangible and intangible information in order to develop the recording process of heritage buildings in the Kingdom of Saudi Arabia, which can help in attempting to fulfil the direction of the Kingdom of Saudi Arabia 2030 vision in culture and heritage sector (Vision2030.gov.sa, 2020, pp. 2-54).

Chapter 07 provides the overall conclusions of the thesis. First, it represents an overview answer to the research question and objectives. It discusses the research's main contributions to knowledge and the potential limitations resulting from the adopted research methods. Finally, it provides recommendations for further research.

Chapter 02: Literature Review



2.0. Introduction

This chapter is divided into several sections. In the first section, arguments about the meaning and value as well as the classification of cultural heritage, are discussed (2.1). In the second section, definitions of heritage buildings are mentioned (2.2). Then, the importance of heritage buildings (2.3), heritage buildings recording for documentation (2.4), methods used in heritage buildings recording, mapping, and modelling (2.5), best practices in heritage buildings recording internationally (2.6), and previous studies in heritage buildings recording in Saudi Arabia are discussed (2.7). Conclusions are drawn regarding this information, which is used to create a digital record of heritage buildings later in this research (2.8).

2.1. Cultural Heritage

Cultural heritage refers to varied fields, intending to collect, archive, and disseminate the heritage that has been recorded during the years of humankind (Dimoulas, 2022, p.1). Cultural heritage has been described by The International Council on Monuments and Sites (ICOMOS) as the way it expresses people's living and development, which transfers from generation to generation (ICOMOS, 2002, p. 21). Moreover, cultural heritage is an inherited resource that can be distinguished and valued by people as a reflection of their developing knowledge, beliefs, and traditions and as an expression of their understanding of other's beliefs and traditions (Drury et al., 2008, p. 19). Furthermore, cultural heritage is the legacy of tangible artefacts and intangible features of a group or society that are transferred from past generations, maintained in the present, and granted for future generations to benefit from their advantages (Unesco.org, 2017). It is also considered a significant feature of society in the modern world. The social value appears when preserving cultural heritage to ensure its transmission to future generations and leading to the conservation of local identity (Jeroscenkova et al., 2016, pp. 18-27). In addition, the Saudi Commission for Tourism and National Heritage defined cultural heritage as passing on culture from predecessor to successor, and this is not limited to language, literature, and thought only but it includes all material and emotional elements of society in terms of thought, philosophy, religion, science, art and architecture (Scth.gov.sa, 2016).

The classification of cultural heritage is illustrated in figure 2. 1. Cultural heritage objects are divided into two types: intangible and tangible. During the United Nations Educational, Scientific and Cultural Organization (UNESCO) General Conference in 2003, intangible cultural heritage was defined in the adopted convention for the safeguarding of intangible cultural heritage in the 32nd session (Jurėnienė. V, 2016, p. 147). Intangible heritage focuses on traditional festivals, customs, ways of life, traditional crafts, etc., While tangible heritage includes but is not limited to buildings, historical places, monuments, and artefacts (Unesco.org, 2017).

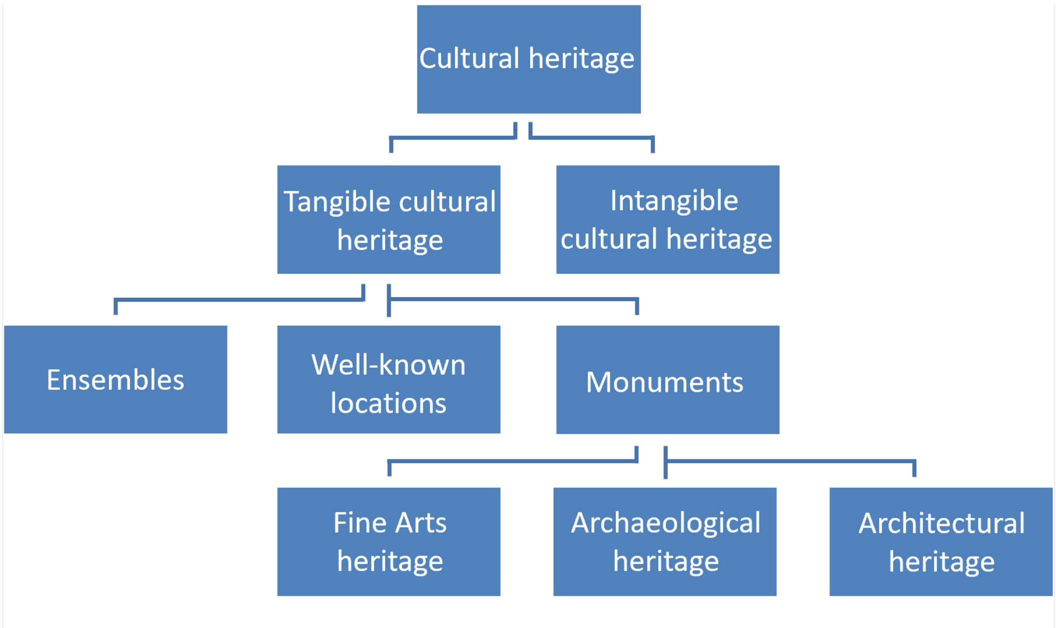


Figure 2. 1: *Classification of cultural heritage.*
(Jurėnienė. V, 2016)

In 1972 during the UNESCO General Conference, the conception of tangible cultural heritage was validated in the convention concerning the protection of world cultural and natural heritage. Based on the conference, tangible cultural heritage was defined as the remaining tangible objects from the past that have historical, archaeological, mythological, memorial, religious, architectural, urban, artistic, and scientific value (Jurėnienė. V, 2016, p. 148).

The objects that belong to tangible cultural heritage are monuments, groups of buildings, and places. Monuments stand for architectural works, monumental sculpture, and painting, in addition to archaeological elements or structures, inscriptions, cave dwellings, and sets of features that have historical, artistic, and scientific global value. Groups of buildings are the buildings that are connected or disconnected due to their architecture, homogeneity, or their location in the landscape and have historical, artistic, and scientific global value. Whereas, places represent the production of humans or a collective production between nature, humans, and districts, including archaeological locations with historical, artistic, and scientific global value (Whc.unesco.org, 1972, p. 2).

To sum up, cultural heritage is an expression of people's living and development, which is transferred from past generations, maintained in the present, and granted for future generations to benefit from their advantages such as knowledge, beliefs, and traditions, which leads to conserving local identity. Cultural heritage is divided into two types tangible and intangible. Cultural heritage is an essential pillar of the nation's identity, while the evidence of region originality is attached to heritage sites in different types and forms.

2.2. Heritage Buildings

One of the inherited assets acquired from the previous generation is built heritage. It represents our built environment in sites that have been made of brick, plaster, wood, metal, and stone, such as cathedrals and cemeteries, factories and fences, houses and hotels, etc… (NSW Environment & Heritage, 2012, p. 1). In addition, heritage assets can be a building, monument, site, place, area, or landscape that is recognized as having a degree of significance that deserves consideration in decision-making, because of their heritage interest (Department for Communities and Local Government, 2012, p. 52), such as Manchester town hall in the UK, Notre Dame cathedral in France, and Jeddah historical city in Saudi Arabia, which are classified as world cultural heritage buildings or sites by either Historic England or the UNESCO (Historicengland.org.uk, 2020; Whc.unesco.org, 2020, p. v).

There are many organizations defined heritage buildings such as Historic England "a non-departmental public body of the British Government sponsored by the Department for Digital, Culture, Media, and Sport", Central Public Works Department (CPWD) under the government of India, and the building code in Ontario regulation by the government of Ontario, Canada. Historic England defined a heritage building as a building having a significant value that deserves consideration in planning decisions due to its heritage interest (Historicengland.org.uk, 2022). Heritage buildings are any building, structure, or artefact which requires conservation or preservation for historical, architectural, artisanry, aesthetic, cultural, environmental, and/or ecological purposes, including part neighbouring lands of the building that is needed for preserving the historical, architectural, aesthetic, or cultural value of such building (Mitra et al., 2013, p. 1). Moreover, it has been defined as a building that has architectural, aesthetic, historical, or cultural values that are announced as a heritage building by the competent authority that has the official power to make legal decisions and judgments about where this building is located (Kannadasiri.kar.nic.in, 2004). The Government of Ontario also mentioned that a heritage building means a building that is selected or documented to be of significant architectural or historical value by a well-known and non-profit public organization whose main objective is the preservation of structures of architectural or historical significance (Ontario.ca, 2022, p. 14).

To conclude, heritage buildings can be buildings, monuments, sites, places, areas, or landscapes that are recognized for their historical, architectural, artisanry, aesthetic, cultural, environmental, and/or ecological significance that deserve conservation or preservation for better decision-making in the future.

2.3. The Importance of Heritage Buildings

In this section, the importance of heritage buildings from various aspects is discussed. The aspect of direct values of heritage buildings is represented in cultural value, national identity, sense of place, belonging, identity, and pride while the aspect of indirect values, which are induced by the direct value of built heritage, are represented in social values and economic values, based on that each value is explained later in this chapter.

2.3.1. Direct Values of Heritage Buildings

The direct values derived from heritage buildings are cultural heritage, architecture, historic environment, originality of the buildings themselves, and a sense of identity and pride from living in a building (Realdania.org, 2015, p.14). The following section defines the direct values of heritage buildings such as cultural value, national identity, sense of place, belonging, identity, and pride.

2.3.1.1. Cultural Value

There are divergent views in previous studies on identifying the cultural values of heritage buildings. The expression of cultural heritage value is synonymous with heritage significance and cultural significance. Cultural heritage value means "aesthetic, historic, scientific or social value for past, present or future generations" (ICOMOS, 2013, p. 2). A valuable place can provide information about the past, enhance the present, and be appreciated by future generations. Furthermore, the National Heritage in Malaysia indicates that cultural heritage value is the cultural heritage that has aesthetic, archaeological, architectural, cultural, historical, scientific, social, spiritual, linguistic, or technological value (Bakri et al., 2015, p. 295).

According to Milne, the cultural significance of a heritage building arises from an appreciation of its physical character and from understanding its connection with persons and events over a period of time. For instance, when a building shows a distinct design and construction techniques, or it has artistic significance due to its uniqueness, or the building has a link with certain events or persons in history (Milne, 2011, p. 108). However, according to the International Council on Monuments and Sites, cultural heritage value probably changes over time, and with use as a result of the uninterrupted history of the place, as well as understanding cultural heritage value may change as a consequence of recent information (ICOMOS, 1999, p. 2; ICOMOS, 2013, p. 2).

2.3.1.2. National Identity

Heritage represents the identity of individuals in both its tangible and intangible forms, and identity is the spirit of heritage (McLean, 2006, p. 3). It is important to indicate the fact that heritage and identity have a strong relationship with one another. Each country has its own heritage and cultural identity that is either conscious or oblivious of it. The cultural identity of a nation demonstrates its constant and distinctive features, which allow the personal identity a sphere that distinguishes it from other personal identities (Light et al., 1997). Henderson states that the concepts of national identity may change over time as a result of certain circumstances (Henderson, 2001, p. 220).

National heritage is important for building nations, and there is a relationship between national heritage and national identity, where it is considered that historic buildings are an important part of the nation's identity (Light et al.,1997, p. 28). Each nation has its historic buildings that represent its past. These historic buildings play an important role in building and strengthening national identity. Therefore, many states decided to protect historic buildings such as castles, palaces, temples of religion, and great walls because of their power to promote the nation (Thatcher, 2018, p. 22).

2.3.1.3. Sense of Place, Belonging, Identity, and Pride

The historic environment generates a strong sense of place. The term' sense of place' is used to link meaning and values to specific sites. It is a feature applied to places where the environment evokes positive feelings such as belonging, identity, and pride (Hayes, 2018, p.12). In addition, the historic environment reinforces a sense of place which can contribute to a greater sense of people's self-esteem and place attachment (Graham et al., 2009, p. 5).

A sense of belonging refers to the idea of "feeling at home" within a socio-geographical location (Karolina Nikielska-Sekula, 2016, p. 97). It is reported in a study by the National Trust that meaningful places arouse a sense of belonging when people visit them, and this encourages people to protect their significant places (National Trust, 2017, p. 36). People's identities are frequently explained in terms of nationality. However, identity has multiple aspects such as attitudes, values, traditions, heritage, and stories. These factors connect individuals to each other and give them a sense of belonging in their communities (Henderson, 2001, p. 220).

Historic buildings and places are witnesses to our history. They provide physical evidence that enhances our sense of local and national identity. Preserving them improves the quality of our surroundings, boosting the sense of well-being and pride in society (Reilly et al., 2018, p. 10). In addition, when people are surrounded by heritage buildings, it gives them a sense of identity and pride (Realdania.org, 2015, p. 14). Therefore, a large number of people visit heritage sites in England due to their significance to local communities (Evan, 2014, p. 2). Moreover, projects and initiatives specialized in historical environments can support local identity and community pride (Reilly et al., 2018, p. 9). Where, the value of historical environments is represented in their contribution of knowledge, sense of identity, and distinctiveness (Evan, 2014, p. 2).

2.3.2. Indirect Values of Heritage Buildings

Heritage buildings have social and economic values as well as cultural and environmental values (Hayes, 2018; Leeson, 2018). In the following section, the indirect values extracted from the direct values such as social and economic values are explained.

2.3.2.1. Social Values

There is a great relationship between the social value of heritage and the built environment. The value of the built environment is defined as the development that links people in society. In addition, it promotes chances for positive social interaction, social identity, civic pride, and social integration. Also, it participates in improving social health, growth, spirits, good intentions, good- good neighbourliness, safety, and security, and reducing sabotage and crime (Evan, 2014, p. 9).

Heritage assets represent a tangible connection to the past when the story of local places and the nation collectively is told (Hayes, 2018, p. 4). Heritage buildings are considered more than just buildings. People usually remember and tell stories about what has happened in heritage buildings, and these stories are part of cultural heritage. Understanding the life inside the building leads to a certain understanding of cultural heritage. Social science researchers bring to life heritage buildings through stories, memories, and ideas, and historians have argued that heritage buildings are dead if there is no story behind them that illustrates people's struggles and ideals (Milne, 2011, p. 52).

There are many pieces of evidence on the ways that the historic environment benefits individuals and communities. The community appreciates the historic environment, which helps to understand the place in the world and creates a sense of belonging and link to places (Hayes, 2018, p. 3). The indirect values of heritage, such as a sense of identity and belonging, can impact the community through several methods, such as when people connect and make new friendships when they visit heritage sites and participate in their projects, leading to increased social capital in society. In addition, levels of tolerance, respect, and community cohesion increase when people understand more about themselves and others who differ from them. Heritage encourages individuals to feel positive about their local area, which enhances the common sense of place and increases civic pride (Evan, 2014, p. 9). Also, the historic environment is significant for health and well-being. It plays a role in preserving and improving individuals' and communities' mental and physical health (Hayes, 2018, p. 8). According to the Department for Culture, Media, and Sport, the rate of satisfaction and happiness increases in people who visit historical places several times a year and have lower anxiety, unlike those who do not (DCMS, 2015, p. 7).

In addition, the historic environment affects how we realize places. England's built heritage is famous for its aesthetic value. Its existence in the landscape has an engaging power to attract people and impact their quality of life (Hayes, 2018, p. 14). In addition, the Heritage Lottery Fund reported that local heritage has an impact on the people's quality of life, making their area a better place to live, and is important for their personal sense of identity (Heritage Lottery Fund, 2015, p. 2). Finally, the historical environment inspires learning and understanding, where visiting historical places helps to learn about the history of the area and other people's cultures (Hayes, 2018, p. 20). The Heritage Lottery Fund cited that visiting heritage sites help understand more about the history of the area and better understand other people's cultures (Heritage Lottery Fund, 2015, p. 10).

2.3.2.2. Economic Values

The importance of heritage assets is represented in their economic value (Bagader, 2016, p. 37). The economic value offered by heritage for communities lies in several forms and types, such as historical buildings. Historical buildings are considered landmarks of the past and investment tools for the future. Where preserving historic buildings can enhance property values, improve the local tax base, and encourage their use as a marketing tool for societies (Cohen, 2011, p. 2). Therefore, there are claims to maintain heritage buildings in the present to remain for future generations (Unesco.org, 2017).

There is much evidence about how the historic environment helps the national economy and local economies. Firstly, heritage sites are attraction factors for businesses, where there are many companies inside historic buildings such as local shops, hotels, offices, etc (Leeson, 2018, p. 8). Secondly, heritage brings life to cities, where built heritage shapes a city's appearance and people's emotional responses to their built environment. According to Deloitte, the historic environment is one of the cornerstones of cities' economic and social revival (Deloitte, 2017, p. 4). Thirdly, heritage plays an important role in construction and development, where residential heritage buildings require maintenance and renovation, requiring experts with skills, knowledge, and experience in this field (Leeson, 2018, p. 28). However, a large number of heritage building projects were done by non-specialist construction companies (CITB, English Heritage and Historic Scotland, 2013, p. 12). Finally, heritage plays an important role in Britain's tourism industry. Millions of tourists come to visit heritage areas or participate in associated heritage activities. This helps create many jobs that contribute to national and local economic growth (Leeson, 2018, p. 32). To summarise this section, heritage buildings are important in terms of cultural value, national identity, sense of place, belonging, identity, and pride as direct values and social and economic values as indirect values.

2.4. Heritage Buildings Recording for Documentation

2.4.1. What is Heritage Buildings Recording?

One of the principal ways of providing meaning, understanding, definition, and recognition of cultural heritage values is documentation (Haddad, 2019, p. 6). Documentation or recording is the process of capturing information at a particular moment that describes the physical composition, condition, and use of monuments, groups of buildings, and sites, which is an extremely important part of the conservation process (ICOMOS, 1996, p. 49). However, in 2015, Letellier et al., defined recording and documentation separately. In their definitions, heritage recording refers to drawing or photography that captures information about the physical configuration, evaluation, and situation of heritage at known points in time. On the other hand, heritage documentation refers to the existing information, which represents the systematic collection and archiving of records to preserve them for future reference. Therefore, it can be said that "Today's recording is tomorrow's documentation" (Letellier et al., 2015, p. xx).

2.4.2. The Importance of Heritage Buildings Recording

Heritage records such as photographs and measured drawings with a series of dimensional, topographic, and structural analyses are essential parts of the understanding of heritage buildings and sites. Heritage records should be readily available for each heritage site, as they are an important requirement at the beginning of any research, investigation, or conservation activity (Letellier et al., 2007, p. 17). In addition, recording built heritage can play an important role in the telling of a region's history (Morgan, 2014, p. 7).

There are several reasons for recording historic buildings. It can be for enhancing the understanding and appreciation of historic buildings, promoting the involvement of the public through the dissemination of recorded information, and providing short or long-term management to improve the quality of management decision-making, including decisions concerning the appropriate use of historic buildings. Recording historic buildings can also help to ensure the preparation of a plan of conservation, repair, or change that respects the qualities and characteristics of heritage places. In addition, it can be for documenting heritage buildings or parts of heritage buildings, which can be at risk of loss as a result of demolition, change, or neglect. Moreover, it can provide permanent records of cultural heritage before a planned or unplanned change, such as supporting data by recording remaining structures (Lane, 2016, p. 1; Letellier et al., 2015, p. 69; ICOMOS, 1996, pp. 49-50).

The recording should be done to an appropriate level of detail to provide information for identifying, understanding, interpreting, and presenting the heritage and for promoting the involvement of the public (ICOMOS, 1996, p. 49). However, before selecting the level of recording, it is important to consider the nature of the building and the purpose of the recording. There are four levels for recording heritage buildings. The first level is a basic visual record, which is the simplest record containing the minimum information needed to determine the location, age, and type of the building. Level 2 is a descriptive record. Both the exterior and interior of the building will be seen, described, and photographed. Level 3 is an analytical record, and it will include an introductory description of the building's origins, development, and use. Level 4 provides a comprehensive analytical record. this level is appropriate for buildings of special importance. The record depends on a full range of information resources about the building and discusses its architectural, social, regional, or economic history significance. Levels 1,2,3, and 4 records consist of drawing, photography, and written accounts (Lane, 2016, pp. 25-27). In this research, recording level 4 was adopted because it merges tangible and intangible information about heritage buildings together, which can give a more holistic response to the research question "How to create a digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia?".

2.5. Methods Used in Heritage Buildings Recording, Mapping, and Modelling

In the past, heritage buildings are often recorded using traditional tools such as tape measures, plumb bobs, pens, paper, and cameras. In recent years, Global Positioning System (GPS) units, Total Stations Technique (TST), photogrammetry, and laser scanner techniques have been entered into the tools used to record structures (Moyano et al., 2022, p.1; Zhang et al., 2022, p.7; Liu et al., 2022, p. 53). In addition, Geographic Information System (GISs) and Building Information Modelling (BIM) approaches and their tools play a significant role in creating maps and 3D models of heritage buildings for future investment. In addition, adopting citizen science methods to collect data has an important role in preserving and documenting intangible and tangible cultural heritage. Each method and technique are defined in the following sections.

2.5.1. Traditional Survey Techniques Used in the Recording of Historic Buildings

Manual recording techniques combine tools such as tape measures, pencil and paper for field notes, plumb bobs, and simple cameras. These methods can provide enough information and accuracy to start conservation (Letellier et al., 2007, p. 124; Morgan, 2014, p. 26).

In the past, hand measurement was used as a key component for heritage recording (Letellier et al., 2007, p. 17). For instance, in 1966, such a traditional method was used to record a building at Independence Hall, Philadelphia, Pa, see figure 2. 2 (MacKee, 1970, p. 36). The sketched measurements can then be converted into a drawing in Computer-Aided Design (CAD) software. When digital techniques are not available or expensive, hand measurements can be used to produce detailed drawings of heritage buildings. The cheapness of hand measurements and ease make it widely used in cultural heritage documentation. In contrast, this technique has several disadvantages such as it is time-consuming, long and difficult field-work, where the data must be recorded on-site and cannot be finished in the office, unable to measure curved and complex detailed surface, high accuracy is limited in this method, and cannot survey features with limited access (Hassani, 2015, p. 209).

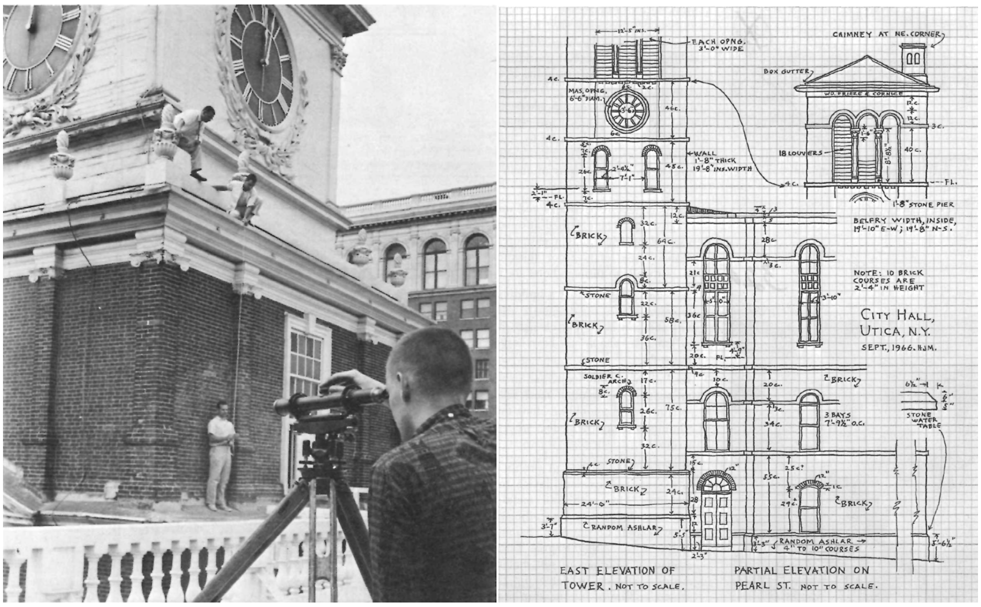


Figure 2. 2: *Hand measurement using two tapes and sketches of Independence hall, Philadelphia, Pa.*
(MacKee, 1970)

Photography is another recording method, considered a significant tool for cultural heritage documentation (Lerma García et al., 2013, p. 1). Photography is easier to understand than drawings. It provides information about the details and condition of a monument through all the preservation processes and captures large areas. Furthermore, measurement analysis can be extracted from photographs when capturing elevations that have completely flat surfaces. However, there are disadvantages when using the photograph method, such as losing important information from the picture due to the shadows cast by objects on the captured surface. Previously, photographs had no in-built coordinates so, which can be time-consuming, and lead to obtaining inaccurate data (Adel Haddad, 2013, p. 215). However, nowadays, modern high-end digital cameras of smartphones have GPS to record positions (El-Ashmawy, 2017, p.67).

In general, there are several advantages to using traditional tools in recording such as their low cost, ease of transport to the site due to their small size, ease of use, the abundant availability of these traditional tools anywhere, ease for a single person to accomplish the recording, and the required training to use one of these tools efficiently and accurately takes a short time (Morgan, 2014, p. 27). In addition, they are known as the cheapest and fastest technique that provides immediate measurements for small and non-complex objects and structures. Moreover, they are fast to install and provide an opportunity for on-site monitoring (Adel Haddad, 2013, p. 214).

In contrast, using traditional tools is time-consuming and difficult to capture or measure fine details and complex forms. Data obtained by these tools are in written notes that then need to be converted into a drawing. This traditional process can be subject to human errors due to misreading, writing, and/or drawing the final product's data and/or measurements (Morgan, 2014, p. 28). Furthermore, no coordinate references are provided when using these old methods (Adel Haddad, 2013, pp. 214-215). However, the latest digital cameras of smartphones have GPS and can record positions. So, the author used digital cameras and smartphones to help obtain better results when recording the tangible information about the heritage buildings, which is discussed in later chapters.

2.5.2. Digital Metric Survey Techniques Used in the Recording of Historic Buildings

Recording using hand measurements and photo survey techniques are the traditional methods used for preserving heritage buildings for many years. Recently, survey techniques such as GPS units, TST, digital photogrammetry, and laser scanners are used for heritage documentation (Moyano et al., 2022, p. 1; Moyano et al., 2020, p. 4; Zhang et al., 2022. P.7; Liu et al., 2022, p. 53; Andrews et al., 2013, p.2).

Geographic location can be a great unique identifier for historic places. Currently, the existing operational Global Navigation Satellite Systems (GNSS) are the Global Navigation Satellite System (GLONASS), GPS, and Galileo systems (Antonopoulou et al., 2017, p. 66). GLONASS is a Russian high-orbit satellite navigation system consisting of 24 satellites (Glonass-iac.ru, 2022); GPS is a worldwide radio-navigation system consisting of twenty-four satellites and their ground stations operated by the USA (Letellier et al., 2015, p. 51); Galileo is the European GNSS consists of 30 satellites, owned by the European Commission, and operated by the European Global Navigation Satellite Systems Agency (GSA) (GNSS.asia, 2018). These systems can help to acquire detailed and comprehensive data quickly with pinpoint accuracy. Where it gives a unique address for each square meter on the earth. For instance, Google Earth can be used as a free tool to acquire the GPS coordinates of a heritage place (Letellier et al., 2015, p. 51). However, the accuracy of GPS can suffer depending on the number of satellite geometry, signal interruption, weather conditions, and receiver design features or quality (Gps.gov, 2022).

The TST appeared to digitally survey horizontal directions, vertical directions, and slope distances (Mill et al., 2013, p. 25). It provides outlines of objects with curved surfaces and produces three-dimensional (3D) wireframe models with high point accuracy (Adel Haddad, 2013, p.214). Modern TST has many built-in digital cameras, which can document the object by capturing pictures as a reference for further off-site applications, however, these pictures have limited resolution (Lachat et al., 2017, p.6; Moyano et al., 2020, p. 4). However, high technical skills are required, and surveys for complex forms can take longer due to the large number of points. Processing may detect false returns of points (Vileikis, 2021, p.180; Adel Haddad, 2013, p.215).

Nowadays, the latest TST can be integrated with, for instance, the GNSS for positioning, additional cameras called Image-Assisted Total Station (IATS) method for documentation, IATS with a scanning function called Image-Assisted Scanning Total Station (IASTS) method, which the latest can be developed by integrating between surveying, spatial geodesy, and photogrammetry to provide high-end technology, which can help to conduct documentation of cultural heritage, etc… (Paar et al., 2021, p.2; Scherer et al., 2009, pp.173-177).

Currently, many different survey techniques appeared in documenting and recording digitally fine details of heritage buildings, such as digital photogrammetry and laser scanning (Moyano et al., 2020, p.4; Haddad et al., 2005, pp. 3-4). The International Society of Photogrammetry and Remote Sensing (ISPRS) and the ICOMOS believe that a monument can be preserved when it is fully measured and development has been documented again and again, taking into account its surrounding environment, and kept in an appropriate heritage information and management systems (Hanke et al., 2002, p. 22).

Digital Photogrammetry methods based on digital cameras are divided into professional digital cameras such as digital single-lens reflex cameras (DSLRs), and amateur digital cameras, such as smartphone cameras (Yilmazturk et al., 2019, p.1). Recently, digital photogrammetry has been widely used in the field of heritage documentation (Vileikis, 2021, p.179; Yastikli, 2007, p. 427). Digital photogrammetry is defined as a measurement technique of an object from images. When capturing two photographs by digital cameras from a minimum of two different stations of an object, 3-dimensional coordinates are produced for that object (Ordóñez et al., 2010, p. 742). It is a quick and accurate method, even for huge and complicated objects (Vileikis, 2021, pp.180-181; Adel Haddad, 2013, p. 216).

Using photogrammetry and PhotoModeler software, for example, can create 3D buildings, calculating and measuring dimensions faster, and cheaper, and it does not require a lot of on-site work (Miaoet al., 2011, p. 608). Nevertheless, photogrammetry is a complicated approach that requires intensive training and professional skills to obtain accurate measurements (Vileikis, 2021, p.185; Morgan, 2014, p. 29). Also, it is affected by the accuracy and resolution of the camera, and the presence of obstacles or lack of proper points to capture limits the photography ability (Hassani, 2015, p. 208).

Laser scanning is the most advanced technology extensively used in the field of architectural, archaeological, and environmental surveying (Moyano et al., 2020, p.4; Adel Haddad, 2013, p. 216). It is defined as 'an active, fast and automatic acquisition technique using laser light for measuring, without any contact and in a dense regular pattern, 3D coordinates of points on surfaces' (Boardman et al., 2018, p. 4). Laser scanning captures data quickly and accurately, even in crowded pedestrian or traffic locations. Unlike other surveying methods, the data can be collected in one visit, and there is no need to re-visit the site due to losing some data. Laser scanning can also be the best way to capture and record irregular building surfaces (Boardman et al., 2018, pp. 6-89; Vileikis, 2021, p.180;). However, a laser-based such as a Terrestrial Laser Scanner (TLS) is expensive and is a heavyweight device. (Alitany, 2014, p. 113). The laser scanner needs skilled experts to apply it to the building documentation process, and processing takes a long time (Vileikis, 2021, p.180). Also, it has many restrictions on documenting surfaces with sharp edges and colour and texture data. Invisible areas, objects with a reflective surface, and small interior spaces limit the ability of laser scanners which prevent a comprehensive survey and fail to provide accurate data about the buildings (Castilla et al., 2021, p.14; Hassani, 2015, p. 210). So, a question arose about what is the possibility of the integration of different techniques to enhance the quality of the acquired data. Could this combination help in gaining rich data collection about heritage sites? (Remondino, 2011, p. 1115). Suggested solutions to these questions are provided and discussed in **chapter 05**. Different techniques for acquiring 3D data based on the object size and complexity of the reconstructed digital model are illustrated in figure 2. 3 (Remondino et al., 2014, p. 14).

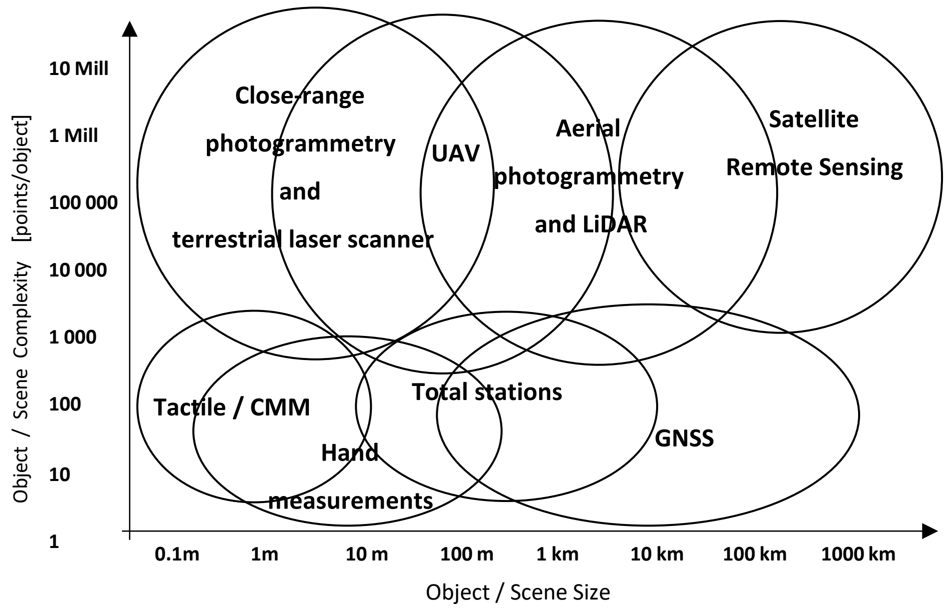


Figure 2. 3: *Techniques for 3D data acquisition.*
(Remondino et al., 2014)

There are different methods of recording heritage buildings. Each recording method has its advantages and disadvantages, as shown in table 2.1 below.

Recording Heritage Buildings Methods				
Recording Tangible Elements			**Recording Intangible Attributes**	
	Pros	**Cons**		**Opportunities**
Measured drawings	▪ Quick on-site.	▪ Difficult to fix missing measurements at plot time.	**Written account**	▪ Help to understand drawings and photographs. ▪ Supports all other record elements by providing locational information, context, description, analysis and interpretation.

Hand measurement	▪ Cheap. ▪ Easy to use and transport to the site.	▪ Time-consuming. ▪ Long and difficult fieldwork. ▪ Data must be recorded on-site and cannot be finished in the office. ▪ Unable to measure the curved and complex detailed surfaces. ▪ High accuracy is limited in this method and cannot survey features with limited access.	**Field notes**	▪ Helps in providing an explanation of measured drawings and assisting in analysing the written report of the heritage buildings. ▪ Field notes include sketches, dimensions, and notes.

Photography	▪ Cheap and easy to use and transport to the site. ▪ Easier to understand than drawings. ▪ Provides information about the details and condition of a monument. ▪ Can capture large areas. ▪ Measurement analysis can be extracted from photographs when the captured object has completely a flat surface.	▪ Losing important information from the picture due to the shadows cast by objects on the captured surface. ▪ Photographs have no in-built coordinates and that can be time-consuming, and lead to inaccurate data.	**Reports**	▪ include images, tables or charts.

Global Positioning System (GPS)	▪ Acquire detailed and comprehensive data quickly with pinpoint accuracy. ▪ Gives a unique address for each square meter on the earth. ▪ Google Earth can be used as a free tool to acquire the GPS coordinates of a heritage place.	▪ There is no international standard for selecting the coordinates of a heritage site. ▪ It is very difficult to use GPS to find coordinates of a heritage place such as rock art caves, heritage cities and, cultural routes existing underneath buildings.	**Inventories**	▪ Provide a list of items such as doors, windows, ceilings, floors, walls, stairs etc...
Total Stations Technique (TST)	▪ Provides outlines of objects with curved surfaces. ▪ Produces 3D wire frame models with high point accuracy.	▪ High technical skills are required. ▪ Surveys for complex forms can take a longer time due to a large number of points.	**Surveying the literature**	▪ such as books, articles, journals, conference studies, etc… to explore previous studies of other authors who have written on a similar subject.

Digital photogrammetry	▪ A cheap, quick, and accurate recording method for huge and complicated objects.	▪ A complicated approach that requires intensive training and professional skills to obtain accurate measurements.	**Historical records from local studies libraries**	Such as: ▪ Paper or digital manuscripts to identify components' names and functions.
	▪ Can create three-dimensional buildings.	▪ It is affected by the accuracy and resolution of the camera.		▪ Historical photographs to identify Shape.
	▪ Can calculate and measure dimensions faster from the 3D object.	▪ The presence of obstacles or lack of proper points to capture limits the photography ability.		▪ Historical stories for recognizing cultural, historical and architectural values, and style, age and significance.
	▪ It does not require a lot of on-site work.			

Laser scanner	▪ Captures data quickly and accurately, even in crowded pedestrian or traffic locations. ▪ Data can be collected in one visit. ▪ Can capture and record irregular building surfaces.	▪ The laser scanner is expensive, and it is a heavyweight device. ▪ Needs skilled experts to apply it to the building documentation process. ▪ The post-processing of the data registration takes a long time around 8 hours if natural targets are used on-site while it takes around 30 minutes if artificial targets are used. ▪ It has many restrictions on documenting surfaces with sharp edges and colour and texture data. ▪ Invisible areas, objects with a reflective surface, and small interior spaces limit the ability of laser scanners.	**Interviews with the public**	▪ Inhabitants' stories of places, life growing up, and the changes in the building use over time.

Table 2. 1: *Methods of recording heritage buildings.*
(Author, 2021)

To sum up, historically, the information about heritage buildings was documented as a drawing and then as a two-dimensional (2D) form. However, lately, survey techniques such as GPS units, TST, photogrammetry, and laser scanners are used for heritage recording. Nevertheless, each technique has its advantages and disadvantages as discussed in the latest articles such as Glonass-iac.ru, 2022; Moyano et al., 2022; Zhang et al., 2022; Moyano et al., 2020; Liu et al., 2022; Gps.gov, 2022; Paar et al., 2021; Vileikis et al., 2021; as well as in older previous research such as Adel Haddad, 2013; Alitany, 2014; Andrews et al., 2013; Antonopoulou et al., 2017; Grussenmeyer et al., 2016; Hassani, 2015; Boardman et al., 2018; Miao et al., 2011; Mill et al., 2013; Morgan, 2014; Letellier et al., 2015.

In this research, the author found that there is a lack of integration between tangible recording methods with intangible recording methods in Saudi Arabia. Therefore, this research integrated these two methods to overcome the restrictions that each method faced independently. This has raised a question about what smartphones' capabilities as capture devices contribute to improving the recording process to obtain accurate records and acquire a better understanding of heritage buildings in Saudi Arabia, which is explored in later chapters.

2.5.3. Digital Approaches Used in Mapping and Modelling Historic Buildings

The need to document and visualize the built heritage assets is increasing for conservation purposes. Thanks to the technological development in the use of digital scanning and photogrammetry techniques. Recently, several approaches and tools have helped to create thematic maps and 3D models of heritage buildings such as GISs and BIM approaches.

As for creating thematic maps, the GIS approach and its platforms are used to create a database including heterogeneous data that can be visualized in their platforms (Tsilimantou et al., 2020, p.2). GIS platforms have been adopted for mapping historical data for heritage conservation and education. They are computer-assisted systems for capturing, storing, retrieving, analysing, and displaying spatial data (Clarke, 1986, pp.175-184). They enable us to see, understand, question, explain, and visualise geographical data using methods that show relationships, patterns, and directions in the shape of maps, globes, reports, and charts. They include layers of geographical information obtained from various sources, allowing visualisation and revealing interrelationships in a map (Pandey et al., 2013, pp.5-6). In addition, GIS has been used extensively for recording data; From a technical perspective, a Historic Geographic Information System (HGIS) is the generation and utilisation of a relational database of historical-geographical information in a geographical information system.

The Environmental Systems Research Institute (ESRI) released several GIS software starting from Arc/Info, and ArcView GIS to ArcGIS, which provided a new generation of users with powerful graphics capability and a graphical user interface (Gregory et al., 2018, p.2). For instance, in England, an online free aerial archaeology mapping explorer was created by Historic England to illustrate identified, mapped, and recorded archaeology utilizing aerial photographs and other aerial sources across England to explore the heritage areas (Historicengland.org.uk., 2021).

In Portugal, A GIS-based workflow was tested on a UNESCO World Heritage Site located in the historic city centre of Guimarães, which includes many heritage buildings. This workflow is for identifying urban features and their processing for index-based fire risk evaluation in heritage buildings. Different tools were used such as QField a smartphone application to obtain and store information, QGIS a desktop software for evaluation and mapping, and a programming language to facilitate information processing. This workflow application was for assessing to what extent heritage buildings are vulnerable to fire, see figure 2. 4 (Tikhonova et al., 2021, pp. 1-3).

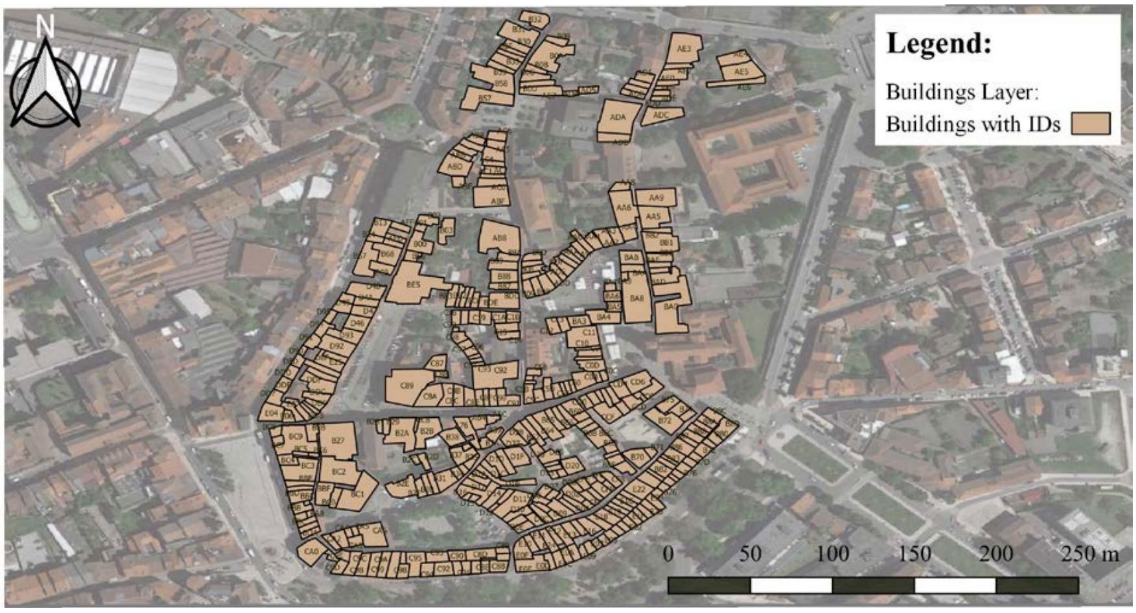


Figure 2. 4: *Building layer with unique numeric IDs and overlayed with areal Google Satellite view in QGIS.*
(Tikhonova et al., 2021).

In Nottingham City, UK, the local list has been compiled by the Nottingham Civic Society in consultation with the general public for many heritage assets remains, which are not recognised or protected by Historic England due to not meeting the criteria for the national listing, to avoid the risk of being neglected or lost through demolition. The local list is presented on a map that illustrates buildings, historic landscapes, and archaeological remains and their addresses, locations, and descriptions. The Nottingham City local and national list can be viewed on the Local List Mapping Website (Figure 2. 5) or the City's GIS Insight Mapping Service, see figure 2. 6 (Nottingham City Council, 2024).

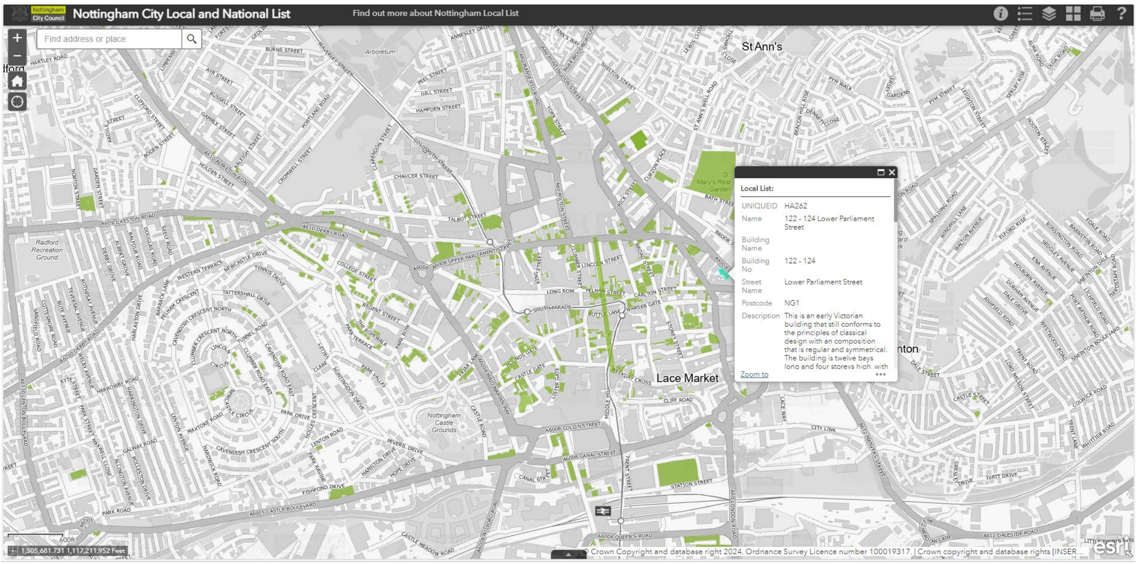


Figure 2. 5: *The Nottingham city local list mapping website.*
(Nottingham City Council, 2024)

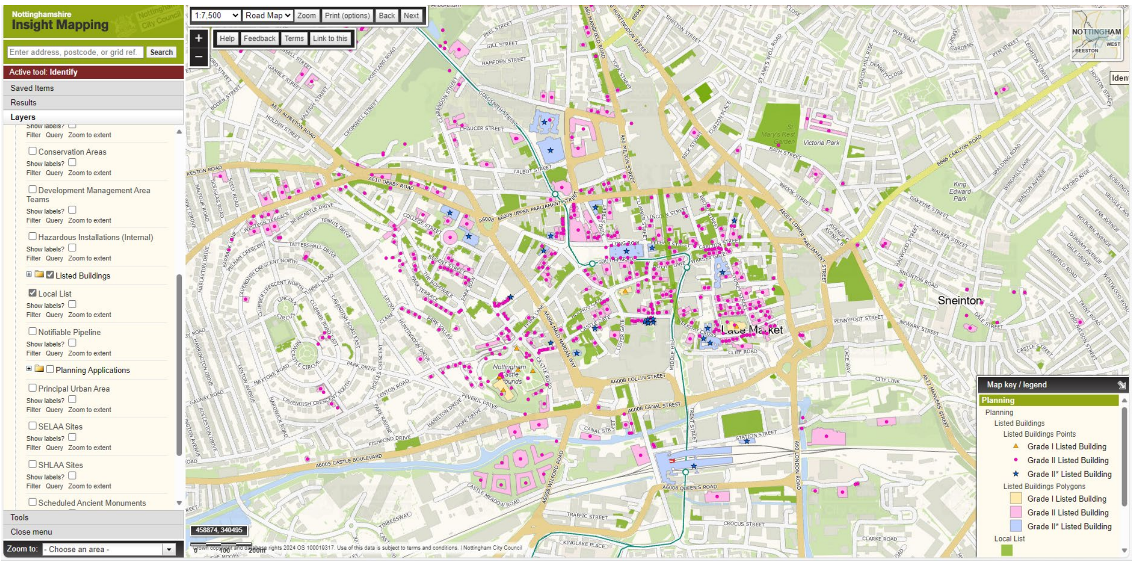


Figure 2. 6: *The Nottingham city GIS insight mapping for local and national lists.*
(Nottingham City Council, 2024).

As for creating 3D models of heritage buildings, research conducted in Seville city in Spain to examine the capability of using 3D models designed in GIS environments for managing and conserving historical buildings (Figure 2. 7), which is one of the strategic actions of the Master Plan for Conservation of Heritage Municipal Buildings (PD-PHiM). Many significant heritage buildings, that include different typologies, chronological scales, and uses, are analysed. An institutional open data including 3D mapping of urban environments and its publication was the initial work begun by the Seville Spatial Data Infrastructure. The work was developed in this research to achieve an increased semantic enrichment of urban models by increasing the Level of Details (LoDs) (Hidalgo-Sánchez et al., 2022, pp. 1-23).

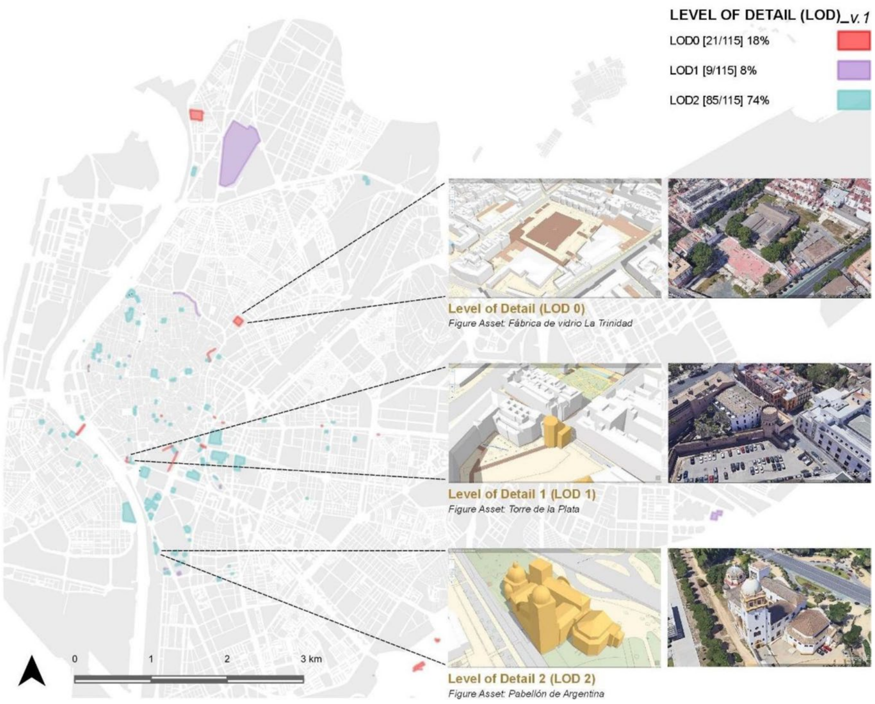


Figure 2. 7: *The LoDs of the 3D-GIS model for the PD-PHiM.*
(Hidalgo-Sánchez et al., 2022).

In traditional Malay settlements located in Malaysia, a conservation approach was tested. This approach adopted the integration between photogrammetry data extracted from DJI Phantom 3 drones and laser scanner data extracted from Topcon IP-S3 HD, a mobile laser scanner, to construct a high-resolution 3D GIS city model (Figure 2. 8), focusing on the architectural uniqueness of Malay buildings. MAGNET Field software was used for capturing the data and providing accurate measurements, and the Magnet Collage software was used for further point cloud processing such as combining and visualising point cloud data from different resources including Light Detection and Ranging (LIDAR) scanners, mobile mapping, GIS, or other sources. In addition, Agisoft photoscan software was used to create orthophotos and Digital Surface Models (DSM) from images collected by drones. The reconstruction of the 3D model was conducted by importing the collected data in ArcGIS CityEngine, ESRI software (Noor et al., 2020, pp.1-11).

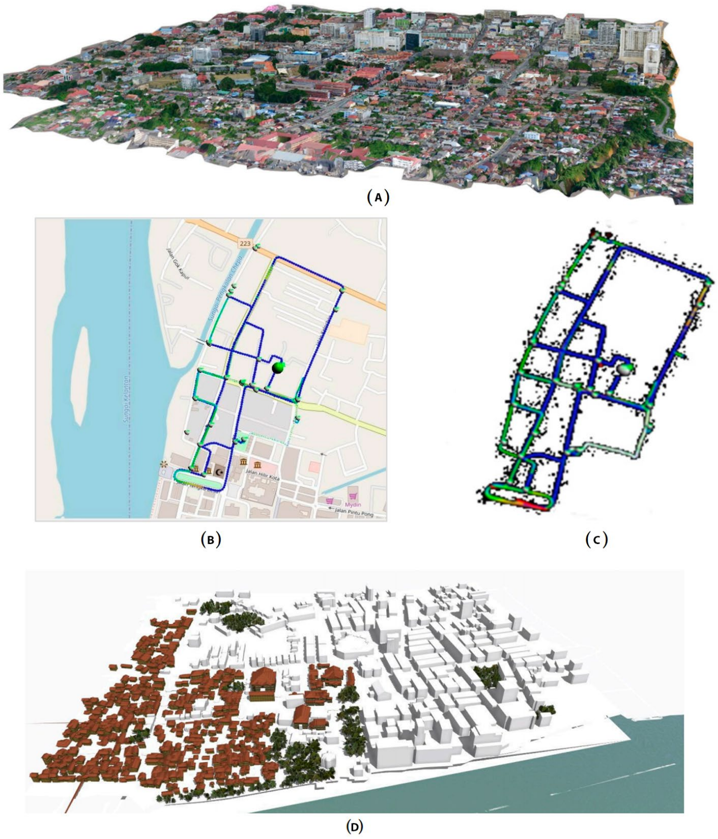


Figure 2. 8: *(A) 3D images obtained from drones; (B) The path of movements in a point cloud obtained using a mobile laser scanner; (C) Different colours reflecting surface and path of movements because of time difference; (D) The Kota Bharu Malay heritage city 3D scene obtained by combining drone and mobile laser scanner data.*
(Noor et al., 2020)

In Firenze city centre in the central Tuscany region in Italy, a UNESCO heritage site, a workflow is presented to propose "a practice for the creation of a relational digital archiving system applied to the knowledge acquired on the stone materials of the external coating of some monuments of international interest". The workflow purpose is to better understand the present condition of the monuments and be beneficial as a reference to monitor, maintain, knowledge, and use in the future. GIS was used for its ability to represent and analyse oriented geometry, update, and implement the built database, the storage capacity and ease of retrieval, and single management of considerable and heterogeneous data. To test the performance of the proposed workflow, it was applied to three different historical buildings including the Battistero di San Giovanni, the Campanile di Giotto, and the Duomo di Prato, which are in the centre of Tuscany, Italy. A lithological cartography was produced and processed by field surveys, geognostic surveys and photo interpretation to create a lithological map of the stone coatings of the different historical buildings (Figure 2. 9). GIS tools were applied to collect geological, and geomorphological surveys, and spatial data in the fieldwork. QGIS is a free desktop GIS that was used to support viewing, editing, and analysis of geospatial data. In addition, mobile apps such as QFIELD integrated with QGIS were used to allow efficient work on GIS data outdoors, as well as using INPUT APP/MERGIN, a free and open source built on top of QGIS, for collecting data. The INPUT APP/MERGIN is divided into a mobile app project to collect data and a web service for data synchronization for collaborative management of data (Iandelli et al., 2021, p.1-13).

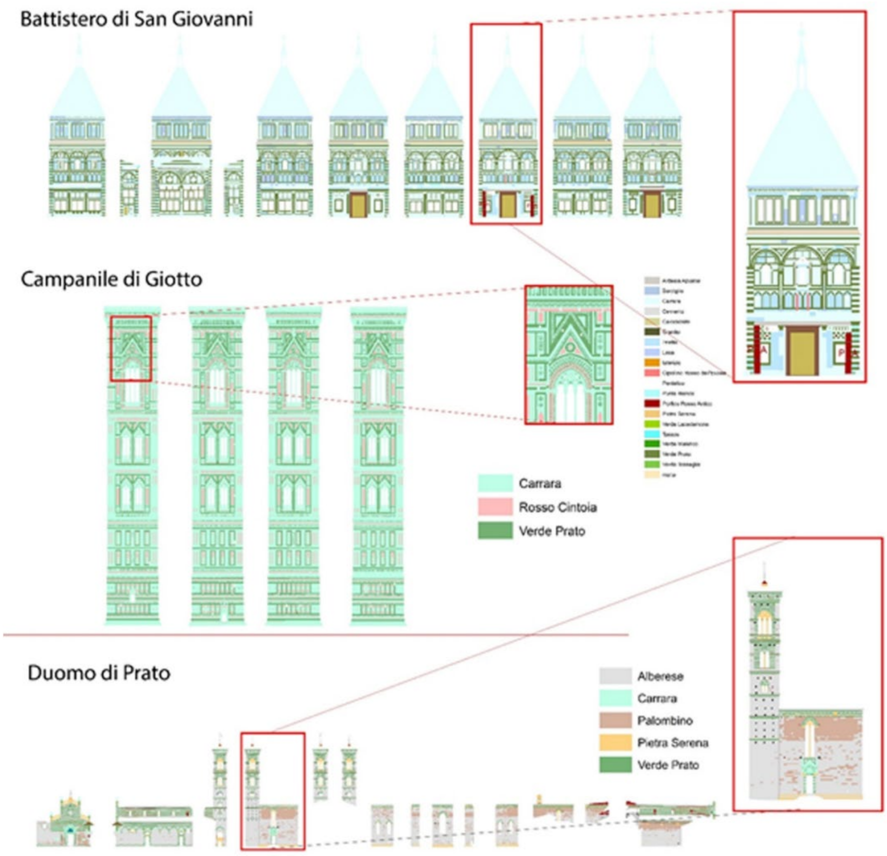


Figure 2. 9: *Lithological map of three heritage buildings.*
(Iandelli et al., 2021)

Web applications as tools can be used as open source for mapping memory and location. For instance, the Barlett Centre for Advanced Spatial Analysis, University College London created a Memory Map Toolkit. It is an open web application for creating interactive maps for heritage or any other field by combining rich media content with an interactive map, which can be viewed either via smartphones, computers, or tablets. It was developed in collaboration with the Survey of London, the Space Syntax Laboratory, and the writer and artist Rachel Lichtenstein. The app was built using Django software to manage its content, and it was built using MapboxGL, a JavaScript library for building advanced web maps. The Memory Map Toolkit supports Mapbox, an American provider of custom online maps for websites and applications, Maptiler Cloud, a cloud-based mapping platform, as well as self-hosted raster and vector tiles (University College London, 2020; Mapbox, 2023; The Lincoln Motor Company, 2013; TrustRadius, 2024).

There are other methodologies used for creating 3D models of heritage buildings, such as BIM, which is adopted in many heritage buildings. It is significant to acknowledge that BIM is a process that has been in the field for at least 15 years and was developed during the early stages of CAD (the late 1970s – early 1980s) (Eastman et al., 2011, p.36). According to the National BIM Standard-United States, BIM is a digital representation of a facility's physical and functional characteristics and a shared data resource for information about a facility, shaping a reliable basis for decisions during its life cycle; defined as existing from the earliest conception to demolition. While BIM has been used for contemporary architectural buildings, it has been adopted recently for preserving and managing heritage buildings due to the absence of information that helps them survive (Garagnani et al., 2013, pp.87-92). Historic Building Information Modelling (HBIM) is a modern methodology that supports documenting heritage buildings (Fai et al., 2011; Garagnani et al., 2013; Volk et al., 2014). It is a method for creating, preserving, documenting, and managing complete engineering drawings and information for heritage buildings (Megahed, 2015). In addition, HBIM provides an understanding of the current state of repair, informing schedules, and changes, forming renovations and conservation policies and planning (Megahed, 2015).

Many researchers have adopted this methodology in their studies. For instance, an experiment study has been conducted on the Cortijo del Fraile heritage building, located in Níjar Municipality at Almería city in Spain, which has a cultural interest and is listed in the General Catalog of the Andalusian Historical Heritage. This experiment was to document the heritage building data due to the building being abandoned for a long time, its facilities being destroyed, and it was exposed to the risk of demolition. The data were captured using Unmanned Aerial Vehicles (UAVs) photogrammetry technology to obtain aerial photographs of the four facades and the interior of the building. The obtained data were then processed in Agisoft PhotoScan Professional software to construct 3D point clouds and then a realistic textured 3D mesh of the heritage building. Autodesk ReCap software was also used to link the 3D point clouds. HBIM was adopted to carry out the research aim as a methodology for creating 3D models of the building and managing data on historical architectural elements by using BIM software such as Autodesk Revit. The 3D modelling is done manually of all the building elements, and it shows the buildings' information in detail. Then, materials and textures were added to the 3D model by using Lumion software, see figure 2. 10 (Carvajal-Ramírez et al., 2019, pp. 271-276).

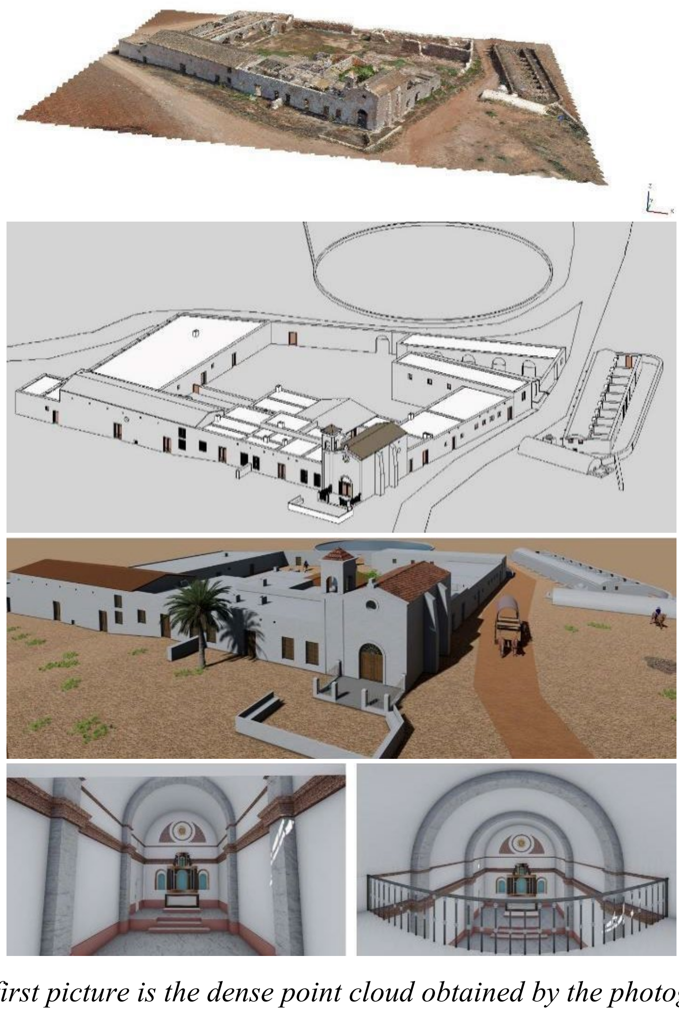


Figure 2. 10: *The first picture is the dense point cloud obtained by the photogrammetry technology; the second picture is the HBIM model of the building created in Revit; the third, fourth, and fifth pictures are the renders obtained with Lumion software.*
(Carvajal-Ramírez et al., 2019).

In Turkey, the integration between HBIM and LIDAR was used to provide documentation and restoration needs for the Ayfer Sönmez historic building in Erminek town due to its significant architectural features and characteristics. The documentation started with using a TLS, particularly the Faro S120 Laser Scanner for recording the building measurements. The acquired point clouds were then processed with the help of Scene software and Autodesk Recap software including alignment, flittering, cleaning, and editing the file format to be exported to Revit software for modelling the heritage building. Before modelling, the original coordinates of the point cloud were set in Revit software to ensure the created HBIM model was georeferenced. When the 3D model was created (Figure 2. 11), consideration was given to choosing the type of walls and their geometric characteristics to obtain a historic building information model and to reach LoD 350; the LoDs in the BIM environment are explained in detail in **chapter 06**. The created HBIM can be used in energy efficiency analysis, structural analysis, disturbance analysis, and mapping (Özeren et al., 2021, pp.27-30).

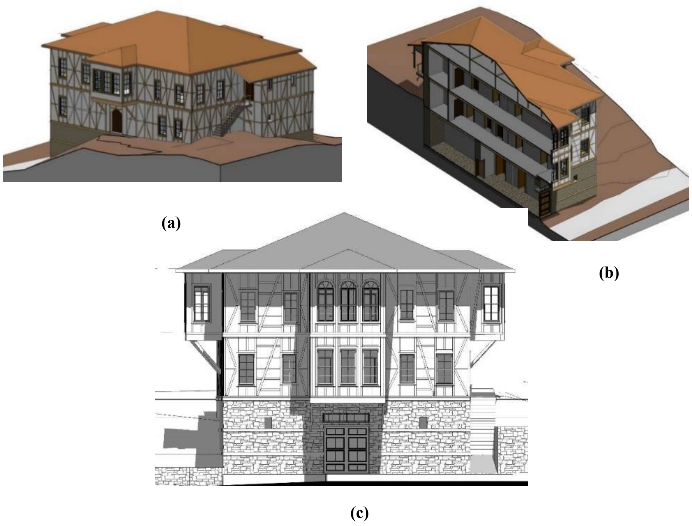


Figure 2. 11: *(a) HBIM Structural model; (b) Section model with LoD 350 detail; (c) HBIM modelling LoD 350.*
(Özeren et al., 2021).

A mesh-to-HBIM modelling workflow and an integrated BIM management system were developed to connect HBIM elements and historical knowledge (Figure 2. 12). A study conducted on the St-Pierre-le-Jeune Church, Strasbourg, France, used two types of UAVs including the Sensefly Albris and the DJI Phantom 3 Professional to acquire aerial images and terrestrial images of the exterior to generate the 3D point cloud (Yang et al., 2019, pp.1-14).

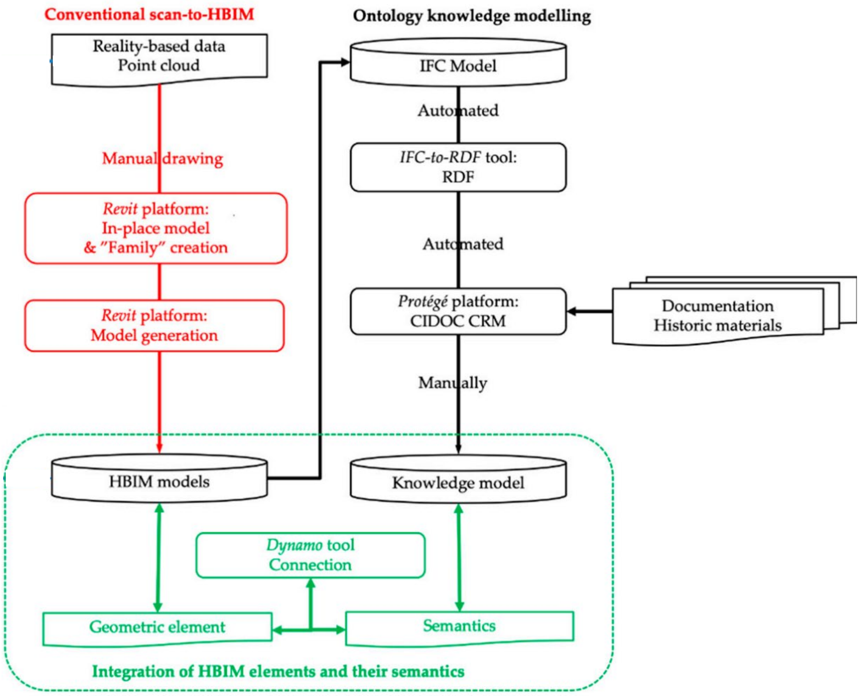


Figure 2. 12: *The integration of the HBIM modelling and ontological knowledge workflows.* (Yang et al., 2019)

The point cloud was exported to Autodesk Revit, a BIM system, to use as a reference for creating the HBIM model of the heritage building manually by visual interpretation, based on the building elements' locations determined by the point cloud, see figure 2. 13) (Yang et al., 2019, pp.1-14).

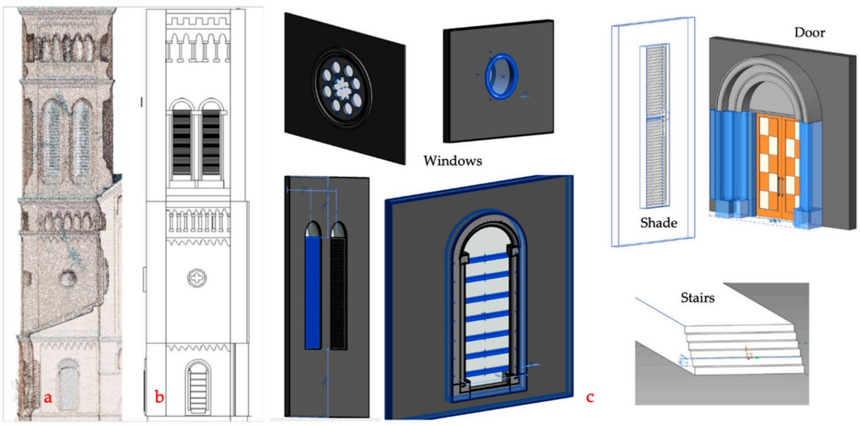


Figure 2. 13: *(a) The imported point clouds in the BIM system; (b) The created HBIM structures; (c) Samples of classes of the church elements created based on the point cloud.* (Yang et al., 2019)

After the HBIM model was created, the extension of the HBIM capability of linking heterogeneous data interactively was conducted by linking databases between the HBIM system and the ontology-based system. The same identifier was assigned to both representations of the corresponding entity in the two modelling environments based on the unique IDs of elements, see figure 2. 14 (Yang et al., 2019, pp.1-14).

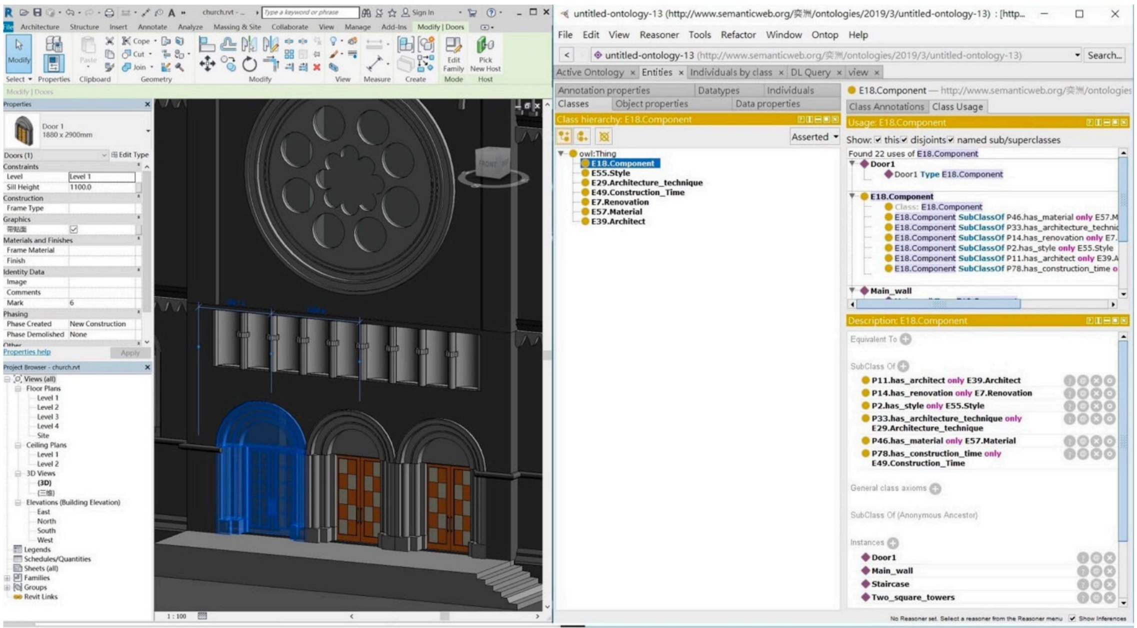


Figure 2. 14*: Ontological knowledge modelling for the HBIM entities.*
(Yang et al., 2019)

Hence, the created HBIM model including geometric elements in the Autodesk Revit was exported to IFC format and transferred to the ontology RDF format by using the IFC-to-RDF conversion tool. To enrich the HBIM entities' properties and relationships, the ontology knowledge model was constructed using the Protégé platform. The data properties act as the attributes and object properties act as the relationship between different classes. The integration between the HBIM model including geometric elements and the knowledge model including semantic data was conducted in the BIM environment through Revit Dynamo, a visual programming platform. It was possible to browse the semantic information documented in the ontology database and the 3D model in BIM at the same time in the platform, see figure 2. 15 (Yang et al., 2019, pp.1-14).

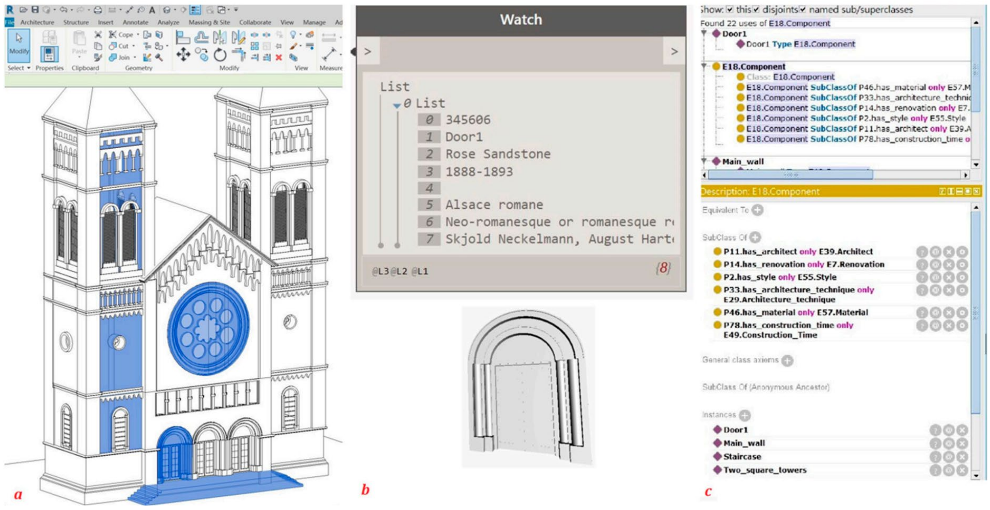


Figure 2. 15: *(a) The selected elements of the HBIM model in the Revit platform display the knowledge in the watch window in the Dynamo interface (b) which derives from an earlier defined knowledge model (c).*
(Yang et al., 2019)

To sum up, the GIS and HBIM approach and their tools play a significant role in creating maps and 3D models of heritage buildings for documentation, conservation, restoration, management assessment, monitoring, knowledge, investment, digital archiving, and use in the future. The following tools work as data collection, processing, mapping, and/or visualization tools: terrestrial or aerial digital photogrammetry tools, terrestrial or LiDAR laser scanner tools, QField application, MAGNET Field software, and MERGIN application; Magnet Collage software, Agisoft photoscan Professional software, Autodesk ReCap, Scene software, Autodesk Recap software, Lumion software and Protégé platform; QGIS software, ArcGIS CityEngine software, MERGIN application Autodesk Revit Software, Revit Dynamo, Django software, MapboxGL, Mapbox, and Maptiler Cloud platform.

Based on that, the author found that there is a lack of integration between the GIS approach and the BIM approach in heritage buildings in Saudi Arabia. Therefore, this research integrated these two methods to create a holistic digital record of heritage buildings in Saudi Arabia and to overcome the limitations of each approach. This has raised a question about what is the role of digital citizens in enriching the HBIM databases and geospatial databases to enhance the digital local content? which explored in later chapters.

2.5.4. Citizen Science as a Method in the Context of Cultural Heritage

In research related to the digital humanities, which is mentioned in **Chapter 01**, the work practice is referred to as “crowdsourcing,” which is the process of motivating a group of people via the internet to contribute to obtaining desired knowledge, goods, or services. Crowdsourcing has a subsection called citizen science, which has its origins in modern science (Brigham, 2022, p.30; Silvertown, 2009, p.467). Citizen science has been defined as collecting and/or processing data by a volunteer as part of a scientific research process, especially in ecology and environmental sciences (Silvertown, 2009, p.467), however has evolved to include diverse sciences (Robinson, 2018, p.27). Citizen science can be described more broadly as the cooperation of a group of non-professional volunteers who can participate and contribute to different scientific research that has various aims, scopes, and results (Gibb, 2019, p. 17). Citizen Science is the practice of people's participation in the processes of hypothesis creation, prediction, experimental measurement, and/or hypothesis improvement to construct science to be preserved for academic institutions, professionals, and industry (Brigham, 2022, p.30).

Participation in projects that adopt citizen science is graded into four levels. The first level: involves the participants contributing to a small part of the research process, for example by providing simple data or providing computing power, referred to as ‘volunteered computing’, and so-called " crowdsourcing". The second level: participants engage as a primary resource who are required to conduct basic training or follow simple instructions before implementing any mission, and so-called ‘distributed intelligence’. The third level: participants define the problem and collect the data about it, while its analysis is done by collaboration with specialists, and so-called ‘participatory science’. As for level four: participants take part in all stages of the research, from defining the problem and collecting it to analysing the data, and so-called ’extreme citizen science’) Hecker et al., 2018, p. 54; Brigham, 2022, pp.31-32).

Several projects have adopted citizen science in their implementation. In the UK a science initiative called the Open Air Laboratories (OPAL) project enables people to contribute to scientific research through practical applications in nature. Where the project aim of the partnership between experts with local people is to exchange knowledge, experience, and skills, and to explore and investigate the natural world, especially local wildlife and their habitats, under changing environmental situations (Imperial College London, 2024).

The Extreme Citizen Science (ExCiteS) practice group at University College London, which looks after local needs, traditions, and culture, has several projects that use citizen science. For instance, the “From Non-Literate Data Collection to Intelligent Maps" project aims to enable people who are illiterate or have limited knowledge of using smart devices such as smartphones and tablets to collect, share, and analyse spatial data. This is for the purpose of designing, developing, evaluating, and publishing a public platform used in multiple projects and in several disciplines such as human-computer interaction, anthropology, and geographic information systems. This project aims to develop the environment through shared representations of its situation, the community's relationship to it, and any challenges it faces, for the purpose of creating community memories. In addition, the project aims to create smart maps to collect spatiotemporal data for visualization, analysis, and editing (University College London, 2024).

The European Citizen Science Association (ECSA) was established as an organization in 2014, which contributes to raising the standards of science, stimulating the development of citizen sciences, and supporting people's participation in scientific research processes in Europe through several sciences, namely natural sciences, humanities sciences, social sciences, and arts sciences. These sciences are open and available to people through the ECSA platforms (European Citizen Science Association, 2024). For instance, EU-Citizen.Science platform is created to share citizen science knowledge, tools, training, and resources through and for the community to be a reference for citizen science knowledge (EU-Citizen.Science, 2024).

Regarding citizen science projects related to protecting and documenting intangible heritage, citizen science researchers can communicate with community members and involve them in projects. For example, in citizen science projects that apply the oral history approach, information can be obtained from community members about historical events, traditions, or daily life, where their involvement helps to produce citizen science projects. This type of project helps to increase social cohesion, linking generations, encouraging appreciation of the value of cultural heritage, and creating cultural resources. Cultural heritage works to reorganize societies based on intercultural dialogue, respect for identities, and a sense of belonging to a community. Intergenerational dialogue is a research tool that can help conserve cultural heritage. For instance, the BreadTime project in the rural region of Lesachtal, Austria, aims to protect and document local knowledge and practices related to the intangible cultural heritage of the ‘Lesachtal bread’, which is listed in the UNESCO Intangible Cultural Heritage list. This is conducted by engaging citizens, either through dialogue in open communication spaces or by writing down experiences in a collection of biographical records. The youth were taught the oral history method to conduct interviews with local elders to learn about the importance of traditional agriculture in their daily rural lives. The method of intergenerational communication resulted in a documentary film of local narratives and local practices related to flax (Hecker et al., 2018, pp.453-458). Utilizing tools such as storytelling and visualization helps deliver information faster. One of the powerful tools in citizen science is "CITIZEN SCIENCE Storytelling". It has a different impact on the human mind and emotions. When information is told as a story, it turns into personal thoughts and experiences for listeners and speakers they can remember (Hecker et al., 2018, pp. 455-456).

When citizen science is applied to the field of heritage science it is called Citizen Heritage Science. There are several projects that have adopted citizen heritage science in preserving tangible heritage. For instance, in the Monument Monitor project, visitors' photographs of heritage sites were used to help monitor the condition of sites under Historic Environment Scotland (HES) (Brigham et al., 2021, p.1). In addition, the field of citizen heritage science, especially with regard to heritage buildings, has witnessed recent developments and contributions through various studies (Brigham et al., 2022, p.33). From the latest research, a comparison of two approaches was conducted in research that uses citizen heritage science to monitor two sites within the Monument Monitor project before and during the first COVID-19 lockdown. The archaeological importance of the Machrie Moor Standing Stone Circles, located on the Isle of Arran, and Clava Cairns, close to the Culloden Battlefield, the ‘guided’ approach and ‘open’ approach were used to collect their data and compare them. The guided approach was through placing banners on both sites, where visitors were asked to use their smartphones to take and submit photos for different purposes. Due to the Machrie Moor Standing Stones site being vulnerable to flooding due to its topography, the site photos act as evidence of waterlogging at the site to understand the extent of the problem across the seasons. As for the Clava Cairns, when parts of the cairn entrances began to erode due to the increase in the number of visitors, photos were required to monitor any changes that occurred on the ground, walls, and stones. As for the open approach, during the Corona pandemic lockdown, a campaign entitled “Monument Monitor at Home” was established. The approach requested the public to send any photos they had taken of the requested locations. After collecting the data, the results are analyzed (Brigham, 2022, p. 1-6).

An online platform called GlobalXplorer supports the use of cutting-edge technologies and citizen science to protect and preserve the world's cultural heritage. It uses satellite imagery, 3D mapping, machine learning, and crowdsourcing as one of the levels of citizen science in analyzing satellite images to make the data easily accessible and open to the public around the world (Draper Richards Kaplan Foundation, 2024). Also, the SiteWatch project was established to identify archaeological sites, buildings, historical places, corridors, neon signs, bridges, and structures by a network of trained volunteers to monitor and document any changes that occurred to them. The engagement of the trained public helps land management agencies and their preservation partners conserve cultural resources in New Mexico (Badner, 2019).

To help make British cities more sustainable, the Alan Turing Institute has launched the Coloring Cities Research Program (CCRP), which includes a free and open platform called Coloring Britain to share knowledge about city buildings. This platform aims to increase data access among countries to help improve its quality, efficiency, sustainability, and resilience. Data and additional features are newly added by the public, each in their field, in the Colouring Cities maps to develop the platform. From here it is clear that the platform adopts citizen science to enrich its databases (Colouring Britain, 2024). For example, volunteers can share their knowledge in colouring London's buildings to create accurate and informative maps through the Colouring London platform, which allows collecting, creating, visualizing and opening spatial data on all of London's buildings. Colouring London, 2021).

In a collaboration between the UCL European Institute, the Faculty of Arts and Humanities and the Bartlett Centre for Advanced Spatial Analysis (CASA), an interactive map of London has been created to illustrate London's remaining relationship with European culture through texts written by European and British writers, artists, intellectuals as guests, visitors, refugees, students, etc. London can be explored through this interactive map and categorised by theme, language, or free search for desired words.

The map was created with the help of the Memory Mapper toolkit developed by Dr. Duncan Hay. Miguel Navarro produced the images and Lucia Scazzocchio produced the audio recordings to let audiences imagine London in a different way (MapTiler & OpenStreetMap contributors, 2024).

To sum up, citizen science plays a significant role in preserving and documenting intangible and tangible cultural heritage. Professional and non-professional audiences are the main methods for collecting data in citizen science. Several projects and studies used platforms and tools that support citizen science which can display the collected data such as EU-Citizen.Science platform, GlobalXplorer platform, Colouring London platform, and the Memory Mapper toolkit. Based on that, the author found that there is a lack of adoption of citizen science in preserving and documenting intangible and tangible cultural heritage in Saudi Arabia. Therefore, this research adopted citizen science methods to create a holistic digital record of heritage buildings in Saudi Arabia as well as to overcome the limitations of other approaches.

2.6. Best Practices in Heritage Buildings Recording Internationally

In Leicester, England, the body remains of King Richard III was discovered in 2012 and reburied in Leicester Cathedral. A plan was made to design a tomb and rearrange the cathedral due to the increased number of visitors. To accomplish that plan, a full 3D scan of the interior of the building, including all structural features and existing fixtures, monuments, intricate plaques, and tombstones, was provided. In addition, the exterior elevations of the Cathedral have also been captured as well as the surrounding landscape (Figure 2. 4).

The recording tools used were the Leica P40 laser scanner and 360° panoramic photography to better understand the complete environment of the Cathedral. Registration of the scanned data was done by using Leica Cyclone software. The laser scanner was used due to its speed, accuracy, and ability to provide a comprehensive scan of the complex internal and external surfaces of the cathedral. In addition, laser scanning allowed the project to be delivered on time for heritage recording and reinstatement (Boardman et al., 2018, p. 82).

Although several techniques were used to record the Leicester Cathedral's tangible elements, and then it was converted into a 3D model, it lacks materials and textures as well as intangible attributes such as its name, history, geographical location, story, cultural values ... etc, and this can lead to misunderstanding of the actual condition, materials, and appearance of the building. So, in this research, there is a need to integrate tangible elements and intangible attributes to better understand the physical and cultural dimensions of a heritage building.

Figure 2. 16: *Leicester Cathedral: a model of the exterior (Left pic); a model of then interior (Right pic). © Plowman Craven.*
(Boardman et al., 2018)

The "good practices in heritage conservation are based on accurate information about conditions, materials, and transformation of built heritage sites" (Mezzino et al., 2017, p. 143). In Bagan, a multidisciplinary team developed a strategy to document four temples using different documentation techniques, including image and non-image-based, to prevent and manage the damages of natural disasters and to support any modification. Electronic Distance Measurement (EDM), terrestrial and aerial photogrammetry, laser scanning, record photography, and hand measurements were used to record the Loka-hteik-pan temple, see figure 2. 5 and 2. 6 (Mezzino et al., 2017, pp. 143- 148). Even though the final 3D points cloud of the tangible elements of Loka-hteik-pan temple was captured also by several recording methods, the 3D point cloud is not converted into a 3D model, which makes it difficult to extract engineering drawings from it to obtain accurate dimensions of each element such as doors, windows .. etc, and it is difficult to add any further intangible attributes on the 3D point cloud. So, in this research after recording and obtaining a 3D point cloud of a heritage building, a digital record needs to be created consisting of a 3D model of the heritage building, and its tangible and intangible information to be added to the model to allow the extraction of tangible elements' engineering drawings to obtain accurate dimensions and/or intangible attributes to understand the cultural aspects of any element.

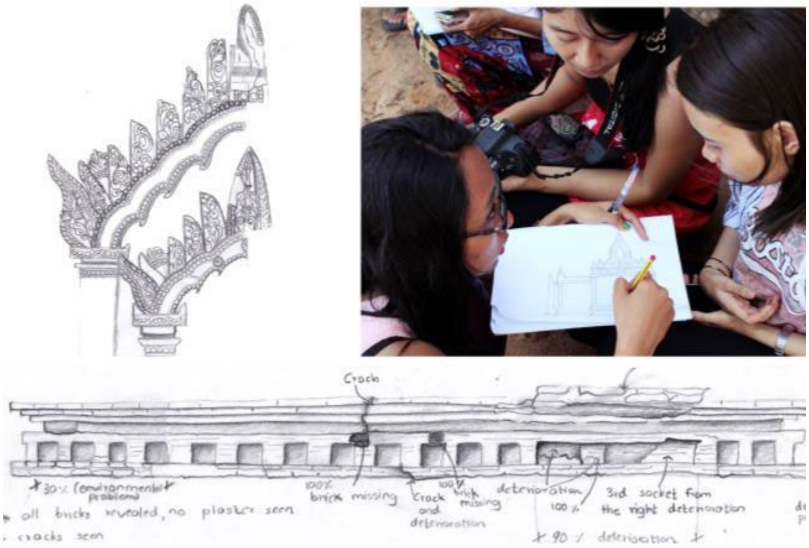


Figure 2. 17: *Examples of the field notes and sketches developed on the site.*
(Mezzino et al., 2017)

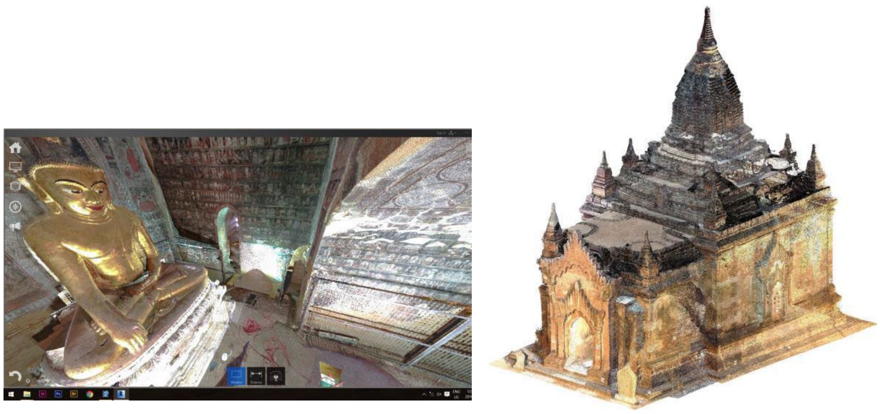


Figure 2. 18: *Point cloud model of Loka-Hteik-Pan temple, point clouds coming from the different techniques (Aerial and terrestrial photogrammetry and laser scanning) combined in Autodesk ReCap.*
(Mezzino et al., 2017)

Another paper identifies the relationship between tangible and intangible elements in the Old Quarter, Melaka Heritage City, Malaysia, which is essential for establishing cultural assets. The study created a database to identify and document cultural heritage resources for protection purposes by using a systematic tool called the Cultural Mapping approach.

This approach collects, analyses, and synthesizes information such as location, name of the element, types of cultural resource, and geographic reference points or GPS coordinates to describe and visualize the cultural resources, and then plotted on a map using GIS technology, see figure 2. 7 (Othman et al., 2013, p. 577-578). Although the Cultural Mapping approach provides intangible attributes of a heritage building and is georeferenced, it lacks information on tangible elements such as building dimensions and materials. In addition, even though, the Cultural Map created by Othman et al., is for residents and visitors, it does not exist digitally, so no one can find this information. Therefore, this research disseminated the information in an open source to allow the user access to the information to deeply understand the physical and cultural dimensions of a heritage building in Saudi Arabia.

Figure 2. 19: *Cultural resource mapping of single properties.*
(Othman et al., 2013)

In the field of smart construction and digital design, the Manchester Town Hall Building project is evidence of how valuable digital engineering can be during the preconstruction and production delivery phases. The UK government adopted BIM in this project to demonstrate its potential for design, construction, and future facilities management purposes and major stakeholders have learned about the project by displaying 3D virtual tours, see figure 2. 8 (Antonopoulou et al., 2017, p. 7).

While BIM can create a virtual and intelligent model of a building, its use is limited to expert users who have access to expensive hardware, and software and have high technical skills. Therefore, the author of this research developed an open digital record system without the need for expensive devices or high technical skills. The author's research motivation is to explore novel survey techniques using smartphone devices to record heritage building information and access it easily through cloud-based applications such as websites, allowing local citizens or visitors to access heritage building information. From this basis, the recording can help promote the visibility and importance of heritage buildings and enhance the educational process in societies.

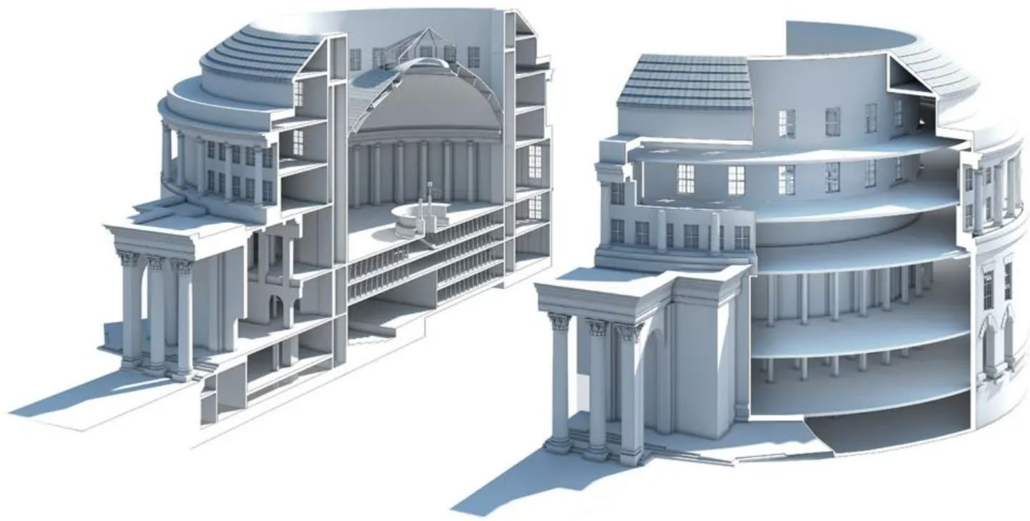


Figure 2. 20: *The Manchester Town hall conservation project.*
(Antonopoulou et al., 2017).

In figure 2. 9, the produced HBIM can be transferred into a WEB-based game engine platform to help users interact and access the semantic rich information that existed in the model data (Murphy et al., 2019, p. 906). Although the Archival and Storage Repository system of building information was drawn up, it was not tested on people to see if its results could effectively enhance the educational process. Therefore, this research created an open digital record system as a reference for interior designers, architects, and others interested in heritage buildings to find out how effective this system is in developing digital recording and enhancing the educational process.

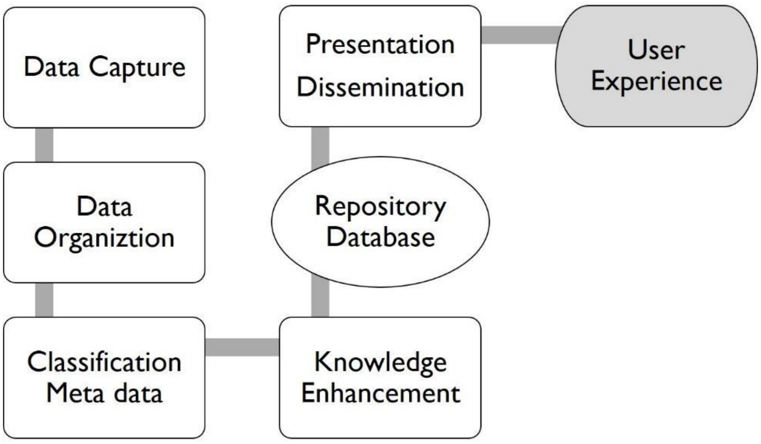


Figure 2. 21: *The architecture of the system of archival and storage repository.* (Murphy et al., 2019).

In April 2019, the roof of a famous heritage landmark located in Paris, France called Notre Dame Cathedral, was damaged by fire (Figure 2. 10). However, restoration from existing documents and manuscripts cannot provide an accurate restoration document (Elbaz et al., 2019, p. 59).

Figure 2. 22: *Fire at Notre Dame Cathedral.*
(BBC News, 2019).

HBIM and Game Engine can be bidirectional data transmission tools (Edwards et al., 2015, p. 2). In 2014, a digital game called Assassin's Creed Unity was created to simulate the cathedral's appearance and character, and it was modelled using photogrammetry in Obisoft (Figure 2. 11). The Vassar College historian Andrew Tallon made another one by using a laser scanner based on more than 50 locations as shown in figure 2. 12 (BBC news, 2019). However, the developers have rejected the idea of using these records to rebuild the roof of Notre Dame Cathedral because they are inaccurate (BBC News, 2019; Elbaz et al., 2019, p. 59). Even though digital photogrammetry and laser scanners were used to record Notre Dame Cathedral in France before the fire, the idea of retrieving information from game platforms for restoration purposes is not acceptable due to the low accuracy of the information.

Figure 2. 23: *A digital game called Assassin's Creed Unity was created by Obisoft.*
(BBC News, 2019).

Figure 2. 24: *A 3D point cloud of Notre Dame cathedral made by using a laser scanner.* (BBC News, 2019).

Luckily, Art Graphique Et Patrimoine (AGP), a French company specializing in 3D digitization and modelling of cultural heritage monuments, has scanned the Notre Dame cathedral in 150 different scan positions of the exterior and interior structure between 2014 and 2016 by using helicopters, drones, and terrestrial scanners. The French government asked AGP to digitally recreate the entire structure of Notre Dame based on their archives which took two months with six supercomputers. As a result, BIM was adopted by AGP to digitally rebuild the cathedral, where integration between a detailed 3D of the building and its architectural elements information is conducted for future restoration work, see figure 2. 13 (Bock, 2019). This clarifies the significant role of Volunteered Geographic Information (VGI), where individuals can use digital tools to collect, analyse, and share geographic information about heritage buildings (Ferster et al., 2018, p.26). So, this research must utilize multiple methods to obtain information, considering the appropriate accuracy of the information in the digital record so that it can be referenced in the future for any conservation work.

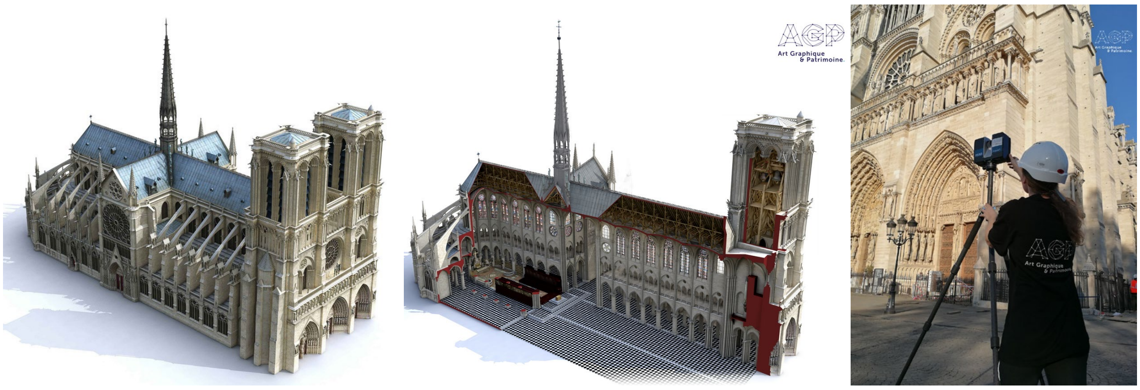


Figure 2. 25: *The adoption of BIM by AGP to digitally rebuild the Notre Dame cathedral.* (Art Graphique Et Patrimoine, 2010-2016).

To sum up, internationally, there is a lack of studies integrating information on tangible elements and intangible attributes of heritage buildings. Furthermore, information sources of heritage building records are often scattered, as no single source can be referred to for understanding the physical and cultural dimensions of a heritage building. Therefore, a single digital record of a heritage building that includes its tangible elements and intangible attributes was created in this research to bridge this scientific gap. The BIM model of a heritage building is limited to expert users with access to expensive hardware, software, and high technical skills. This research explored an open digital record to allow local citizens or visitors to access heritage building information models easily through a website without the need for expensive devices or high technical skills. That can help recognise the importance of heritage buildings and enhance the educational process in societies. The idea of retrieving information about Notre Dame Cathedral from game platforms for restoration purposes is not acceptable due to the low accuracy of the information. However, when the cathedral was recorded by volunteers who utilized multiple methods and obtained an accurate archive of its information to record the building elements, the government approved it to recreate the building after the fire digitally. This explains that VGI, with the support of using multi-recording methods, is fundamental, which can help digitally recreate heritage buildings with precise information as a reference in the future for any conservation work.

2.7. Previous Studies in Heritage Buildings Recording in Saudi Arabia

In Saudi Arabia, Alitany (2014) focused on his research on documenting the Roshans, which is a Hijazi architectural element, of Jeddah Historical City using a method integrating image-based modelling and CAD modelling. These two techniques provide a precise and inexpensive solution to survey, document, and digitally reconstruct architectural heritage features (Figure 2. 14).

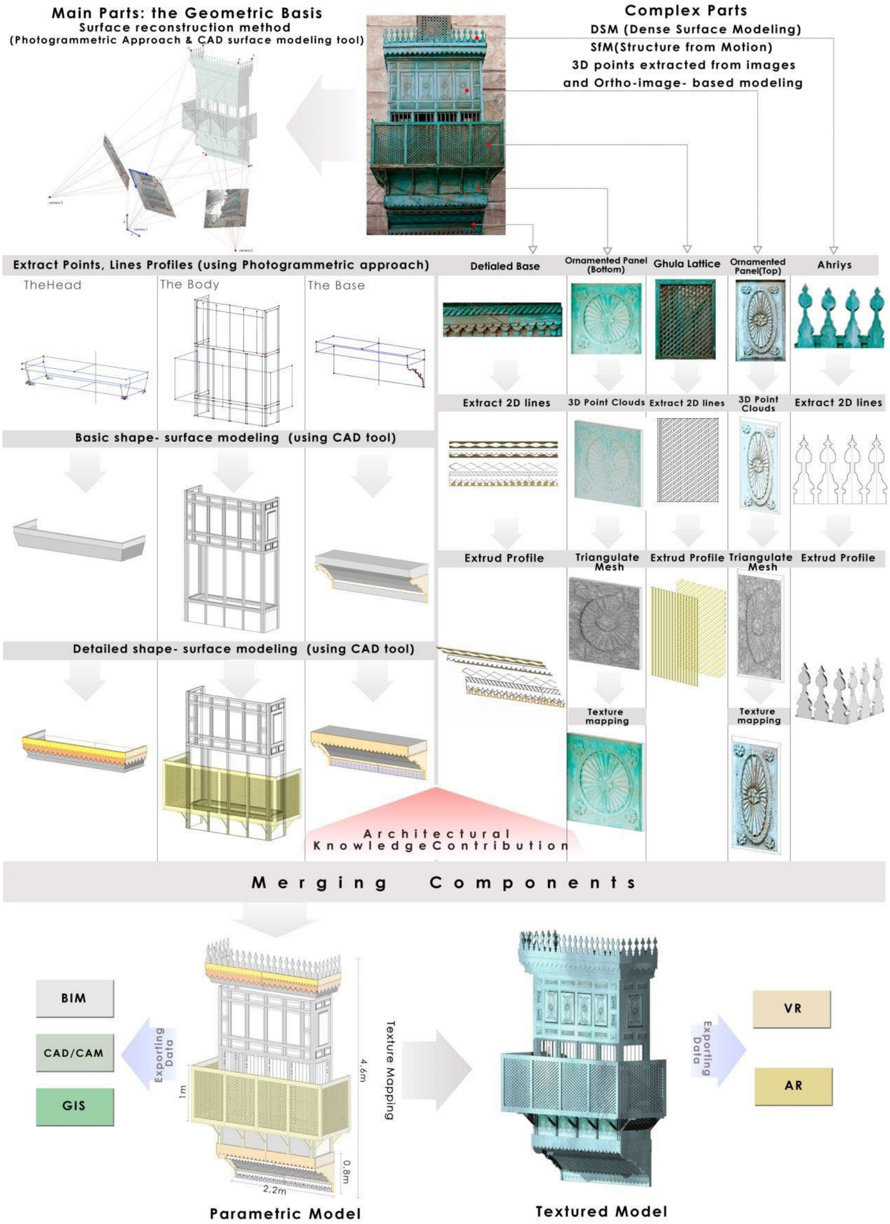


Figure 2. 26: *Surveying and modelling process of the Roshan.* (Alitany, 2014).

However, the interior of the Roshan was ignored from this application due to the limitation of the applied techniques. Where image-based methods are not always appropriate to capture the narrow passageways and areas under the historical wooden windows due to the lighting conditions. Therefore, there is a need to integrate image-based and range-based techniques to overcome these limitations. In addition, although students participated in this process for educational purposes, the 3D model which was created is for visualization only. No information can be extracted from the 3D model, such as the type of the used materials, detailed dimensions of the Roshan, or any further information. Therefore, providing semantically rich information about heritage objects' tangible and intangible data should be considered, which can help better understand such a magnificent element.

Baik et al., (2014) discussed the Jeddah Historic Building Information Modelling (JHBIM) Object Library, which provides a solution for an issue in creating historical buildings elements as 3D models by using BIM. Creating BIM of historic buildings can take significant amounts of time due to the complexity of the architectural objects. This can be reduced, however, by establishing an object library for historical building elements. The object library can then be used for further work in the Old Jeddah historical buildings (Baik et al., 2014, p. 41). No doubt creating 3D object libraries for historical building elements can help to speed up the planning process for future work in historic buildings. However, despite the use of TLS in Baik project, some issues arose while capturing the building details such as time limitation, the difficulty of moving the laser scanner, the produced 3D object is not georeferenced, and the model was produced with plain materials and textures which do not simulate the reality of the actual building form, and these issues can affect the accuracy of the information acquired (Figure 2. 15).

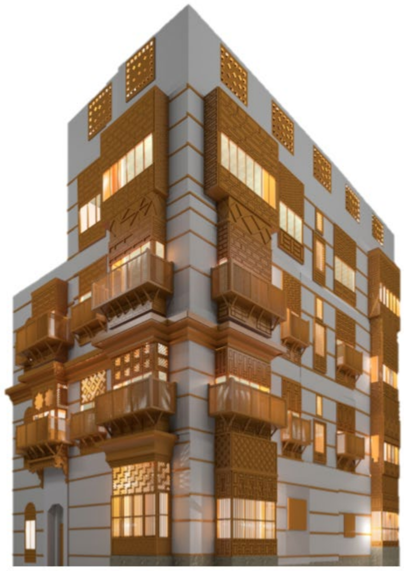


Figure 2. 27: *JHBIM model by Autodesk Revit.*
(Baik et al., 2014)

In addition, it has been mentioned by Baik et al., (2013) that historic preservation can help in understanding the condition, materials, and construction techniques of heritage buildings in Old Jeddah. On the other side, JHBIM can help in the decision-making process in heritage preservation by providing suggestions for improvement in maintenance and repairs, and damage detection before making the final decisions for any changes, and that can be done from off-site by using free viewer software (Baik et al., 2013, p. 74). However, the role of HBIM in the decision-making process in heritage preservation can be improved by offering open access and interactive experience of the historic site's information by using a cloud-based, web-based, and free open-sources content management system to get a better understanding and visualization experience.

Almaimani and Nawari have suggested creating BIM-driven objects and strategies by digitally classifying Islamic architectural elements based on historical era and style. Such a classification, they argue, can assist in better understanding and utilization of Islamic Architecture (Almaimani et al., 2015, p. 2). Nevertheless, the data used to generate the details of the BIM objects were extracted from photographs and sketches found in Islamic Architectural references. Unfortunately, these photographs and sketches are not current and inaccurate enough to create a historical object that can be used for future conservation work (Figure 2. 16).

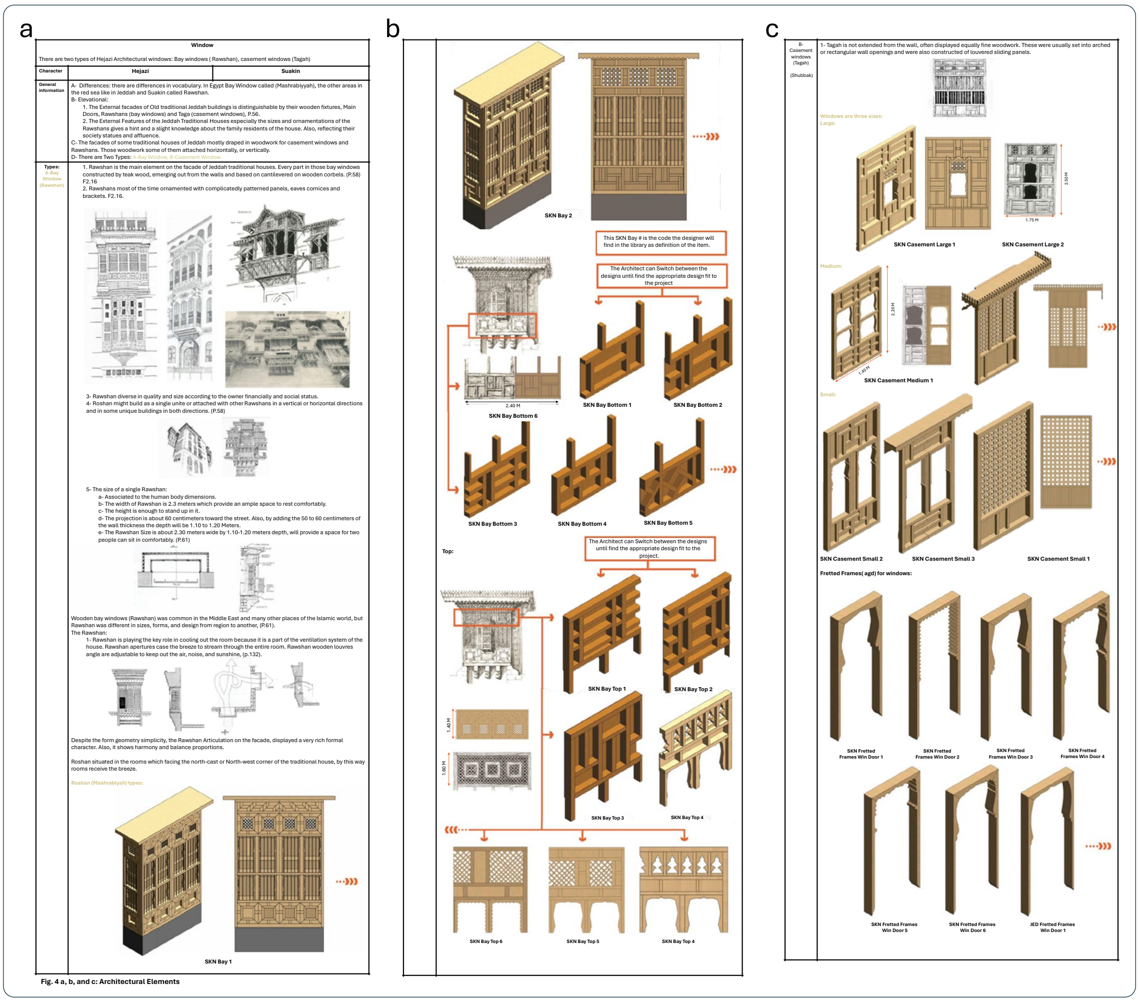


Figure 2. 28: *Modelling Islamic architectural elements through the use of pictures and illustrations.*
(Almaimani and Nawari, 2015).

2.8. Chapter Summary

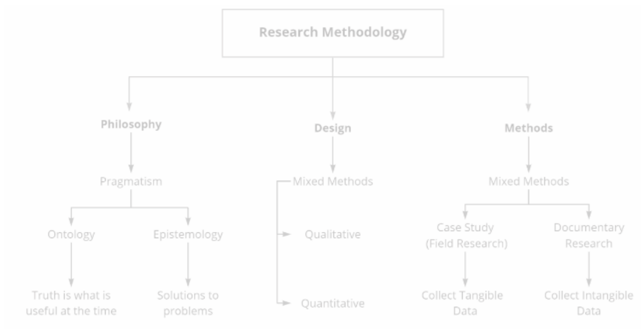
In Saudi Arabia, there is a lack of digital recording for information on heritage buildings, which puts these buildings and their spaces at risk and makes it difficult to create any digital documentation or make decisions for future conservation works. In addition, if a source of record is found, it is often not accessible because of its sensitivity. Therefore, this research also focused on the absence of digital recording of heritage buildings' tangible elements and intangible information in Saudi Arabia.

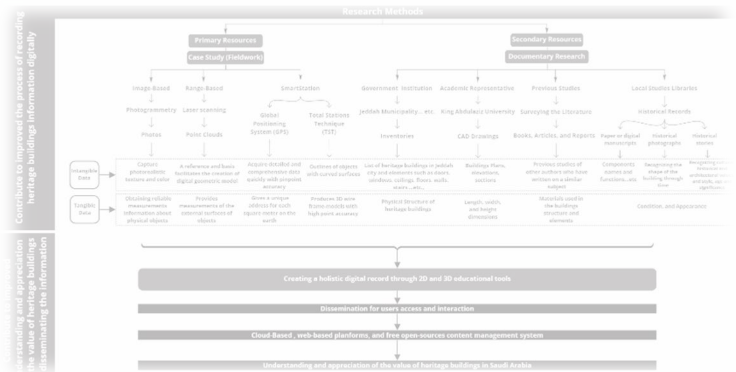
In addition, there is a lack of application in integrating many recording methods to capture data in the fieldwork of heritage buildings in Saudi Arabia, which leads to acquiring inaccurate data. Each method used in heritage buildings for recording tangible elements and intangible attributes has its advantages and disadvantages as stated by Glonass-iac.ru, 2022; Moyano et al., 2022; Zhang et al., 2022; Moyano et al., 2020; Liu et al., 2022; Gps.gov, 2022; Paar et al., 2021; Vileikis et al., 2021; as well as in older previous research such as Adel Haddad, 2013; Alitany, 2014; Andrews et al., 2013; Antonopoulou et al., 2017; Bopp, 2014; Hassani, 2015; Boardman et al., 2018; Lane, 2016; Letellier et al., 2015; Miao et al., 2011; Morgan, 2014; and Historic American Buildings Survey (HABS) and Historic American Engineering Record (HAER), 2000. So, integration between many methods for recording heritage building information is needed to overcome each method's limitation and obtain better and more accurate records. In this research, laser scanners and digital photogrammetry, including amateur cameras such as smartphones, were adopted as digital recording systems of tangible elements with the support of public contribution of written records for the intangible attributes for a deep understanding of the records.

There is a lack of integration between the GIS approach and the BIM approach in heritage buildings in Saudi Arabia. In addition, there is also a lack of studies in producing a photorealistic and georeferenced 3D model of heritage buildings in Saudi Arabia, often the 3D model is created with plain materials and textures, as well as it is not georeferenced, which does not simulate the reality of the actual building form and location, and these issues can affect the accuracy of the information acquired. In addition, there is a lack of studies on the adoption of citizen science in conserving and documenting intangible and tangible cultural heritage in Saudi Arabia.

So, in this research the role of the HBIM is not limited to 3D modelling of heritage buildings in Saudi Arabia, it is suggested to improve it by integrating the GIS approach, the BIM approach and the citizen science approach and using their different tools, which can help in digital documenting, mapping, and modelling heritage buildings in Saudi Arabia. This is for creating open access and interactive experience of the historic site's information by using cloud-based, web-based, and free open-source content management systems to get a better understanding and visualization experience (García et al., 2018, p.100-102; Brumana et al., 2013, P.497; Barazzetti, 2015, p.35). To summarise, several limitations in the digital recording of heritage buildings can be overcome by adopting several methodologies and different methods, which are discussed in **chapter 03**.

Chapter 03: Research Methodology and Methods





3.0.Introduction

The chapter defines the research question and objectives based on the literature review **chapter 02** (3.1). It then focuses on explaining the research methodology, including the research philosophy and design (3.2). Next, it discusses the research methods and their capability to produce effective results that meet the aims and objectives of this study. Finally, the chapter concludes by discussing the advantages and disadvantages of each method used in this research (3.3).

3.1. Research Question and Objectives

3.1.1. Research Question

- How to create a digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia?

3.1.2. Research Objectives

1- Determine what type of information will be included in the digital record and why.

2- Identify the most appropriate recording method to capture information about a heritage building.

3- Understanding the relationships between tangible and intangible information.

4- Establish and experiment with process-based methods of integrating tangible and intangible information.

5- Verify the effectiveness of the integration of information and stakeholder interactions.

3.2. Research Methodology

Conducting research requires an essential understanding of the interrelationship of the critical components of the research process, including research philosophy, methodology, methods, and sources (Grix, 2002, p.175). Initially, to distinguish the research philosophy, types of research assumptions, including ontology, epistemology, methodology, and methods, need to be explained (Figure 3. 1).

Paradigm	Ontology *What is reality?*	Epistemology *How can I know reality?*	Theoretical Perspective *Which approach do you use to know something?*	Methodology *How do you go about finding out?*	Method *What techniques do you use to find out?*
Positivism	There is a single reality or truth (more realist).	Reality can be measured and hence the focus is on reliable and valid tools to obtain that.	Positivism Post-positivism	Experimental research Survey research	Usually quantitative, could include: Sampling Measurement and scaling Statistical analysis Questionnaire Focus group Interview
Constructivist / Interpretive	There is no single reality or truth. Reality is created by individuals in groups (less realist).	Therefore, reality needs to be interpreted. It is used to discover the underlying meaning of events and activities.	Interpretivism (reality needs to be interpreted) • Phenomenology • Symbolic interactionism • Hermeneutics Critical Inquiry Feminism	Ethnography Grounded Theory Phenomenological research Heuristic inquiry Action Research Discourse Analysis Femenist Standpoint research etc	Usually qualitative, could include: Qualitative interview Observation Participant Non participant Case study Life history Narrative Theme identification etc
Pragmatism	Reality is constantly renegotiated, debated, interpreted in light of its usefulness in new unpredictable situations.	The best method is one that solves problems. Finding out is the means, change is the underlying aim.	Deweyan pragmatism *Research through design*	Mixed methods Design-based research Action research	Combination of any of the above and more, such as data mining expert review, usability testing, physical prototype

Figure 3. 1: *The research paradigm – methodology, epistemology, and ontology.* (Patel, 2015).

As for ontology, it indicates beliefs about the nature of reality (What is Reality?) on the other hand, the epistemology indicates to: How do you know reality? As for the methodology is: How do you go about finding it out? And finally, the methods are: What techniques do you use to find out? (Saunders, 2009, p. 127; Creswell, 2014, p.23). This means each research philosophy paradigm has ontological, epistemological, methodological, and methods assumptions, and the researchers need to consider recognizing them before starting any research, based on that, the researcher can identify the best philosophical position of the research that is being conducted.

Therefore, this chapter aims to explain the research methodology implemented in this research, which is divided into research philosophy, design, and methods based on Creswell's framework for research (Figure 3. 2).

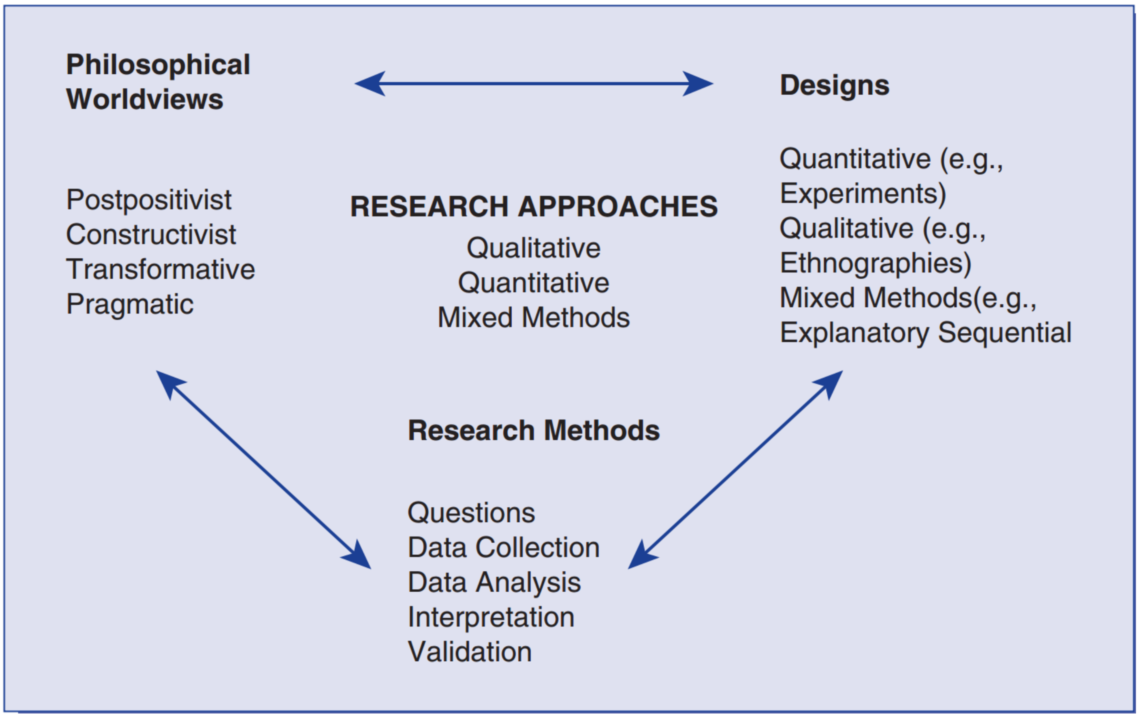


Figure 3. 2: *A framework for research—the interconnection of philosophical worldviews, design, and research methods.*
(Creswell, 2014).

The philosophical positions of research include but are not limited to positivism, interpretivism, and pragmatism, which are the three most popular paradigms from philosophical worldviews (Grix, 2002, p.177; Saunders, 2009, pp. 122-135).

Awareness of philosophical beliefs improves research quality and can add to the researcher's creativity; therefore, they are briefly defined as follows:

1- Positivism indicates that there is one actual reality which can be observed and measured. Therefore, quantitative methods are used to measure and analyse reality (Saunders, 2009, pp. 136-137; Creswell, 2014, p.7).

2- Interpretivism indicates that there is no one reality or truth, and multiple realities need to be interpreted. Consequently, qualitative methods are used to interpret and analyse reality (Saunders, 2009, pp. 136-137; Creswell, 2014, p.8).

3- Pragmatism indicates that 'Reality' is the practical meaning of knowledge that emerges from actions, situations, and consequences. Therefore, it is continually renegotiated, debated, and interpreted, resulting in the best method to use that solves the problem (Saunders, 2009, pp. 136-137; Creswell, 2014, pp.10-11).

The author started examining the available research methodologies to find the most appropriate methodologies and methods for this study. Initially, to select a research methodology, defining the research question and objectives was necessary. So, this research started with initial readings on conservation, documentation, and heritage building fields, and then collecting secondary and primary data, moving back and forth between them until the end of this research. Based on the obtained data and after defining the research question in section (3.1.1) and objectives in section (3.1.2), the author identified in detail the research methodology, including the research philosophy in section (3.2.1), design in section (3.2.2), and methods in section (3.2.3) and the justification to design this thesis in this way is explained.

3.2.1. Research Philosophy

This research implemented the pragmatism research approach using qualitative and quantitative research strategies. Pragmatism originated from the work of Peirce, James, Mead, and Dewey and other writers, including Rorty,1990; Murphy,1990; Patton,1990; and Cherryholmes,1992 (Creswell, 2014, p. 10). Pragmatism " as a worldview arises out of actions, situations, and consequences rather than antecedent conditions," and the truth is: What is useful at the time? (Creswell, 2014, p. 10). Creswell mentioned that the researcher implements pragmatism as an approach to obtain the best understanding of a research problem, which is derived from both quantitative and qualitative data and consequently involves mixed methods and action research design. He also cited that one characteristic of pragmatism is an interest in applications – what works – and solutions to problems (Creswell, 2014, p. 11; Creswell et al., 2019, p. 12). Therefore, for this research, the author chose the pragmatist approach because determining the type of information that the digital record of a heritage building will include, determining the most appropriate recording method to capture the information, and determining the relationships between the tangible and intangible information (Figure 3. 3). From this basis, the author established and experimented with practice-based to explore the research question with the adoption of mixed methods action research design of integrating tangible and intangible information, determining the effectiveness of the integration of information, and for whom are parts of the objectives of this research. All information cannot be collected without using mixed methods research for collecting and analysing data, therefore, pragmatism is found to be the most applicable.

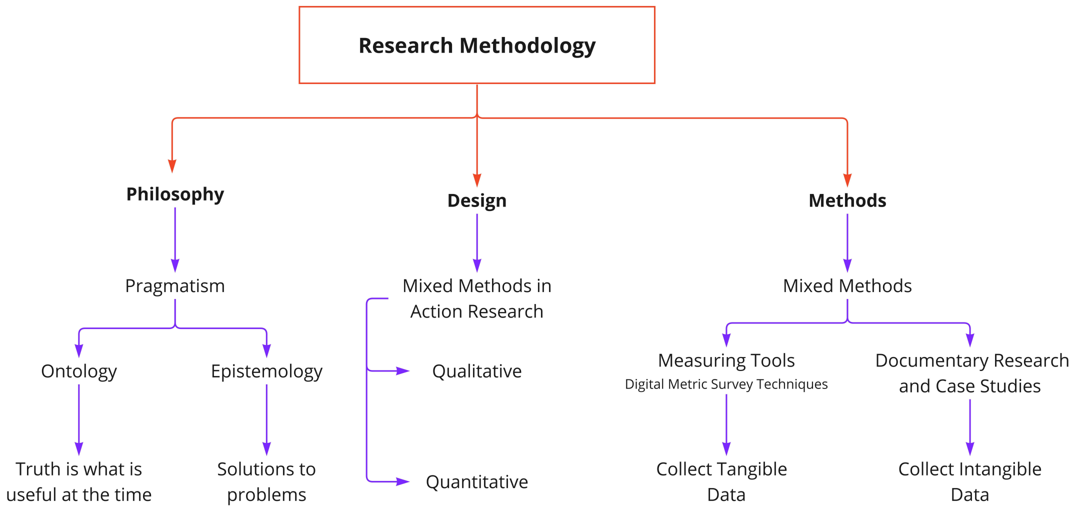


Figure 3. 3: *Research methodology.*
(Author, 2021)

3.2.2. Research Design

Action research design can intersect with mixed methods research design to establish an integrated approach for addressing complex practical problems. The similarities between mixed methods and action research in the concept, philosophy, and procedure make the integration achievable and reasonable to investigate a problem and take action to solve it (Ivankova et al., 2018, p. 979; George, 2023). However, the differences are present in terms of analysing data, presenting results, and the way in which a study combines quantitative and qualitative methodologies (Ivankova, 2015, p. 52). This research used mixed-methods and action research in the sense that there were qualitative and quantitative methods (Morgan, 2017, p. 3; Creswell, 2014, p. 4; Thanavathi, 2017, p.98). Mixed methods aim to offer comprehensive answers to study research questions while action research aims to offer comprehensive solutions to practical problems (Ivankova et al., 2018. p. 982). Therefore, the mixed methods in action research design were appropriate to apply for this research. This adopted design was needed to reach a more effective and complete answer to the research question, which was 'How to create a replicable holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia'.

The mixed methods in action research design were also useful in providing an effective and more comprehensive solution for integrating heritage building information in a digital record system, which needs to be determined through practical application. This is to offer comprehensive solutions to practical problems that arise during the phase of the recording process of heritage buildings in the Kingdom of Saudi Arabia (Morgan, 2017, p. 9; Ivankova, 2015, p.53). This required research tools that can be used in mixed methods in action research design for collecting numeric and qualitative information which include measuring tools as well as documentary research and case study as research methods (Ivankova, 2015, p. 102; Saunders et al., 2016, p.178), which were adopted in this research. The motivation for using these methods was to take advantage of one method to improve the performance of another method (Morgan, 2017, p. 9).

3.2.3. Research Methods

For this research, the researcher used mixed research methods, including a combination of several scientific research tools: digital metric survey techniques as a primary resource and documentary research and case study as a secondary resource, and the advantages and disadvantages of each tool are discussed below (Figure 3. 4), which can be used in mixed methods in action research design (Sileyew, 2019, p. 5; Saunders et al., 2016, p. 178).

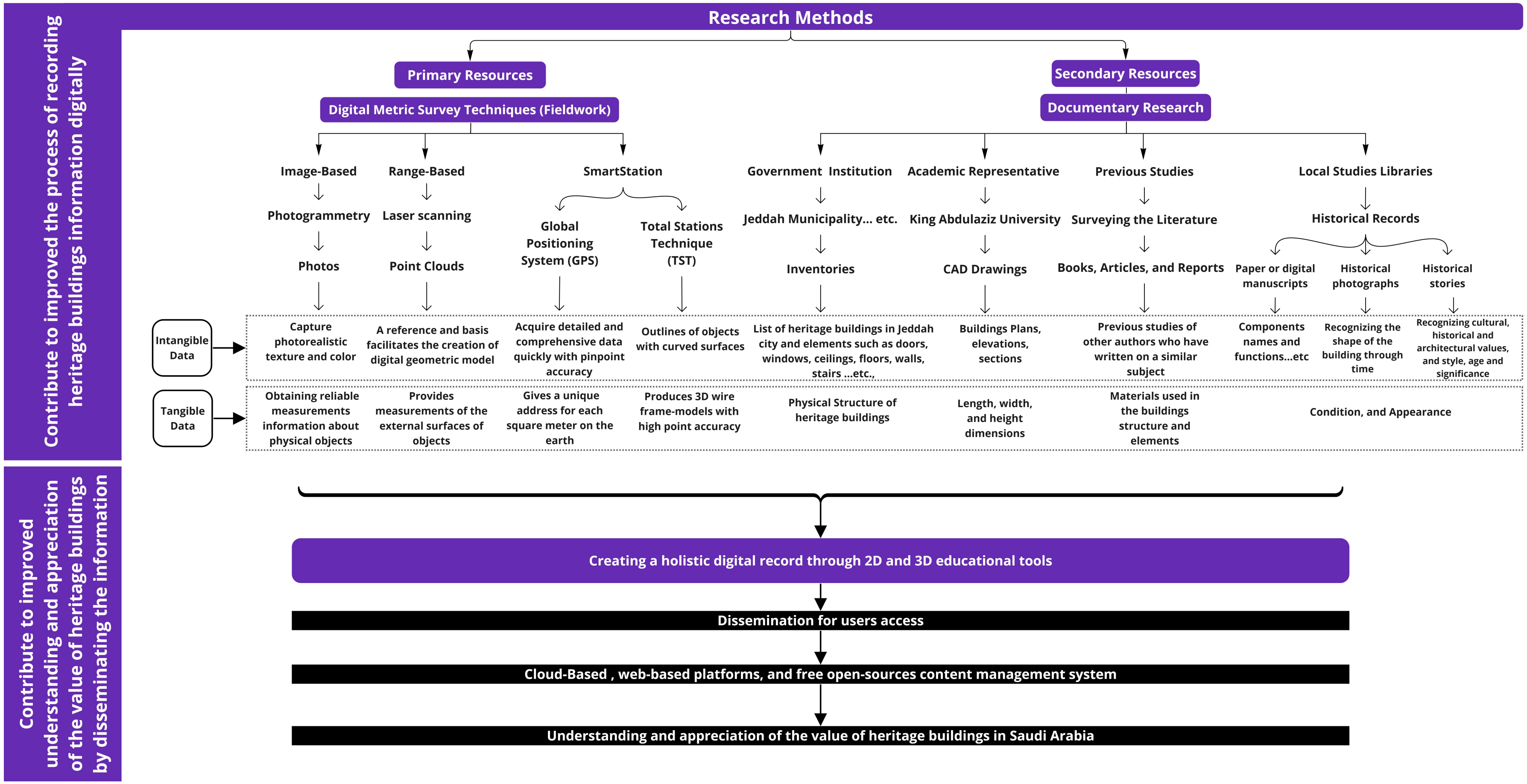


Figure 3. 4: *Research methods.*

(Author, 2021)

The digital metric survey techniques were adopted as a primary resource for a deeper understanding of the research issues, and their advantages and disadvantages are briefly explained and discussed in **chapter 02**. For instance, the digital photogrammetry technique is for obtaining reliable information about physical objects through capturing photorealistic texture and colour (The National Institute of Standards and Technology, 2023). The laser scanner technique provides measurements of the external surfaces of objects and works as a reference and basis to facilitate the creation of digital geometric models (Orlando et al., 2023, p.4). Also, the Global Positioning System (GPS) techniques can help to acquire detailed and comprehensive data quickly with pinpoint accuracy such as providing a unique address for each square meter on the earth (Costa et al., 2023). Lastly, the Total Stations Technique (TST) can help to produce three-dimensional (3D) wireframe models with high point accuracy of objects with curved surfaces (Adel Haddad, 2013, p.214).

The case study as another research method was adopted as a secondary resource to fully explain the research problem, where understanding the research problem needs to be holistic, comprehensive, and contextualized (Ritchie et al., 2003, p. 52). In addition, it provided a deep and detailed study and helped acquire a reliable and accurate report of settings and actions about the research topic (Gray et al., 2007, p. 117). Therefore, when starting this research, the researcher considered case studies as a possible method to obtain rich, reliable, and accurate information that must be included to meet the research objectives through fieldwork and surveying archival documents for acquiring, capturing, and extracting tangible and intangible information of heritage buildings using the digital metric survey techniques and documentary research. The digital techniques include laser scanning and digital photogrammetry to determine the most appropriate recording method to capture information about a heritage building. As for the documentary research, it is explained in detail in the next paragraph. The disadvantage of the case study method is that generalizations that exceed the specific case cannot be made, except if a reasonable number of cases are studied (Gray et al., 2007, p. 117).

The documentary research method was used as a secondary resource to obtain various textual and visual online and offline documents (Saunders et al.,2016, p. 183; Sileyew, 2019; p. 7). Documents provide background information that can help the researcher understand the historical roots of an issue and valuable supplementary information that helps to enhance the research topic (Bowen, 2009, pp. 29-30). So, the researcher used a documentary research method to gain insight into the intangible attributes of a heritage building. Documents including firstly, inventories from government and academic institutions to provide a list of information about architectural elements such as doors, windows, ceilings, floors, etc..; secondly, surveying the literature from previous studies such as books, articles, journals, conference studies, etc.… to explore previous studies of other authors who have written on a similar subject; thirdly, historical records from local studies libraries such as paper or digital manuscripts to identify components names and functions, and/or historical photographs to identify the shape, and/or historical stories for recognizing cultural, historical and architectural values, and style, age and significance.

The disadvantage of the documentary research method is that sometimes documents cannot be retrievable or be blocked from the responsible parties (Bowen, 2009, pp. 31-32). After collecting the tangible and intangible information, digital educational tools, including two-dimensional (2D) and 3D programs, were used to integrate the collected data into a single digital record, which can assist in understanding the relationships between the tangible and intangible information in a heritage building and can help to establish and experiment with process-based methods of integrating tangible and intangible information. In addition, creating a digital record system that includes tangible elements (geometric models), non-geometric information, and intangible characteristics of such a historical building can digitally record, document, reconstruct, interact, and share information about the historic buildings in the region with interior designers, architects, and others interested in heritage buildings in a single digital record through cloud-based platforms, web-based platforms, and/or free-open sources content management systems. These platforms and systems can help determine the effectiveness of integrating information through digital dissemination (Megahed, 2015, pp.130-147; Jay, 2019; Shore, 2021). Digital dissemination aims to meet the research aim which is to create a digital record system that integrates tangible and intangible information that can contribute to improved understanding and appreciation of the value of heritage buildings in Saudi Arabia.

Working on cloud-based or web-based platforms of heritage buildings is not addressed fully. Where this thesis addressed the system design and processes in the creation of a digital record through practical application. The author has chosen to establish a workflow and framework for disseminating a holistic digital heritage record for future replication by other researchers. Participatory research is another area of enquiry outside the scope of the thesis and an area for further investigation. Participatory research was omitted due to the large-scale organisation, training, collection, and processing of crowdsourced imagery beyond the capability of a single scholar and a PhD timeline. Participatory research is intrinsically connected, and the emerging work of participatory in digital urban planning, architectural design, and heritage safeguarding (Wargent, 2023, Dortheimer, 2023, Alivizatou, 2021).

3.3. Chapter Summary

This chapter outlines the research methodology that was implemented. Due to the nature of the research, the writer chose the mixed methods in action research design attached to the pragmatism approach "the practical application". The main research tools were digital metric survey techniques, documentary research, and case studies. In addition, digital educational tools, including 2D and 3D programs, were identified to integrate the collected data into a single digital record, which was utilized and discussed in **chapter** 0**5**, and 0**6**. Then, a workflow and framework for digital dissemination were established to determine the effectiveness of integrating the information, which aims to meet the research objectives. In conclusion, the chosen research methodology can assist in exploring the general information about the Kingdom of Saudi Arabia and its historic buildings, and it helps to explain the criteria, processes, and information that can be used for selecting a suitable sample of heritage buildings to be studied in detail in this research in **chapter 04**.

Chapter 04: Study Area General Information

4.0. Introduction

The chapter presents broad geographical information about the Kingdom of Saudi Arabia (4.1), and its policy and governance, heritage and timelines for the protection and documentation of historic buildings in an international comparison (4.2). It elaborates on the vernacular characteristics of its historic buildings (4.3). It then focuses on exploring the historic buildings of Jeddah City in particular and explaining the criteria for selecting a suitable sample of five buildings to be studied in detail in this research, where such details are investigated in order to determine the complexity of intangible and tangible information and range of approaches to fieldwork (4.4). It explains the process and information used to select the five historic buildings (4.5). Conclusions are drawn regarding this selection, which is studied in detail and digitally modelled in this research (4.6).

4.1. The Kingdom of Saudi Arabia

The Kingdom of Saudi Arabia is located in the Middle East (Figure 4. 1), (General Authority for Statistics, 2015). The land area of the kingdom is about 2,000,000 square kilometres, and the topography is varied (Figure 4. 2). The topography of the kingdom consists of coastal plains, mountain chains, plateaus, large valleys, deserts, dunes, salt marshes, and sandy areas (General Authority for Statistics, 2015).

Figure 4. 1: *Geographical location of the Kingdom of Saudi Arabia.* (Google map, 2021)

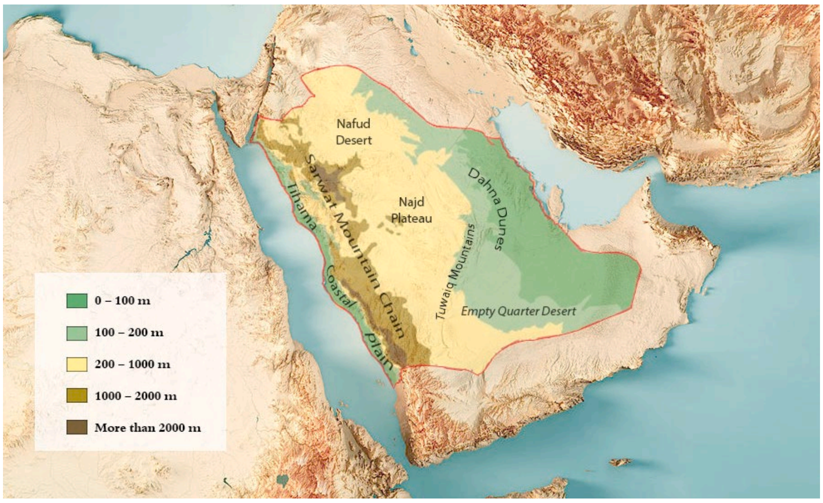


Figure 4. 2: *The topography of the Kingdom of Saudi Arabia.*
(General Authority for Statistics, 2015; the author, 2021)

Due to these variations in topography, the Kingdom's climate varies from one region to another in terms of temperature and humidity (General Authority for Statistics, 2015), which clearly influences the traditional architectural characteristics of each region discussed in the following section.

4.2. Policy and Governance, Heritage and Timelines for the Protection and Documentation of Historic Buildings Internationally and Locally

Policies and governance decisions have a direct influence on the conservation of historic buildings. So, recognising this intersection is essential for ensuring the sustainable development of heritage sites, and balancing cultural, social, economic, and environmental benefits with conservation needs.

In England, the conservation and documentation of historic buildings are governed by various laws, policies (Figure 4. 3), and the work of various organizations and agencies (Figure 4. 4).

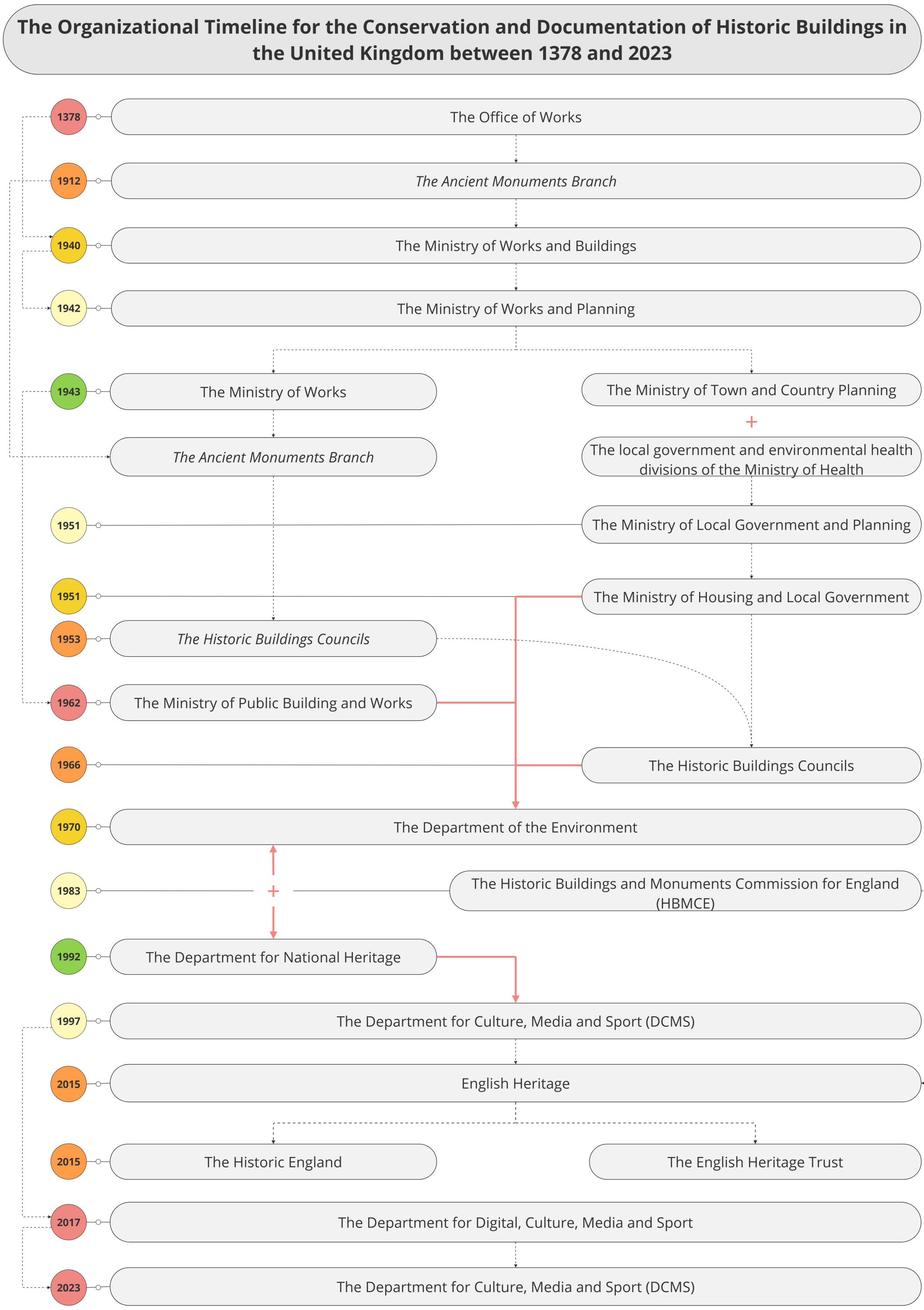


Figure 4. 3: *The organisational timelines of governance for the conservation and documentation of historic buildings in the United Kingdom.*
(The author, 2024)

Figure 4. 4: *The organisational timelines of policy for the conservation and documentation of historic buildings in the United Kingdom.*
(The author, 2024)

Essential laws related to the conservation of historic buildings in England started in 1882, the first Ancient Monuments Protection Act was established for better protection of ancient monuments (UK Parliament, 2023). Based on the act, a list of 50 prehistoric ancient monuments that required conservation was established. In 1912, the full responsibility of the Ancient Monuments Branch was assigned to the Office of Works, which was empowered to buy any monuments in case the owners wished to dispose of them to prevent the damage or destruction of any of them (The National Archives, 2009c; Historic England, 2023a). In 1940, the Office of Works transformed into the Ministry of Works and Buildings to be responsible for arranging all the Office of Works, new civil works, and buildings required by other government departments (The National Archives, 2009b). In 1942 the Ministry of Works and Buildings was renamed the Ministry of Works and Planning, and all physical planning policies for England and Wales were brought together under this ministry (The National Archives, 2009a).

However, in 1943, the planning divisions of the Ministry of Works and Planning were removed to form the Ministry of Town and Country Planning, and the Ministry of Works and Buildings was renamed to the Ministry of Works. The Ministry of Town and Country Planning was established by the Town and Country Planning Act in 1944. The act was to move the responsibility of historic buildings from the Ministry of Works to the Ministry of Town and Country Planning, to provide comprehensive lists of historic buildings for conservation, for local authorities when preparing plans, and to require owners of listed buildings to give two months' notice of suggested works (The National Archives, 2009c; Historic England, 2023a). In 1951, the combination of the Ministry of Town and Country Planning and the local government and environmental health divisions of the Ministry of Health led to form The Ministry of Local Government and Planning, which then was changed in the same year to the Ministry of Housing and Local Government (The National Archives, 2009a). In 1953 the Historic Buildings and Ancient Monuments Act was passed, which resulted in the establishment of the Historic Buildings Councils under the Ancient Monuments Branch listed under the Ministry of Works in the UK (The National Archives, 2009b; Legislation.gov.uk., 2011b). This act established plans for the repair of historic buildings and ancient monuments of distinct historical or architectural significance and stipulated their conservation and acquisition of their contents and related properties (Legislation.gov.uk., 2011b; Legislation.gov.uk., 2011a).

In 1962, the Ministry of Works was renamed the Ministry of Public Building and Works; and the Historic Buildings Act was established. The act provides for enabling local authorities to contribute to the repair and maintenance of listed or unlisted buildings of historical or architectural interest and the maintenance of the gardens occupied by them; and for related purposes (The National Archives, 2009c; Historic England, 2023a). In 1966, the responsibility of the Historic Buildings Councils was transferred from The Ministry of Works to the Minister for Housing and Local Government (The National Archives, 2009d). In 1970, the overlapping works between the Ministry of Public Building and Works and the Ministry of Housing and Local Government led to absorbing them into the newly created Department of the Environment, where the Historic Buildings Councils were moved (The National Archives, 2009c; The National Archives, 2009d).

The Historic Buildings and Monuments Commission for England (HBMCE) was established by the National Heritage Act in 1983. The act established English Heritage, which works as the lead advisor for the government regarding the built historic environment in England. English Heritage consultation on listing buildings and referring certain applications for listed building consent for guidance was the responsibility of the Ministry of Environment (Historic England, 2023a; Historic England, 2023b). In 1992, the Department for National Heritage was established and then merged with the Department of Environment due to the change in the government to form the Department for Culture, Media and Sport (DCMS) in 1997 (The National Archives, 2009e).

In 2011, The National Heritage List for England was launched for the first time on a computerised and publicly searchable database (Historic England, 2023a). In 2016, the enhancing the list initiative enabled both amateurs and professionals to contribute heritage information and photos to an additional layer of the National Heritage List. The goal is to enhance knowledge, especially for older and more concise entries on the list (Historic England, 2023a).

In 2015, the HBMCE was known as English Heritage, which was divided into two organisations, including 1) Historic England, which is a public organisation that promotes and conserves England's historic environment, and 2) the English Heritage Trust, which is responsible for managing the National Heritage Collection, which consists of more than 400 historic sites. Both organizations are sponsored by the DCMS, which was then renamed to the Department for Digital, Culture, Media and Sport in 2017, and recently retitled the Department for Culture, Media and Sport (DCMS) in 2023 (Historic England, 2023b; The National Archives, 2009d; GOV.UK., 2023; GOV.UK., 2014; English Heritage, 2023). In 2023, based on the enriching the list initiative, Historic England launched a project entitled 'The Missing Pieces'. The project encourages individuals to share their photographs and stories about the distinctive, and meaningful places on the National Heritage List for England, to unveil hidden histories and overlooked stories (Historic England, 2023a).

As in Singapore, the history of conserving and preserving Singapore's built heritage dates back to the post-war period when the colonial government accepted the recommendations in the report of 1918, by the Housing Commission to create a body of improvement commissioners to carry out improvement and town planning schemes in Singapore (Ho, 2016), until it reached the construction of the master plan in 2022 to guide the state's strategies from 2023 to 2027 in the field of heritage (Figure 4. 5). During this period, several laws were issued to achieve such a development in the field (Figure 4. 6).

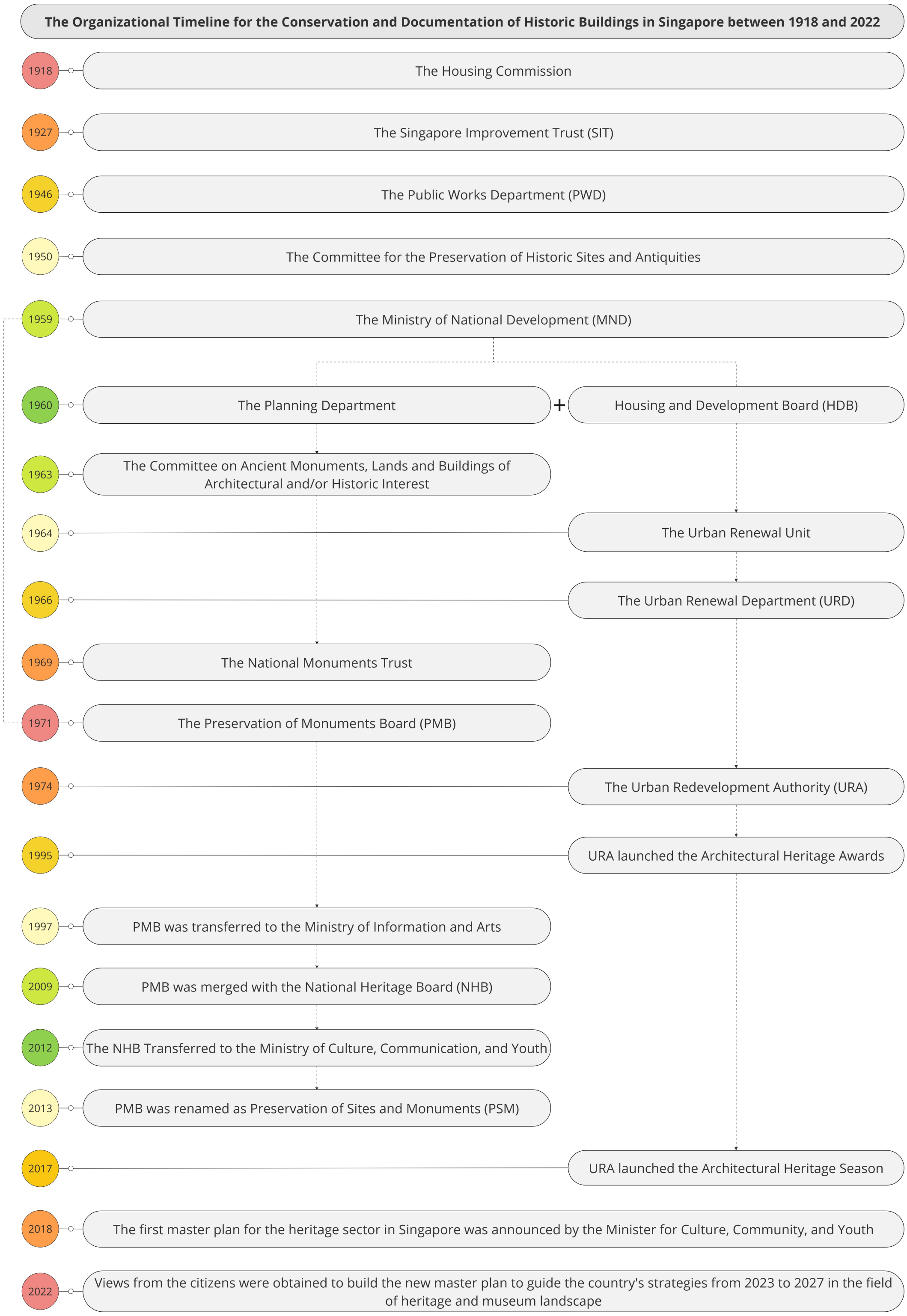


Figure 4. 5: *The organisational timelines of governance for the conservation and documentation of historic buildings in Singapore.*
(The author, 2024)

Laws Development for the Preservation and Documentation of Historic Buildings in Singapore

Year	Law	Link
1927	The Singapore Improvement Ordinance	NA
1959	The Planning Ordinance	URL
1971	The Preservation of Monuments Act	URL
1989	The Urban Redevelopment Authority Act	URL
1989	Planning (Amendment NO. 2) Act	URL
2009	The Preservation of Monuments Act	URL
2020	The Preservation of Monuments (Amendment) Act	URL

Figure 4. 6: *The organisational timelines of policy for the conservation and documentation of historic buildings in Singapore.*
(The author, 2024)

After the Singapore Improvement Ordinance was passed to provide for the improvement of the town and island of Singapore, the Singapore Improvement Trust (SIT) was established in 1927. Since that time, the SIT had the responsibility of carrying out improvement works, condemning insanitary buildings, and providing suitable housing for the people (Fraser,1952, p.10; Chew, 2009). In 1946, the Public Works Department (PWD) was established to develop and manage public works such as schools, roads, and airports in Singapore. It also placed and managed building and housing control and parking policies (Singapore Graphic Archives, 2023; National Archives Singapore, 2023).

After that, the colonial government formed the Committee for the Preservation of Historic Sites and Antiquities in 1950 under the PWD. It was a committee that looked into the preservation of individual buildings and sites of historical value. In 1954, the committee members were requested to make a list of historical sites in Singapore and place plaques at these sites describing their importance. The committee identified around 30 sites, most of which were built in the 19th century. Besides identifying historic sites, the committee was also keen to restore and preserve the historical buildings for future generations. Due to the need for the preservation of historic sites in the urban planning process, the SIT was commissioned to prepare and amend from time to time the list of ancient monuments and buildings of historical and/or architectural significance for the 1958 Master Plan (Lim, 2019). Although the list only included consideration of their potential for preservation, except that in 1959 the Singapore Improvement Ordinance was replaced by the Planning Ordinance, which provided rules relating to the protection of the sites and buildings identified in the list (Chew, 2016; Lim, 2019).

In 1959, Singapore had become a self-governing state and the People's Action Party (PAP) Government transferred most of the City Council's functions to the Ministry of National Development (MND), which is "responsible for national land use planning and development". The MND included many statutory boards, such as the Housing and Development Board (HDB) and the Urban Redevelopment Authority (URA) (Chew, 2016; National Archives Singapore, 2023; Government of Singapore, 2018). As a result of the Planning Ordinance, the SIT was dissolved in 1960, and its urban planning works were moved to the Planning Department, and its public housing programme was moved to the HDB (Chew, 2016; Ho, 2016; Government of Singapore, 2019).

When the PAP took power in 1959, it focused on improving the housing situation in Singapore. In contrast, it paid little attention to preserving built heritage. As a result, by 1960 many buildings in the city centre had collapsed or were crudely constructed, possibly exposed to fire hazards, and lacking proper ventilation and sanitation. To solve this issue, the government launched an aggressive public housing program to build housing complexes outside the city centre (Lim, 2019). In 1964, The Urban Renewal Unit was established as a department under the HDB to lead the urban renewal program to redevelop the central area (Tay, 2016). In 1966, the Urban Renewal Unit was restructured into the Urban Renewal Department (URD), and the central area was redeveloped with a very low priority on historic preservation (Lim, 2019; Chew, 2009). This does not mean that the government was not aware of the need to preserve historical sites in the city. Consultants were engaged in 1962 and 1963 to propose a long-term framework for urban renewal and to take measures to conserve, rehabilitate and rebuild suitable buildings instead of demolishing them (Lim, 2019).

In 1963, the Committee on Ancient Monuments, Lands and Buildings of Architectural and/or Historic Interest was established under the Planning Department to review the historic sites identified by SIT in the 1950s. It established new criteria for selecting historic sites such as removing the age criterion and adding the cost of preservation as a factor to be taken into account (Blackburn et al., 2015, p. 353; Lim, 2019).

In 1969, plans were announced by the government to establish a National Monuments Trust "as a body serving the interests of the state and concerned with constructing a national identity and promoting economic benefits" (Blackburn et al., 2015, p. 357). In 1971, based on the Preservation of Monuments Act, the Preservation of Monuments Board (PMB) was established "to preserve monuments of historic, traditional, archaeological, architectural or artistic interest" (Blackburn et al., 2015, p. 357).

In 1974, the URA replaced the URD. It began to look at conserving and rehabilitating entire areas and regions. In 1982, the URA expanded its conservation approach by developing a conservation plan. In 1989, a comprehensive master plan was launched for the conservation blueprint, the Planning Act was significantly amended, and the Urban Redevelopment Authority Act was established to enable the URA to act as a national conservation authority. The Urban Redevelopment Authority Act enables the URA to identify areas of historical importance for conservation, establish guidelines on how to carry out conservation work, and act as approval authority for developers, who wish to carry out works on their properties located in conservation areas (Republic of Singapore, 1989; Republic of Singapore, 2020; Lim, 2019).

In 1997 the PMB of the MND was transferred to the Ministry of Information and Arts. In 2009, the PMB was merged with the National Heritage Board (NHB) with the passing of the revised Preservation of Monuments Act of 2009. This act is "to provide for the preservation and protection of national monuments by the NHB and for matters connected therewith". In 2013, the PMB was renamed the Preservation of Sites and Monuments (PSM) after transferring the NHB under the Ministry of Culture, Communication, and Youth in 2012 (Lim, 2019; National Library Board, 2016; Singapore Statutes Online, 2023). The PSM is an authority that provides advice on the conservation of nationally significant monuments and sites in Singapore, which relies on the Preservation of Monuments Act to provide "the preservation and protection of National Monuments" (National Heritage Board, 2017).

The first master plan for the heritage sector in Singapore was announced by the Minister of Culture, Communication, and Youth in 2018. It is "a comprehensive and holistic national blueprint that defined the strategies and initiatives for the country's heritage sector from 2018 to 2022". The plan would give citizens better accessibility to museums and cultural institutions and would support the documentation, research, and protection of intangible cultural heritage. A partnership between the NHB, communities, heritage groups, and volunteers would be worked on to enhance Singapore's heritage, laws, and frameworks to protect archaeological heritage (National Heritage Board, 2023; Tan, 2023). In 2022, views from the citizens on the main aspects of the future of heritage in Singapore were obtained to build the next heritage masterplan. The new master plan will guide the country's strategies from 2023 to 2027 in the field of heritage and museum landscape (National Heritage Board, 2023).

As for the Kingdom of Saudi Arabia, the idea of built heritage conservation was not completely understood in the country, as it focused on conserving the monuments of the Kingdom of Saudi Arabia associated with royal authority, such as palaces and fortresses, especially in the central region of the Kingdom (Bagader, 2016, p.98). There were a large number of historical monuments and elements of architectural and built heritage dating back to the time of the Ottoman Empire in the Kingdom of Saudi Arabia. However, a large number of them were demolished, often due to the many social, political, cultural, religious and legal issues faced by the new government (Bagader, 2016, pp.97-99). Awareness of the importance of issuing laws (Figure 4. 7) and establishing a body responsible for conserving antiquities in the Kingdom of Saudi Arabia came somewhat late (Figure 4. 8).

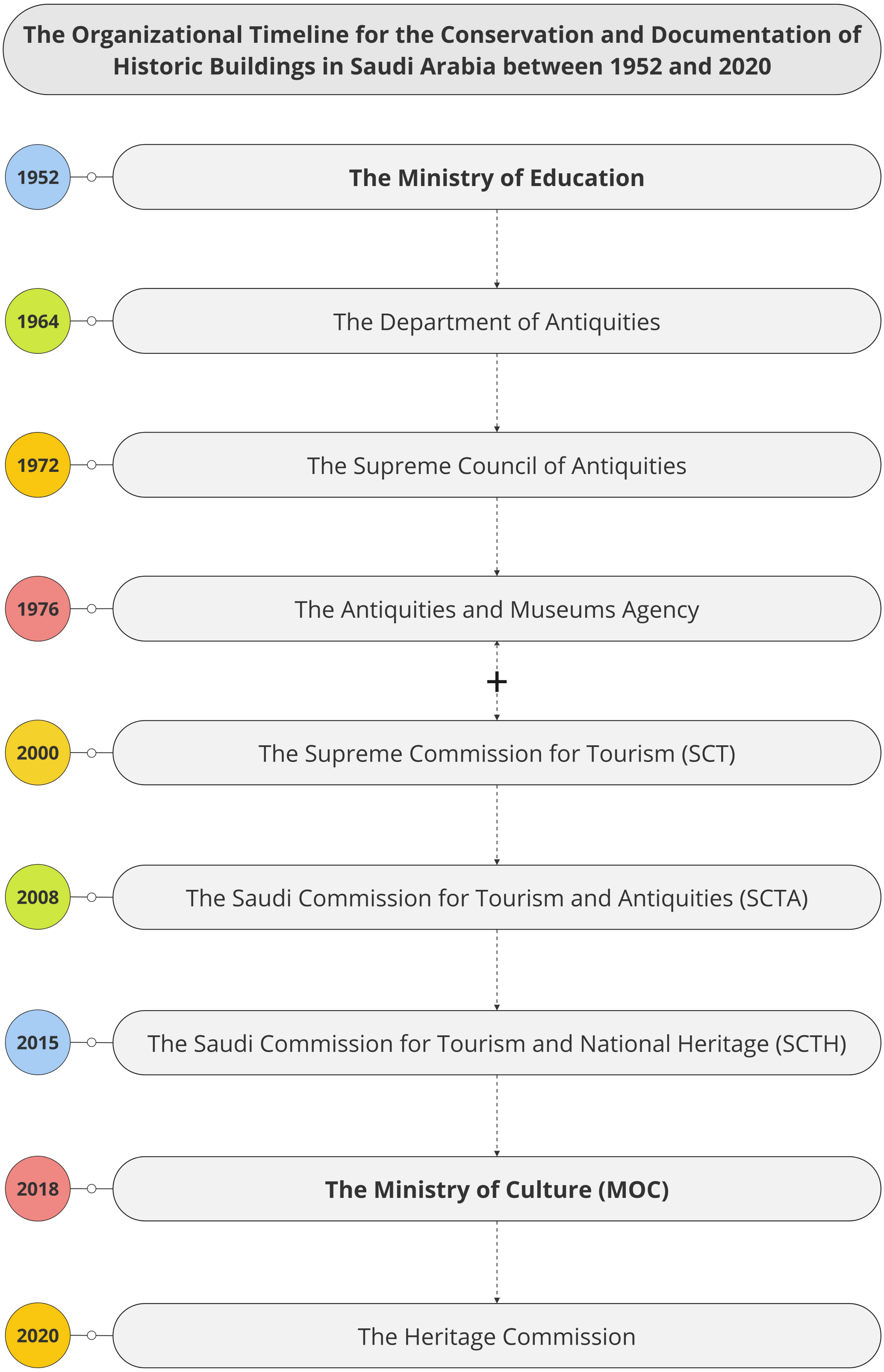


Figure 4. 7: *The organisational timelines of governance for the conservation and documentation of historic buildings in The Kingdom of Saudi Arabia.*
(The author, 2024)

Figure 4. 8: *The organisational timelines of policy for the conservation and documentation of historic buildings in The Kingdom of Saudi Arabia.*
(The author, 2024)

In 1964, the Council of Ministers issued a decision approving the establishment of a Department of Antiquities linked to the Ministry of Education. The rationale for the decision included the importance of antiquities as: "a source of history and civilization, a source of science and knowledge, a link between the past and the present, a resource of the national economy, and a requirement to keep pace with the pace of civilization and the wheel of progress and keep pace with the rest of the world in interest in antiquities (Alrashed, 2023). After around eight years in 1972, the Antiquities Law in the Kingdom of Saudi Arabia was issued, which laid the legislative foundations to protect immovable and movable national monuments. The law included the establishment of the Supreme Council of Antiquities to undertake a proposal for general tourism of antiquities in the areas of maintenance, restoration, and excavation, the validity of a proposal to amend the antiquities law, and a proposal to establish new museums. The Supreme Council of Antiquities evolved into the Antiquities and Museums Agency in 1976 to conserve national heritage sites (UNESCO, 2023).

The presence of the Antiquities and Museums Agency within the Ministry of Education indicated that heritage conservation was not seen as the country's prime concern, and the nonexistence of a specialized body responsible for conserving Saudi heritage led to the loss of many heritage sites (Bagader, 2016, p. 99). So, the Supreme Commission for Tourism (SCT), was established in 2000 as a new government body concerned with the tourism industry and its involvement in changing the concept of architectural heritage in the discourse of key actors, which led to a significant impact on the development of built heritage conservation policies in the Kingdom of Saudi Arabia (Bagader, 2016, p.104). In 2008, the Antiquities and Museums Agency was merged with the SCT and renamed the Saudi Commission for Tourism and Antiquities (SCTA) (Macdonald, 2021).

In 2014 Antiquities, Museums, and Urban Heritage Law and its executive regulations were approved by the government (Unified National Platform, 2014; Bureau of Experts at the Council of Ministry, 2014, p.3; The Saudi Commission for Tourism and National Heritage, 2014). This law includes the terms and expressions and general provisions for antiquities or archaeological sites, urban heritage, historical sites, folk heritage sites, folk heritage artefacts, museums, archaeological surveys, and archaeological excavators. It also includes heritage classification by the determination of the significance of antiquities based on their historical, cultural, artistic, scientific, or national value. In the Urban Heritage Chapter, there are articles assigned to the built heritage protection measures as well as penalty provisions for failure to comply with them (Bureau of Experts at the Council of Ministry, 2014, p.3-4; Official Translation Department, 2014).

In 2015, the SCTA name changed to the Saudi Commission for Tourism and National Heritage (SCTH) (Macdonald, 2021). The primary goal of establishing the SCTH was to pay attention to the tourism sector in the Kingdom to organize, develop, and promote it, enhance its role by overcoming any obstacles that may prevent its development, in addition to conserving, preserving, developing, and maintaining the national heritage, and enhancing the contribution of ancient times to the cultural and economic development of citizens (Saudi Conventions and Exhibitions General Authority, 2023).

The Kingdom of Saudi Arabia has sponsored sciences, literature, and culture since 1992. It is concerned with encouraging scientific research, conserving and preserving Islamic and Arab heritage, and contributing to Arab, Islamic, and human civilization. In 2018, the Ministry of Culture (MOC) was established to take care of the cultural scene in the Kingdom at the local and international levels (The Ministry of Culture, 2019).

In late 2019, the Council of Ministers issued a decision to transfer the national heritage activity from the SCTH to the MOC (The Ministry of Culture, 2019, p.35). In the same year, the MOC launched its vision and directions that reflect its goals, which is represented in that the Kingdom of Saudi Arabia flourishes in various forms of arts and culture, to enrich the individual's lifestyle, contribute to strengthening national identity, and encourage cultural dialogue with the world (The Ministry of Culture, 2019). Based on that, the Ministry planned to establish 11 new sector commissions on which its efforts and activities focus and one of them was the Heritage Commission (The Ministry of Culture, 2019, p.17-18).

The Heritage Commission was established in 2020, as it plays a role in supporting efforts for preserving national heritage, by promoting conservation methods, increasing awareness, encouraging interest, and supporting the evolution of the sector and its practitioners (Heritage Commission, 2021). The field of conserving and promoting the Islamic, Arab and national heritage of the Kingdom is the ambition that the Kingdom of Saudi Arabia is experiencing within its Vision 2030 in the Quality-of-Life Program (Vision 2030, 2021, p.5).

In the Kingdom of Saudi Arabia, the quality of life can be raised in heritage sites by adopting smart city advanced technologies and strategies for obtaining more data about its historical buildings to improve the lifestyle and build an ideal community for citizens, residents, and visitors. Noticeable attempts are being witnessed by the Kingdom of Saudi Arabia to keep pace with the enormous and fast development in the field of digital and urban transformation around the world to achieve its Vision 2030. Adopting advanced technologies and applying smart urban planning strategies helped the Kingdom of Saudi Arabia find its place on the global “smart cities” map for the year 2023. Smart cities are cities in which hundreds or thousands of sensors are used to collect electronic data from people and infrastructure as well as about them to improve efficiency and quality of life, which is one of the Kingdom's Vision 2030 programs, as mentioned previously in this chapter (National Geographic Society, 2023).

Traditional networks and services in smart cities become more efficient when using digital solutions. This is for the benefit of their residents and businesses to better use resources and reduce carbon emissions, in addition to providing smarter and more efficient ways of transport networks, water supplies, waste disposal facilities, and lighting and heating buildings to manage a more interactive and responsive city, safer public spaces, and meet the needs of residents with special needs such as the elderly (The European Commission, 2023).

The Smart Cities term has become a slogan in our time (Bloomberg, 2023). So, based on the Smart City Index 2023 there are 141 cities ranked as the smartest cities around the world (World Competitiveness Center, 2023, p.30). The International Institute for Management Development (IMD) Smart City Index 2023 is based primarily on studying residents' experiences and perceptions of the impact of structures and smart technology applications in their daily lives in their cities. This index assesses the ability of the existing infrastructure and the available technologies provisions and services of the cities to improve people's quality of life and the extent of balance they achieve between health and safety, mobility, activities, opportunities, and governance areas (World Competitiveness Center, 2023, p.34).

According to the IMD Smart City Index Report 2023, Zurich in Switzerland is ranked the top smartest city in the world. The city achieved high scores for its structures in health and safety, activities, work and school, and governance areas except for the area of air pollution and the availability of affordable rental housing. As for the technology, it achieved average rank and scored higher in the work and school criteria (World Competitiveness Center, 2023, p.177). At the international level, based on the IMD Smart City Index Report 2023 the city of Riyadh in the Kingdom of Saudi Arabia ranked 30th, and in the meanwhile the cities of Makkah, Jeddah, and Medina also joined the IMD index list for the first time. Makkah ranked 52nd, Jeddah ranked 56th, and Medina ranked 85th globally out of the 141 cities included in the Smart City Observatory (Writer, 2023; El-Assasy, 2023; World Competitiveness Center, 2023, pp. 96-143). At the Arab world level, the city of Riyadh in the Kingdom of Saudi Arabia ranked third as the smartest Arabic city while Makkah, Jeddah, and Medina cities ranked 4th, 5th, and 7th respectively.

This improvement in the classification of Saudi cities in the smart city index is a result of the efforts undertaken by the authorities responsible for the cities to transform them into smart cities by activating the smart city enablers, preparing a strategy related to smart applications, spreading awareness among the city's residents about the smart technologies applied in the city concerning security and smart sustainability, and adopting the latest technologies and digital solutions to facilitate and digitize government transactions and services to improve healthcare and security indicators (Ministry of Communications and Information Technology, 2023, p. 44). This confirms the Kingdom of Saudi Arabia's commitment to developing its cities in accordance with the latest international standards in smart urban planning (Writer, 2023; El-Assasy, 2023).

4.3. Historic Buildings in Saudi Arabia

Historic buildings varied in their architectural characteristics based on their regions in the Kingdom of Saudi Arabia. These differences are specially marked among the Kingdom's older historic buildings' characteristics, which are important to investigate to inform site selection. Some researchers divide the country into four regions, as shown in figure 4. 9 (King, 1998; Ishteeaque et al., 2008). These regions differ in their architectural style, construction techniques, and materials. The regions are:

1) **Central and Northern (Najd) region**, mainly a vast hot and dry plateau in the centre of the country. The buildings are made of mud and include courtyards to form shade and promote ventilation.

2) **The Southern (Asir) region**, a high mountainous province, has cold weather. The buildings' walls are made of rammed earth and protected from rain with flat thick stone pieces to help in protection and thermal insulation. In addition, the walls have small openings to promote ventilation.

3) **Eastern region**, a hot and humid region along the Arabian Gulf, and the buildings used courtyards, wind catchers, and wind towers to control ventilation.

4) **Western (Hijaz) region**, a hot and humid coastal plain along the Red Sea. The buildings used courtyards, air wells, and evaporative cooling to control ventilation. It is also known for its wood-crafted elements as traditional Hejazi architecture to control ventilation and residents' privacy.

In this research, the Western (Hijaz) region's architectural style, especially in Jeddah's historical city (Figure 4. 10), was chosen as the area to be studied for several reasons, which are explained below.

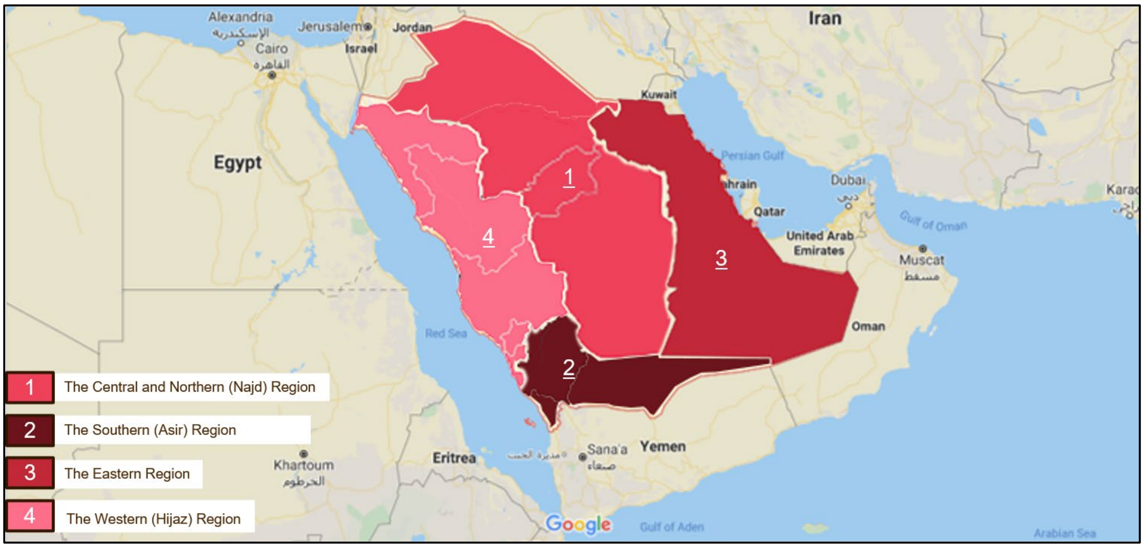


Figure 4. 9: *Historic buildings by region in the Kingdom of Saudi Arabia.*
(Author, 2021)

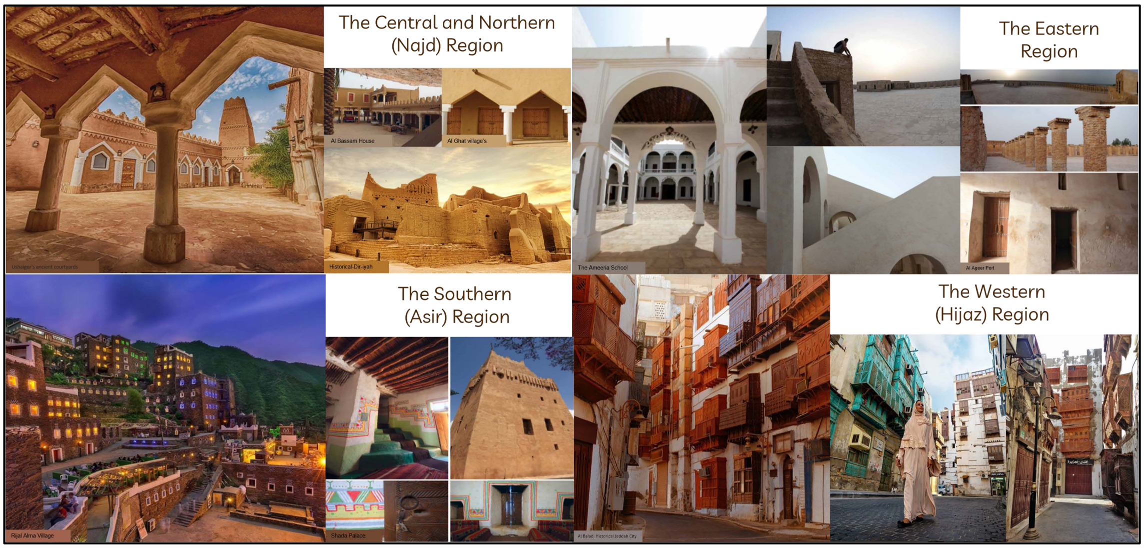


Figure 4. 10: *The four Saudi regions' architectural styles, construction techniques, and materials.*
(Saudi Commission for Tourism and Antiquities, 2010, pp. 9-225; Visitsaudi.com, 2021)

4.4. Historic Buildings in Jeddah City: Reasons and Criteria for Choosing

There are many reasons for choosing to focus this study on the historic buildings of Jeddah city. First, Jeddah has a historical region with several buildings listed as world cultural-historic by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2014 (Figure 4. 11). This region is suitable for a holistic historic model through the fusion of rich data assets. Second, from a practical standpoint, Jeddah is a city where the researcher has access to technical resources such as laser scanner, digital photogrammetry, and Total Stations Technique (TST) integrated with the Global Navigation Satellite System (GNSS), as well as non-technical resources such as inventories, literature, and historical records from government institutions such as King Abdulaziz University, Jeddah Municipality, and/or Saudi Geological Survey. Finally, the researcher has personal contacts in the city that are useful for conducting both secondary and primary research.

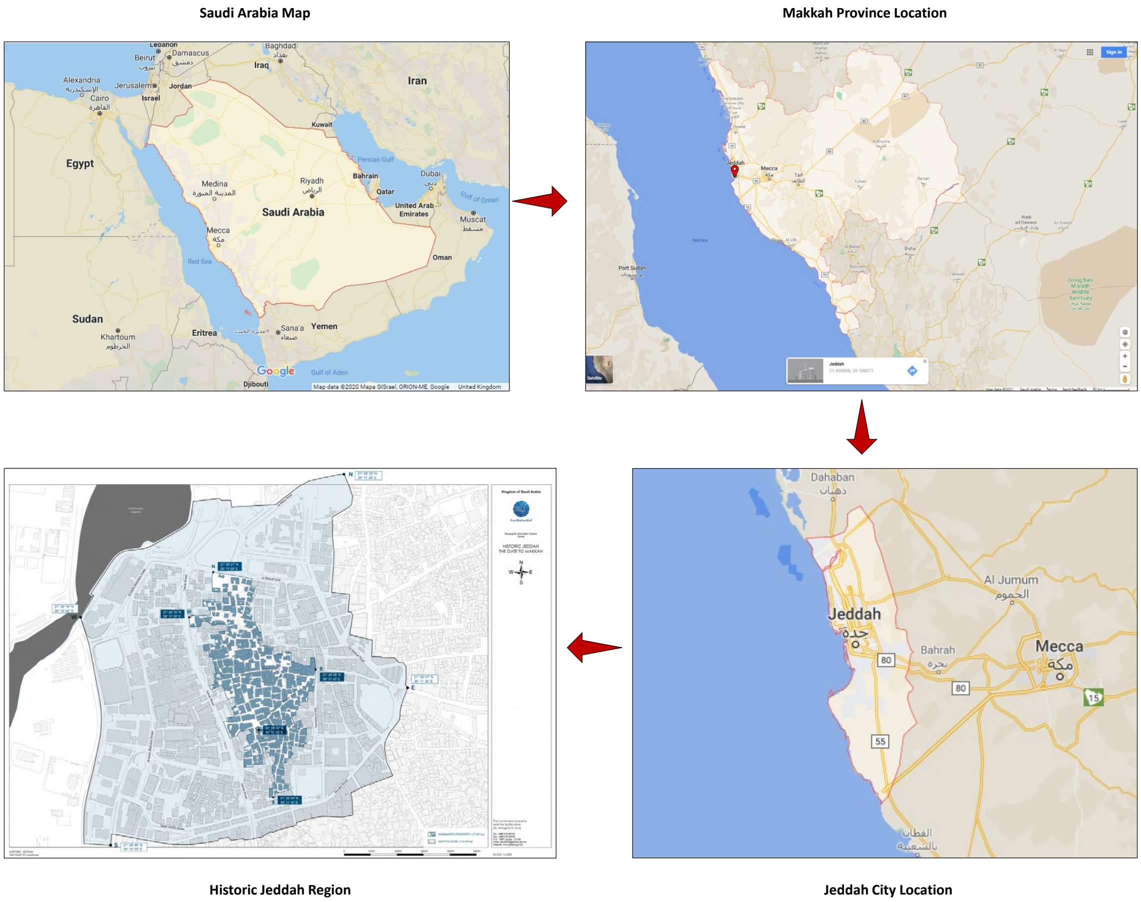


Figure 4. 11: *Makkah province map shows Jeddah city location.*
(Google Map, 2021; Saudi Commission for Tourism and Antiquities, 2013, p.21)

Based on an initial review of the literature in **chapter 02**, four evaluation criteria were identified for selecting suitable historic buildings in Jeddah city as case studies for this research, which are explained later in detail in this section, where such details are investigated in order to determine the complexity of intangible and tangible information and range of approaches to fieldwork. The four evaluation criteria are:

1) **Of significant value,** such as historical, religious, cultural, and/or economic,
2) **Unique structures,** such as architectural styles, construction techniques, and/or materials,
3) **Accessibility of site** for collecting primary data,
4) **Availability of data** in specialized government and academic depositories, including previous studies and historical records.

As for buildings of significant value, Jeddah is famous as a major economic and business centre in Saudi Arabia because it is the largest city in Makkah Province that has significant concentrations of historic buildings in its historical regions, such as residential buildings, popular markets, mosques, and educational schools (Jeddah Chamber of Commerce and Industry, 2017, p.18). Moreover, these buildings are well known as income generators because they are tourist destinations where historical, cultural, and entertainment festivals, annual seasons, and paid tours are held. These activities shed light on the area and introduce visitors to it, including landmarks and a great historical heritage to conserve it and revive its people's customs and traditions.

Significantly, because we are focusing on historic buildings, Jeddah is a very ancient city whose origins date back almost 3,000 years. It began as a place where fishing communities settled. After the arrival of Islam in the Arabian Peninsula, the city gained a significant place in Islamic history. In 647 AD or 25 AH, Caliph Othman bin Affan chose it to become a major port for Makkah city as it is the gateway to the Two Holy Mosques. A Mamluk Prince, Hussain Al-Kurdi, built a wall around Jeddah to protect it from Portuguese attacks coming from the Red Sea. He ordered building a wall with castles, towers, and cannons (Figure 4. 12). In 1947 the wall was demolished as the urban area was expanding (Jeddah Municipality, 2021). However, some of the gates still remain.

Figure 4. 12: *Aerial photo of old Jeddah city and its wall in 1938.*
(Jeddah Municipality, 2021).

Jeddah's historical buildings are unique based on their architectural style, construction techniques, and traditional materials, including sea mud, Al Mangabi coral stone, and wood (Jeddah Municipality, 2021). The coral stone extracted from the Arbaeen Lake was coated with a layer of plaster as wall paint to prevent the effects of the salty sea air on the building's walls (Jeddah Municipality, 2014, p.11). The stone walls were separated by' Tkalil' wooden planks to spread the load on the walls. Planks were made from local woods, mainly from Wadi Fatima, or imported from India (Jeddah Chamber of Commerce and Industry, 2017, p. 20). In addition, "Jawi", teak wood from Java, was used to make the elaborate front doors, Roshans, and windows, as well as "Gandal" wood, for reinforcement and flooring (Jeddah Municipality, 2014, p.11).

When choosing the case studies, practical action necessities were also taken into consideration, such as site accessibility and data availability. Site accessibility is important for collecting primary data. Some historic buildings in Jeddah are open to visitors, such as the old Jeddah wall gates. Some are partly open, such as mosques, which open five times a day only during prayer times. Also, during the time of this research, some were closed for maintenance and restoration work, including some residential homes and schools.

Secondary data, including information about the historical, religious, economic, and architectural value of historic buildings in Jeddah, are available in various specialized government and academic depositories and libraries. As for collecting primary data about historic buildings in Jeddah, including building and element dimensions, materials, condition, and appearance, this was collected on-site using laser scanning, digital photogrammetry, Global Positioning System (GPS), and TST.

4.5. The Process and Information Used for Selecting Suitable Historic Buildings in Jeddah City

The process of selecting the suitable historic buildings in Jeddah to be studied in this research began by identifying the four evaluation criteria for selecting the suitable buildings, as explained in section (4.3) above. In addition, secondary and primary data were surveyed, and field visits were conducted to view and determine available information about the buildings in the historical area of Jeddah.

4.5.1. Secondary data

For secondary data acquisition, the documentary research method was used to obtain diverse textual and/or visual information via both online and/or offline documents. These documents contained background information about current or historical events, conditions, or practices that could be used later in this research. As for collecting primary data, a practice-based approach was adopted to collect the data including building element dimensions, materials, condition, and appearance, the methods and tools used are explained later in section (4.4.2) in this chapter.

The process of data collection from secondary sources of Jeddah's historic buildings was divided into two stages: 1) planning of the secondary data collection and 2) implementing the process of secondary data collection.

- ***Stage 1: Planning of Secondary Data Collection of Jeddah Historic Buildings***

Secondary data is required to answer the **RQ**: What type of information will be included in the digital record and why?

Preparation for data collection from secondary sources of Jeddah's historic buildings began by determining both types of data needed and the targeted parties (Figure 4. 13).

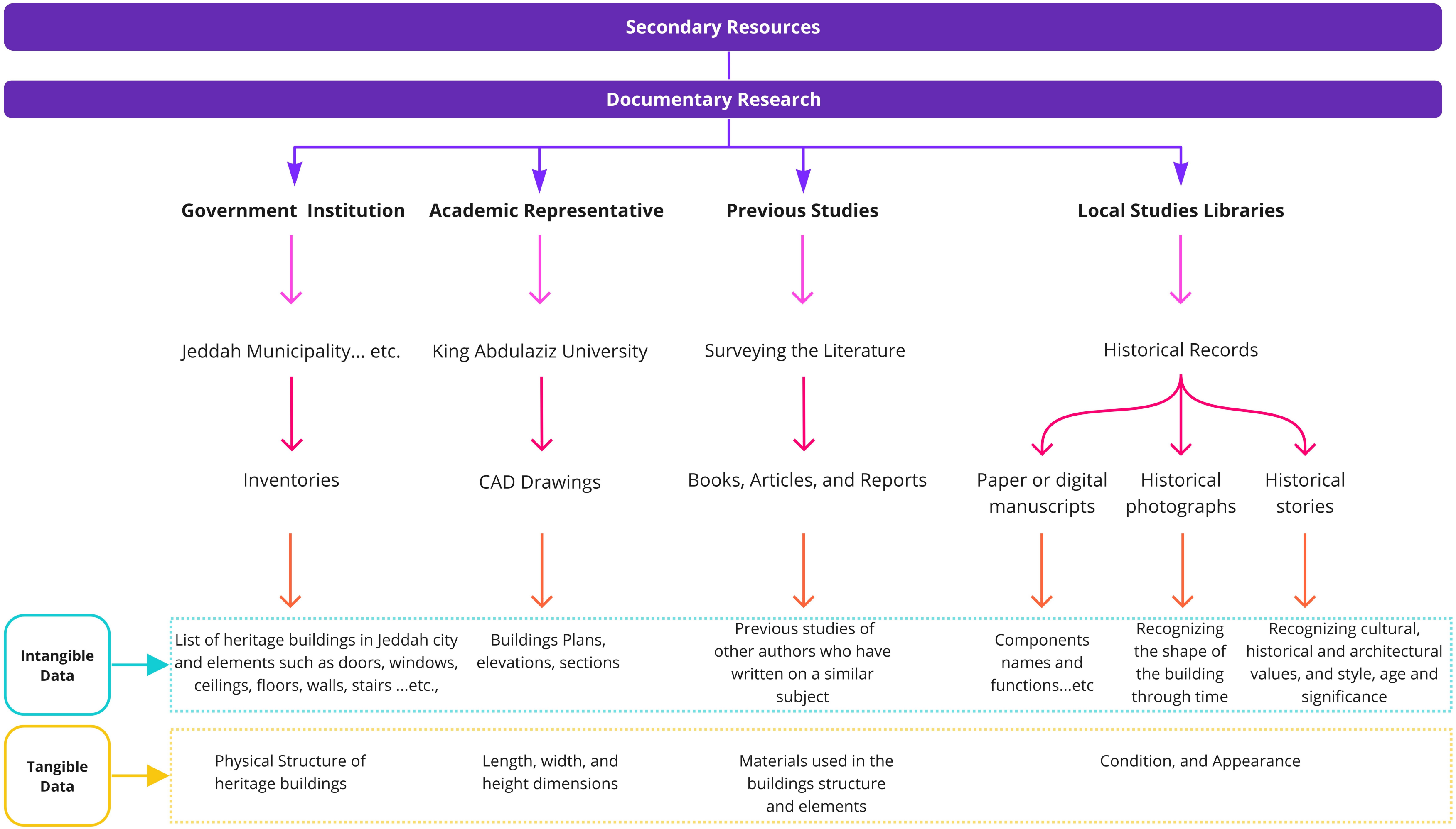


Figure 4. 13: *Secondary resources to obtain intangible and tangible information about historic buildings.* (Author, 2021)

Data were divided into four main categories:

1) **Inventories from government institutions** – to be obtained from Jeddah municipality, which is the responsible party for developing Jeddah historical city,

2) **Computer-Aided Design (CAD) drawings from academic sources –** especially the Faculty of Architecture and Planning, Geomatics Department at King Abdulaziz University in Jeddah which also works with Jeddah municipality to record and survey historic buildings in Jeddah city,

3) **Literature survey** – of previous studies such as books, reports, and articles,

4) **Historical records from local studies** – are available in libraries such as King Fahad Library and the Saudi Digital Online Library.

Based on the UNESCO Cultural Heritage Classification (2011) and (2017), the obtained data from the previous four main categories are divided into intangible data and tangible data:

1) **Intangible data** include:

- ***Oral traditions and expressions***
    i. Songs for instance sea, folklore weddings, and Ramadan nights songs, as well as the owner of crafts or goods in the market, displays his goods by singing a song related to the type of his goods (Traboulsi, 2008, pp.415-426)
    ii. Poetry, such as Alkasrat, folk poetry includes two verses (Diab, 2003, pp.118-119).
    iii. Tales for instance:
        1. Love on the Sea of Forty (Abu Al-Khalakhil and the Mermaid),
        2. The Haunted House (Abu Alsibae),
        3. Wedad and Attia story (Diab, 2003, p.178)

- ***Saying or proverbs in:***
        1. Education, love, beauty, ageing, grey hair, parents, relatives, marriage, married life, professions, business, trading, financial conditions, lies, liars, contentment,

cooperation, unhappiness, friendship, neighbourhood, stealing, patience, tolerance, Caution, foreignness, stories, and legends (Diab, 2003, pp.168-177).

- ***Performing arts***
    i. Vocal music such as:
        1. Al-Sihba, is a combination between poetry and songs of Arab Andalusia (Saudi Embassy, 2021)
        2. Almajas, is a song, particularly for weddings and engagement parties. It is usually performed before starting to sing (Traboulsi, 2008, p.419; Cable, 1996, p.146).
    ii. Instrumental music, such as drums and oboes like woodwind instruments (Traboulsi, 2008, p.415)
    iii. Dance, such as Almezmar dance, is a combination of singing, drumming, clapping, and dancing with sticks. In 2016, it was listed on the Representative List of the Intangible Cultural Heritage of Humanity (SACM, 2021; UNESCO, 2016).
- ***Social practices, rituals, and festive events such as:***
    i. <u>Worship rites:</u>
        1. The holy month of Ramadan season, when Muslims fast from dawn to dusk (SACM, 2021).
        2. The holy month of Hajj season is when Muslim pilgrims from around the world come to Makkah every year (SACM, 2021).
    ii. <u>Birth rites:</u>
        1. Birth at home by midwives,
        2. circumcision, naming, and "Rahmani" a party held for the children of relatives and neighbours on the seventh day of birth. They distribute candles to them, perform the anthem around the house, and at the end juices and sweets are served to them (Traboulsi, 2008, pp.378-379).
    iii. <u>Wedding rituals usually take place in stages, the first of which is:</u>
        1. On the engagement day,
        2. The marriage contract ceremony,
        3. Al Dabash, the name of the bride's clothes, jewellery, and furniture, is taken to the groom's house several days before the wedding date.
        4. Al Rafd, is the name of the gifts offered by family and friends to the groom to help him with the requirements of the wedding night
        5. The wedding ceremony,

6. Al Sabha, is a name of a simple party held in the groom's house on the next day of the wedding party (Diab, 2003, pp.94-99).

iv. <u>Traditional games and sports</u> include AL-Berbers, AL-Brajoh, AL-Zaqeeqa, AL-Komkom, AL-Kerem, and AL-Baloot (Diab, 2003, p.123; (Traboulsi, 2008, p.316).

v. <u>Seasonal ceremonies such as</u>
   1. Eid-Al-Fitr holiday
   2. Eid Al-Adha holiday

vi. <u>Special clothing in Jeddah:</u>
   1. For ladies are:
      1- Kurta, a dress with long sleeves
      2- Al-muharama and Al-mudawara are two pieces used as head coverings (Diab, 2003, p.102).
   2. For men are:
      1- Jubbah, is an outer garment with wide and narrow sleeves, open from the front,
      2- Al-Thawb, a long garment that was worn in several colours and over time became mostly white,
      3- Hijazi turban, which covers the head,
      4- The centre-wrapped cashmere belt,
      5- Some young men would put a Javanese cap (a Javanese keffiyeh) on their head, and then put a shawl on their shoulders or wrap it around their shoulders,
      6- One of the most famous customs in Jeddah is that they used to carry long sticks in their hands to lean on, and these sticks were called “Almond sticks” (Cable, 1996, pp.26-28).

vii. <u>Special food in Jeddah is</u>
   1. Fish is known as the main food source in Jeddah (Traboulsi, 2008, p.160)
   2. Food, in general, was influenced by pilgrims' visitors from all over the Islamic world, with the entry of many touches or flavours from Jeddah due to it being the port of Makkah Al-Mukarramah (Traboulsi, 2008, p.343).

- ***Knowledge and practices concerning nature and the universe such as:***

i. At that time, the treatment of diseases did not depend on doctors, but the main dependency was on the spice dealer, who treated patients with natural herbs (Cable, 1996, p.136).

- ***Traditional craftsmanship such as:***
    1. Calligraphy
    2. Carpentry and woodturner craftsmanship
    3. Traditional pottery arts
    4. Gold and silver jewellery craftsmanship,
    5. Muslim rosary craftsmanship,
    6. Fishing, the manufacture of sails, and sailing boats were some of the old and popular professions in Jeddah, which were inherited by younger generations from their fathers' and grandfathers' generations. In sailing boat manufacture, teak, Swedish wood, and some local wood brought from the offshore islands were used (Traboulsi, 2008, p.168; Diab, 2003, pp.47-53; Cable, 1996, p.88; Saudi Embassy, 2021).

- ***Traditional buildings in Jeddah are generally constructed by the use of local building materials such as:***
    1. Coral stone is known as “Mangabi” stone,
    2. Coated by a layer of plaster
    3. Coral blocks,
    4. Dark-brown clay served as mortar for binding the stone blocks,
    5. Teak beams are horizontally inserted in the walls,
    6. Wooding boards used for flooring were called “Gandal” and were imported from India,
    7. Jawi wood, which is teak wood imported from Java used for front doors, Roshan-s (wooden windows), and windows,
    8. Houses were usually painted with pastel colours of yellow, cream, blue, and pink (Saudi Commission for Tourism and Antiquities, 2013, p.50).

- ***List of historic buildings in Jeddah city, with their conservation status, historic listing, and status.***
- ***Buildings Plans, elevations, and sections,***
- ***Previous studies of other authors who have written on a similar subject, and***
- ***Building's components' names, functions, shapes, style, age, cultural, historical, and architectural values.***

2) **Tangible data** in several report files and two-dimensional (2D) CAD drawings include:

a. Building materials,
b. Construction details,
c. Building elements, such as foundation, walls, floors, and roof,
d. Architectural elements such as doors, windows, cabinets, lattice, railings, and
e. Decorative elements (Figure 4. 14) such as Roshan combined with shish nets (lattice grilles) in the upper part, Mashrabiya, Manjur Pattern and Plaster decoration (Saudi Commission for Tourism and Antiquities, 2013, pp.52-58).

Figure 4. 14: *Examples of Roshan (Wooden window), wooden doors, decorated doorways, and Manjurs in Jeddah buildings.*
(Saudi Commission for Tourism and Antiquities, 2013, pp.52-58)

It appeared during the literature survey stage that the Kingdom of Saudi Arabia is rich in its tangible and intangible heritage. These heritage buildings have historical, architectural, artisanry, aesthetic, cultural, environmental, ecological, social and/or economic values, which are discussed in **chapter 02.** These values cannot be ignored in the significance evaluation process of heritage assets due to their influence in improving understanding of the significance and meaning of heritage to governments and citizens, which can help in preventing destruction and reducing damage.

Based on that, it can be noted that every tangible element is linked to intangible attributes to give them meaning and cannot be separated. For instance, heritage buildings, as tangible assets, are considered dead if there is no story behind them as an intangible attribute, which gives them a historical value. Also, vice versa, most intangible attributes can give architectural, artisanry, and aesthetic values to tangible elements through traditional craftsmanship, such as calligraphy, carpentry, and woodturner, apparent in the heritage building's decoration.

Despite heritage importance, the researcher noticed that the intangible and tangible heritage data is dispersed in different data sources, which led to a weakness in understanding the relationship of tangible elements with intangible attributes in order to highlight their importance. Also, most of the research and studies focus on one aspect, either intangible or tangible, so there is a need to conduct studies that integrate the two aspects together to know the relationships and values of the heritage aspects in a comprehensive manner.

- ***Stage 2: Implementing Secondary Data Collection of Jeddah Historic Buildings***

The collection of data related to the intangible attributes and tangible elements of Jeddah's historic buildings began by contacting governmental institutions such as Jeddah municipality and King Abdulaziz University and by visiting the site several times to obtain any helpful information about historic buildings in Jeddah city. In addition, the literature from previous studies and historical records, including books, online reports, and articles, were obtained from Lancaster University Library, the Saudi digital online library, King Fahad Library, Google Scholar, ResearchGate, and other online websites (Table 4.1).

Tangible Data				
	Type of data	**Title**		**Responsible Party**
1	**Photos and videos**	a.	Photos and videos were taken of several historic buildings in Jeddah _ site visit	By Author
2	**2D AutoCAD Drawing**	a.	A Plan of the Historical Jeddah - City Map (Appendix A)	Jeddah Municipality
		b.	Approved Balad Map-Model (Appendix B)	King Abdulaziz University
		c.	Plans, elevations, and sections of Sharif Gate (Appendix C)	King Abdulaziz University
		d.	Plans, elevations, and sections of Shafei mosque (Appendix D)	King Abdulaziz University
		E.	Historical Jeddah Coordinates with Contour Lines Submitted (Appendix E)	King Abdulaziz University / Sourced from Masaken Engineering Consulting Office
Intangible Data				
3	**Online Reports**	a.	The Antique Mosque – The Shafei Mosque in Historical Jeddah	The Saudi Commission for Tourism and Antiquities
		b.	Volume 2 – Management Plan Guidelines	
		c.	Nomination Document for the Inscription on the World Heritage List	
		d.	Historic Jeddah, the Gate to Makkah	

		e. Volume 2 – Legal Annexes	
		- Historic Jeddah, the Gate of Makkah State of Conservation Report, November	The Saudi Commission for Tourism and National Heritage
		- Guidelines for the Building Regulation of Historic Jeddah, the Gate to Makkah	Jeddah Municipality
		- United Nations Educational, Scientific and Cultural Organization, Convention Concerning the Protection of the World, Cultural and National Heritage World Heritage Committee, Forty-second session, Manama, Bahrain 24 June - 4 July 2018	UNESCO
		- Historic Jeddah, the Gate to Makkah (Kingdom of Saudi Arabia) No 1361	ICOMOS
4	**Arabic and English Books**	- Craftsmen in the City of Jeddah	Wahib Cable, (1996)
		- Jeddah: History and Social Life	Mohamed Sadiq Diab, (2003)
		- Housing, Habitat, and Environment	Salwa Ahmed Mohammed Saeed, (1986)
		- Jeddah..Tale of a City	Mohamed Youssef Traboulsi, (2008)
		- Abdulraouf Hassan Khalil Museum – The Introduction	Abdulraouf Hassan Khalil, (1985)
		- Heritage Building Information Modelling for Implementing UNESCO Procedures: Challenges, Potentialities, and Issues	Baik, A. (2020)

5	**Articles**	Ph.D. Theses: A New Methodology for A Detailed three-dimensional (3D) Modelling and Documentation of the Complex Architectural Heritage Elements: A Feasibility and Case Study of Wooden Projected Window "the Roshan" in the Historical City of Jeddah	Alitany, A. (2014)
		A New Methodology for A Detailed 3D Modelling and Documentation of the Complex Architectural Heritage Elements: A Feasibility and Case Study of Wooden Projected Window "the Roshan" in the Historical City of Jeddah	Alitany et al. (2014)
		The 3D Documentation of Projected Wooden (the Roshans) in the Old City of Jeddah (Saudi Arabia) Using Image-Based Technologies.	Alitany et al. (2013)
		Jeddah Historical Building Information Modelling "JHBIM" Old Jeddah - Saudi Arabia	Baik et al. (2013)
		Jeddah Historical Building Information Modelling "JHBIM" Object Library	Baik et al. (2014)
		Integration of Jeddah Historical BIM and 3D GIS for Documentation and Restoration of Historical Monument	Baik et al. (2015)
		From Architectural Photogrammetry Toward Digital Architectural Heritage Education	Baik et al. (2018)
		From Point Cloud to Existing BIM for Modelling and Simulation Purposes	Baik, A. (2019)

		BIM-Driven Islamic Construction: Part 1 – Digital Classification	Almaimani and Nawari, (2015)
		BIM-Driven Islamic Construction: Part 2 – Digital Libraries	Almaimani and Nawari, (2017)
		Wooden Bay Window (Rowshan) in Saudi-Hejazi Heritage Buildings	Adas, A. (2013)
		The Old City of Jeddah: from a Walled City to a Heritage Site	Bagader, M. (2014)

Table 4. 1: *Summary of the data obtained from different secondary sources.*
(Author, 2021)

Based on Jeddah Municipality guidelines for the building regulation of historic Jeddah (2014) and initial viewings via field visits, it is found that the buildings classification system of Jeddah historical city is divided into:

1) Markets,
2) Roshan tower houses,
3) Educational schools
4) Mixed residential and commercial buildings,
5) Ribat-s (buildings used for defence, merchants as well as pilgrims),
6) Mosques, and
7) Wall gates, (Jeddah Municipality,2014, p.9)

So, site selection was based on evaluation criteria discussed in section (4.3), which are significant value, unique structure, accessibility of the site, and availability of data to establish a holistic digital record. Consequently, the selection of buildings to be studied in this research was limited to Rabat's, mosques, and wall gates (Figure 4. 15). In addition, optimal candidates were further developed for the case studies (Table 4. 2).

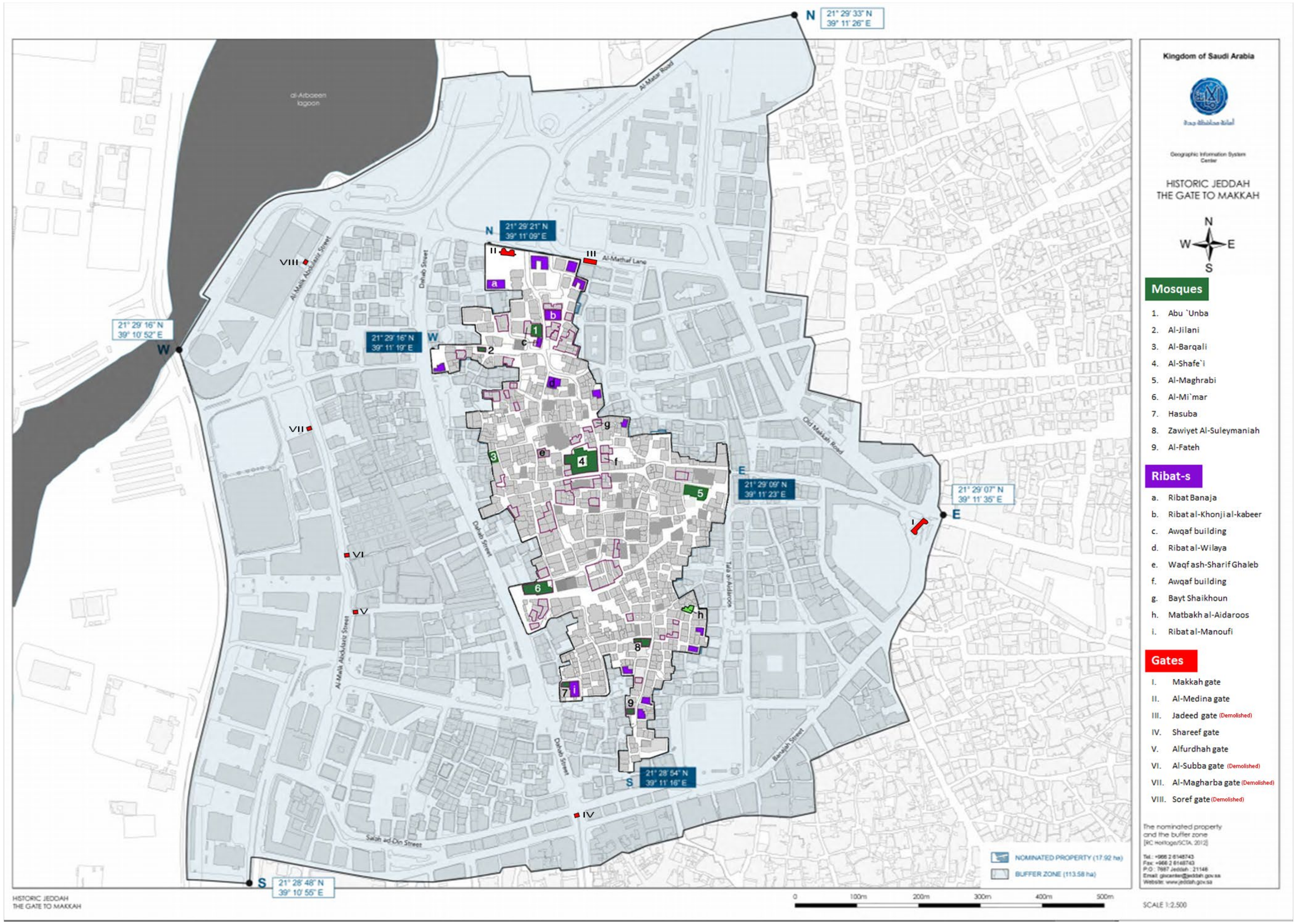


Figure 4. 15: *The mosques, Ribat's, and gate's locations in Jeddah historical city.*
(Saudi Commission for Tourism and Antiquities, 2013; Jeddah Municipality, 2021, and edited by the author, 2021)

Building Type and Name	The Evaluation Criteria			
	Significant Value	Unique Structure	Accessibility of Site	Availability of Data
Mosques				
1. Abu `Unba	✓	✗	✓	✗
2. Jilani	✓	✗	✓	✗
3. Barqali	✓	✗	✓	✗
4. Shafe`i	✓	✓	✓	✓
5. Maghrabi	✓	✗	✓	✗
6. Mi`mar	✓	✓	✓	✗
7. Hasuba	✓	✗	✓	✗
8. Zawiyet Al-Suleymaniah	✓	✗	✗	✗
9. Fateh	✓	✗	✓	✗
Ribat's,				
1. Ribat Banaja	✓	✓	✓	✓
2. Ribat al-Khonji al-kabeer	✓	✓	✓	✗
3. Awqaf building	✓	✗	✗	✗
4. Ribat al-Wilaya	✓	✓	✗	✗
5. Waqf ash-Sharif Ghaleb	✓	✓	✗	✗
6. Awqaf building	✓	✓	✗	✗
7. Bayt Shaikhoun	✓	✓	✗	✗
8. Matbakh al-Aidaroos	✓	✓	✗	✗
9. Ribat al-Manoufi	✓	✓	✗	✗
Gates				
1. Makkah Gate.	✓	✓	✓	✓
2. Medina Gate.	✓	✓	✗	✓
3. Jadid Gate.	✓	✓	✓	✓
4. Sharif Gate.	✓	✓	✓	✓
5. Bantt Gate.	✓	✓	✗	✗
6. Magharba Gate.	✓	✓	✗	✗
7. Subba Gate.	✓	✓	✗	✗

Table 4. 2: *Jeddah historic buildings filtering based on the four evaluation criteria of selecting the suitable buildings to be studied in this research.*
(Author, 2021)

As a result of the evaluation criteria used in selecting the optimal case studies in this research, the choice fell on five historic buildings, including Ribat Banajah, Shafei Mosque, Sharif Gate, Jadid Gate, Makkah Gate (Figure 4. 16).

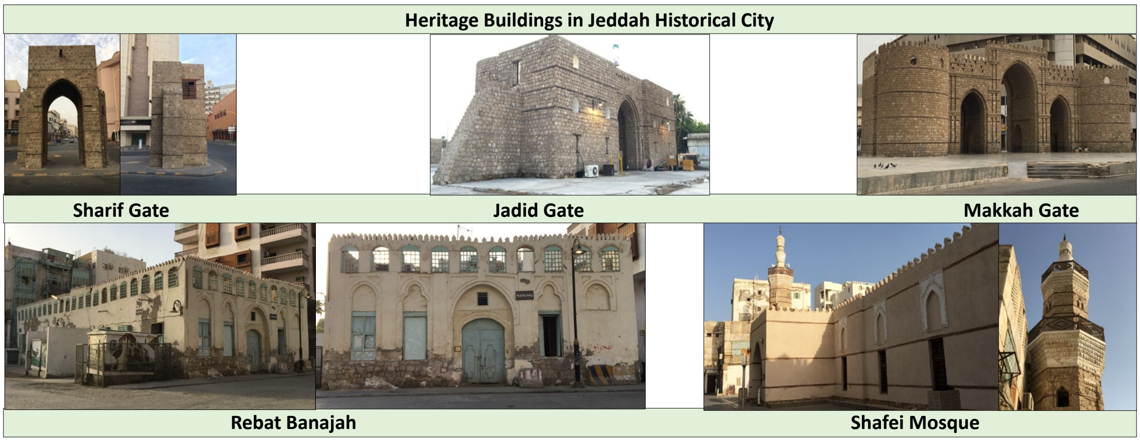


Figure 4. 16: *The five historic buildings selected in Jeddah historical city for this research, are Sharif Gate, Jadid Gate, Makkah Gate, Ribat Banajah, and Shafei mosque.*
(Author, 2021).

4.5.1.1. Detailed Evaluation Criteria

4.5.1.1.1. Sharif Gate

The Sharif Gate was chosen for many reasons, which intangible attributes and tangible elements:

Intangible attributes

- The Sharif Gate has historical, social, and economic value as well as architectural value. It is considered the southern gateway to Jeddah's historic district (Jeddah Municipality, 2020). It is a historical witness to the Portuguese attack on the Ottoman Empire, which was at that time at an early stage of influence in this region. The gate helped the city resist the Portuguese attack, commemorated by the existence of a Portuguese cemetery, which is the only cemetery for non-Muslims in Jeddah located near Sharif Gate (Al-Hitar et al., 2006).

- The Sharif Gate has social and economic values. Some people shopped from the Al-Asr market outside the old Jeddah wall, and some visited 'Al Hamala,' a high hill, which was an outlet for the people of Jeddah, especially the elderly. It is cited that when a person sits above that hill, he can overlook a wonderful view of Bab Sharif and Al-Asr market, and this illustrates both the economic and social values of Sharif Gate, see figure 4. 17 (Jeddah Municipality, 2020).

Figure 4. 17: *A view of Sharif Gate from inside and outside the wall in 1918.*
(Bakr, 2014)

<u>*Tangible elements*</u>

- Location Access – the Sharif Gate is in the middle of the street, so it is easy to access the gate any time of the day without the need for permeation from governmental or private parties (Figure 4. 18).

- Manageable Size – it is a building of a relatively small size, which helps to quicken the data collection and processing stages to reach the final result. Its size is quite small, where it has a length of 5.39 m, a width of 3.74 m, and a height of 6.77m.

- It is distinguished by its architectural features. It has a Gothic style which was built with coral limestone ‘Mangabi stone, ' sea mud, and wood. It has one Gothic vault passage with a pointed arch. In addition, it has two latticework wooden windows.

Figure 4. 18: *Sharif Gate, Jeddah, Saudi Arabia.*
(Author, 2020)

4.5.1.1.2. Madina and Jadid Gates

The intangible attributes and tangible elements of the gates are as follows:

<u>*Intangible Attributes*</u>

- The Madina Gate has historical and economic values in the early days. As for historical value, it is considered as one of the old Jeddah's wall gates which were built in the 15th century, see figure 4. 19 (Jeddah Municipality, 2020). It was named the Medina Gate because it faces the access road that leads to the city of Medina (Bagader, 2014, p.368).

- As for the economic value, the Medina Gate was used for the travellers to and from Medina City and Makkah City because it was impossible for convoys to move from the western region of Jeddah to Makkah Gate in the east. The Medina Gate was used to enter carts loaded with stones extracted from the north side of Jeddah and the mud extracted from the Mud Sea, or what became known as Lake Arbaeen, that were used to build Jeddah homes at that time (Jeddah Municipality, 2020).

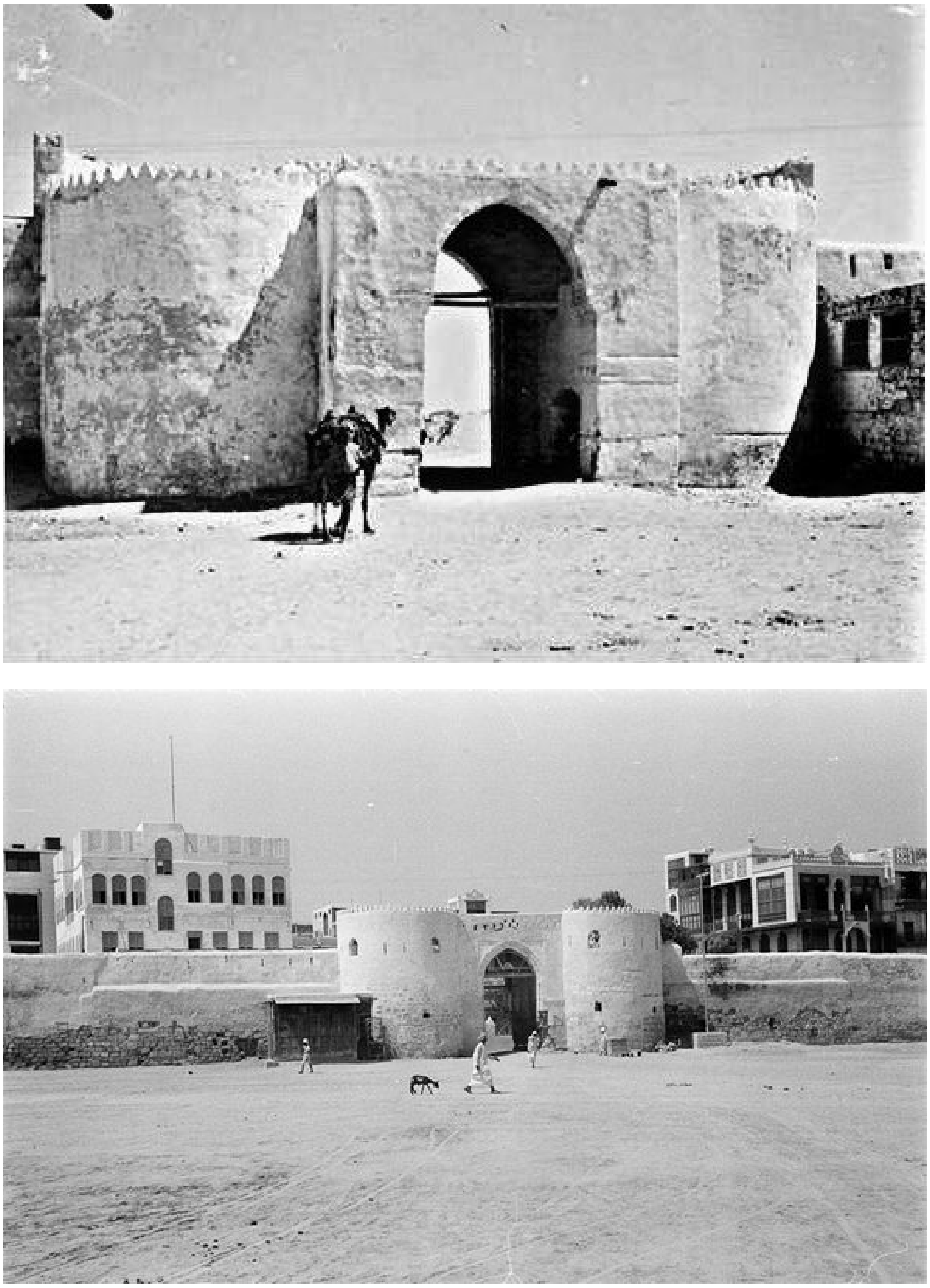


Figure 4. 19: *The Madina Gate in 1918 at the top, and the bottom before demolishing the wall, the picture from 1945 by the globetrotter Wilfrid Thesiger.*
(Abu Alama, 2010; The Pitt Rivers Museum, 2012)

- In the east of the Madina Gate, the Jadid Gate was located (Figure 4. 20), which has historical and economic values. For historical value, it was built at the beginning of the Saudi era at the end of the thirties or the beginning of the forties AD. It was located in the northern sector of the wall, beside Madina Gate, facing the house of al-Hazzazi (Jeddah Municipality, 2021). It was named after Jadid, which means new in Arabic because it was the last gate built on the Jeddah city wall (Figure 4. 21). As for the economic value, it was built to ease the passage of cars, which began to replace camel convoys in transporting passengers, pilgrims, and goods between Jeddah, Makkah, and Madinah through its double gate (Bakr, 2014). Unfortunately, Madina Gate and Jadid Gate were demolished in 1947 AD.

Figure 4. 20: *The northern wall shows Madina Gate on the left, and Jadid Gate on the right.*
(Jeddah Municipality, 2021)

Figure 4. 21: *The Jadid Gate in 1945 AD before demolishing the wall in 1947 AD. Source: Dr. Zaher Othman, Photograph by: Wilfrid Thesiger.*
(Bakr, 2014; Othman, 2019)

- Madina Gate and Jadid Gate were demolished in 1947 due to the urban development of the city outside the city's wall, but to commemorate these ancient historical gates, the Jeddah Municipality recently established a memorial whose shape simulates the Madina Gate and was named the Jadid Gate similar to the demolished ones (World Heritage Committee, 2014, p.90; Bakr, 2014).

<u>*Tangible elements*</u>

- Location Access – The Jadid Gate is located in the Sham neighbourhood on the front of the main street, so it is easy to access the gate at any time of the day.
- Manageable Size – its structure size is quite small, which can facilitate speeding up the data collection and processing stages to reach the result.
- It is well-known for its architectural features. It has a Gothic style which was built with coral limestone ‘Mangabi stone, ' sea mud, and wood. It has one Gothic vault passage with a pointed arch, two towers with six widows, and two small doors and windows inside. The towers have many small squares and rectangular openings at the top that were used for observation in the bast (Figure 4. 22).

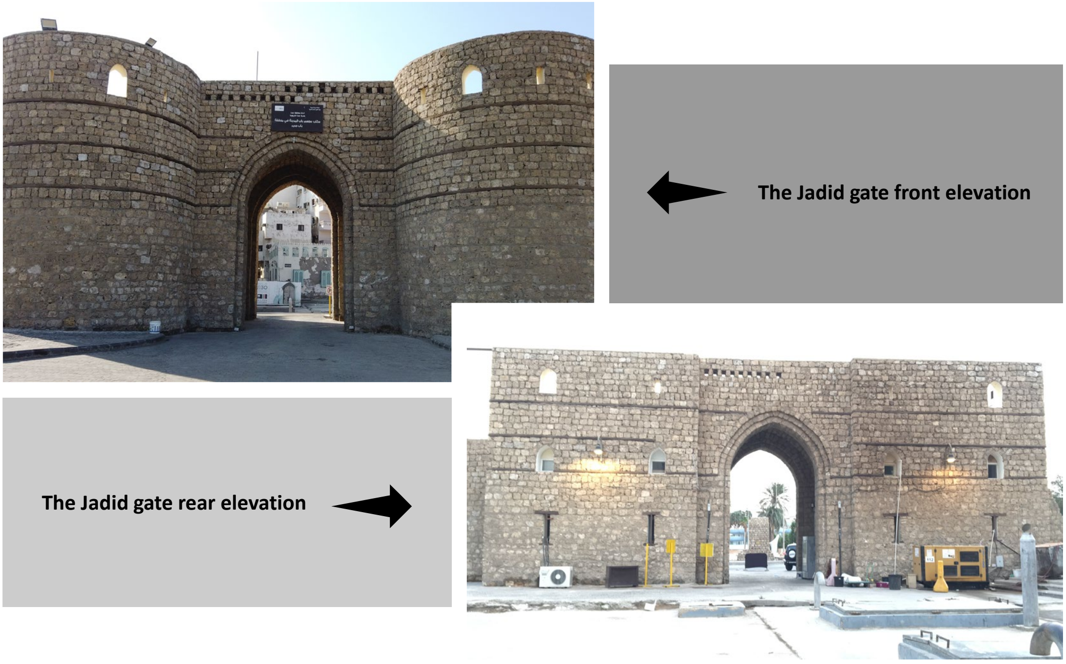


Figure 4. 22: *The Jadid Gate, Jeddah, Saudi Arabia.*
(Author, 2020)

4.5.1.1.3. Makkah Gate

The Makkah Gate was chosen for its intangible attributes and tangible elements.

Intangible Attributes

- Makkah Gate has historical, religious, economic, and architectural values discussed later in this section. It is considered a famous historic landmark in the old Jeddah wall. It was named Makkah Gate because it faces the holy city of Makkah (Bagader, 2014, p.368).

- Its religious and economic importance were formed due to its distinguished location, as it was the destination of pilgrims and goods that arrived at the port to go either to Makkah to perform the rites of pilgrimage or to sell goods in the markets located outside the wall in front of the gate, see figure 4. 23 and 4. 24 (Al-Matrafi, 2017, p.239).

Figure 4. 23: *Illustrates pilgrims and goods that arrive at Makkah Gate, pictures 1 & 2 from 1918, picture 3 from 1937.*
(Jeddah Municipality, 2022; Bakr, 2014)

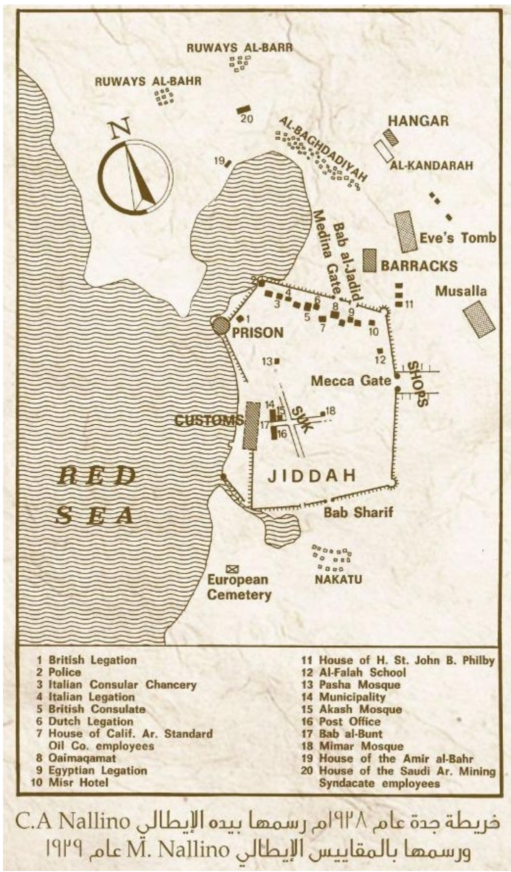


Figure 4. 24: *Illustrates Makkah Gate and shops' location, Jadid Gate, and Sharif Gate.*
(Drawn by C.A Nallino,1939; Jeddah our Days of Bless Establishment, 2016)

<u>*Tangible elements*</u>

- Location Access – Makkah Gate is located in the east of the historic Jeddah region, in front of the Bedouin market (Jeddah Municipality, 2020). Due to its significant value, it remains in its same location, which is now in the middle of the street (Figure 4. 25).

- Manageable Size – it is considered the biggest gate in the old Jeddah wall. Its size is 30m in length, 7m in width, and 8.50m in height.

- As for its architectural values, Makkah Gate was constructed in the Gothic style with coral limestone 'Mangabi stone,' sea mud, and wood. The gate has three great Gothic vault passages, each passage has a pointed arch, and within these passages, two smaller size passages aid in transforming from one passage to another. Previously, all three main passages had doors made from wrought iron, which no longer exist. The transverse beams in the wall of the passage play a role in carrying the load of the arches. In addition, four wooden beams are placed at different levels all around the gate to distribute the load of the walls. The gate has two towers; each tower has an iron door, six windows, and two embrasures. On the roof, there are fifty-four square openings and a set of 'Arayees Alsama', which are architectural elements that are used to prevent birds from standing or building their nests on the top surface.

Figure 4. 25: *Makkah Gate.*
(Author, 2020).

4.5.1.1.4. Ribat Banajah

Several reasons led the researcher to select Ribat Banajah to be studied in this research. It has interesting intangible and tangible information.

Intangible Attributes

- Ribat Banajah has historical, religious, social, and architectural values. Regarding its historical value, it is a historical residential building located within the UNESCO World Historic Site of Historic Jeddah. Its name goes back to the owner of the building Abdullah Banajah, which was built in the late 19th century (Alkayyali, 2020; Zarban, 2014, Jeddah Municipality, 2014, pp.2-14).

- As for its religious and social values, it was one of the religious and charitable institutions. At first, it was used as a hostel for hosting pilgrims, other travellers, and their animals. Then, it became a charitable endowment for housing widows and the elderly, and free food was offered to poor residents. Finally, however, pilgrims were still hosted during the pilgrimage season, where the residents of Ribat used to go up to the roofs to stay overnight and leave their rooms for the pilgrims free of charge in order to get a reward from God (Alkayyali, 2020; Al-Nimr, 2017; Jeddah Municipality, 2013, p.44).

- Indeed, the Ribats in the historical city of Jeddah represent a form of solidarity and social sympathy between the rich and the poor, which Islam has urged. The rich people give the poor people money, food, charity, zakat, or a monthly or yearly allowance that covers their needs. Some people suggest building Ribats in new neighbourhoods to help those in need (Yeslam, 2019).

Tangible elements

- Location Access – Ribat Banajah is located in the Sham neighbourhood in front of Jadid Gate, see figure 4. 26 (Jeddah Municipality, 2013).

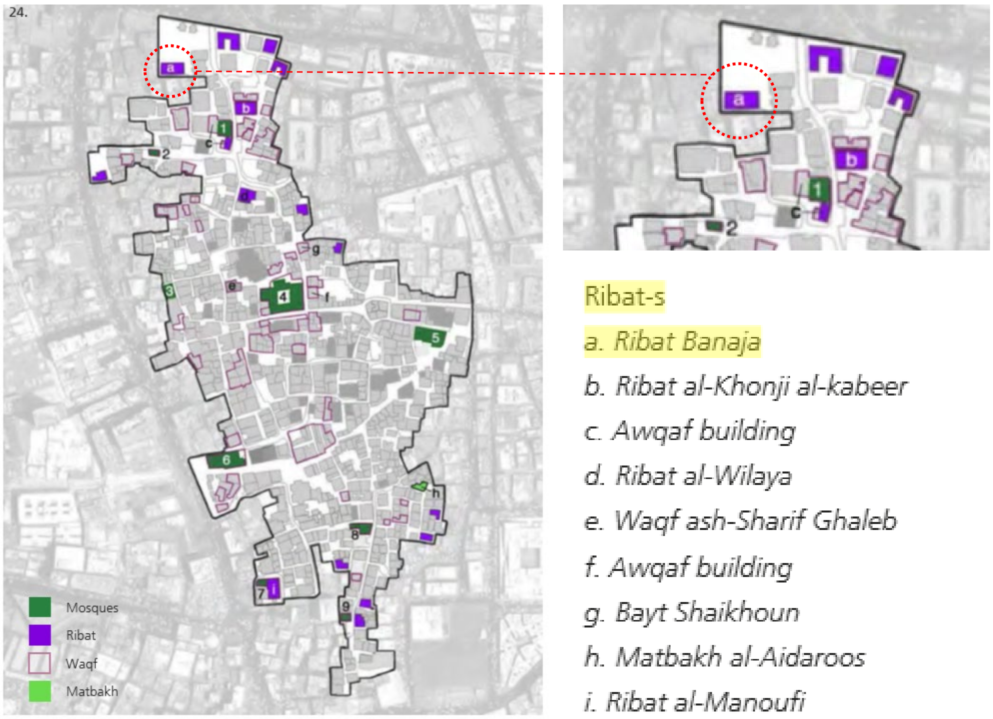


Figure 4. 26: *Nominated property: Ribat-s.*
(Jeddah Municipality, 2013, p.44)

- It has iconic architectural characteristics. It is a one-floor building designed in the Ottoman style. Its crenellated walls end with a lance shape called "Araiyes". It has light blue colour wooden windows called "Roshans" and "Shish or Mashrabiya" which are rare and unique in Jeddah's historic buildings, (Figure 4. 27). Like other historic buildings in Jeddah, raw materials were used in Ribat Banajah construction, including sea mud, Mangabi stones, and wood (Ministry of Tourism, 2020; Jeddah Municipality, 2014, p.11).

Figure 4. 27: *Ribat Banaja with its light blue colour wooden windows "Roshans" and "Shish or Mashrabiya".*
(Author, 2020).

4.5.1.1.5. Shafei Mosque

The significant intangible attributes and tangible elements are the main reasons for choosing the Shafei mosque in this search.

<u>*Intangible attributes*</u>

- The Shafei mosque is selected because of its historical, socioeconomic, religious, and architectural values. The mosque was built in the 13th century, 1400 years ago, in the reign of the second Muslim Caliph, Omar bin Al Khatab. It is cited that the first main construction of the mosque was done in the reign of Sultan Muzafar Shams Al Deen Yosif. In addition, in 1533 AD, an Indian merchant named Khawaja Muhammad Ali refurbished the mosque except for the minaret. Then in 2012, King Abdullah bin Abdul Aziz adopted the restoration of the Shafei Mosque, the ancient and largest historic mosque surviving in Jeddah, and in 2015 the restoration project was completed according to the UNESCO standards (Ministry of Tourism, 2020; Al Arabiya, 2020; Destination Jeddah, 2016).

- As for the social value of the mosque, it plays several roles in the community. The mosque is a place to gather for prayer, a centre for celebrating Islam's great religious festivals such as Eid Al-Fitar, which comes at the end of Ramadan, the month of fasting, and Eid Al-Adha during the annual season pilgrimage to Mecca. In addition, the mosque is a learning centre, providing a library containing Islamic books that help expand knowledge for understanding and learning of the Islamic religion (Abdul Ruff, 2016; Abu-Ghazzeh, 1994, p.57).

- Historically, the mosque was a socio-economic centre in addition to a religious centre. At the time of the Prophet Muhammad, peace be upon him; besides using the mosque as a place for praying, learning, and educating, it was used for offering support for the poor people, judging legal cases, organizing war plans, welcoming delegates from abroad and others (Budiman et al., 2017, pp.95-96).

Tangible Elements

- Location Access – It is a historical mosque located within the UNESCO World Heritage Site of Historic Jeddah in the Al-Mazloom neighbourhood in Al-Jamie Market, see figure 4. 28 (Jeddah Municipality, 2020; Ministry of Tourism, 2020; Jeddah Chamber of Commerce and Industry, 2017, pp.22).

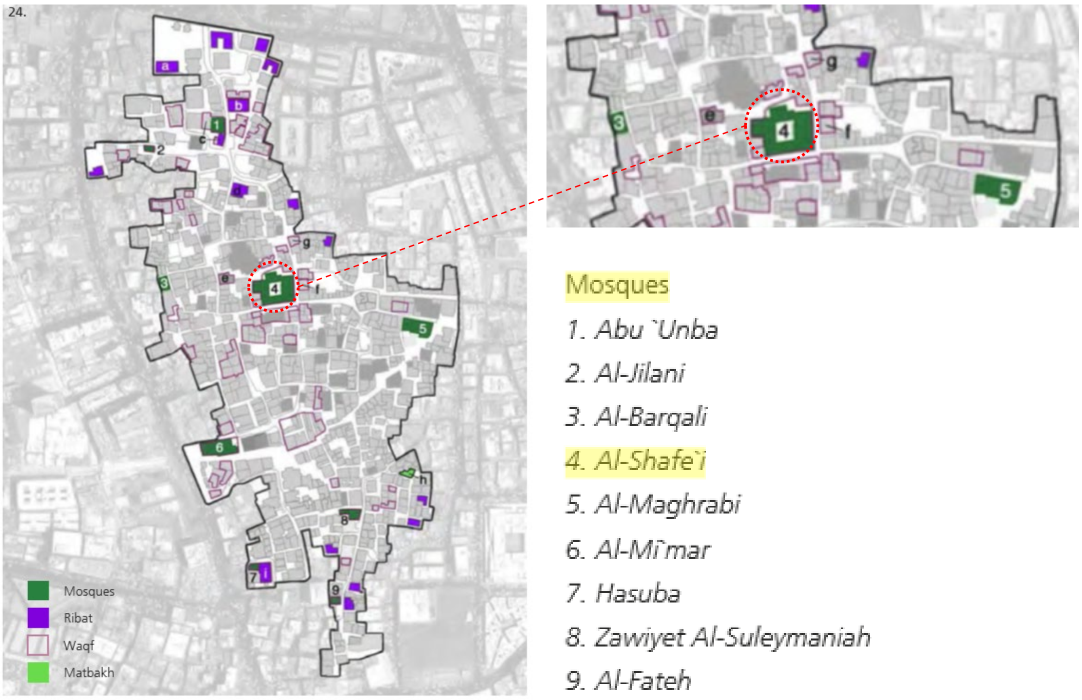


Figure 4. 28: *Nominated property: Mosques.*
(Jeddah Municipality, 2014, p.44)

- Except for the minaret, the architectural style of the Shafei mosque is Fatimid. It is a single-storied building built in a square form and has an open in its centre to provide indoor ventilation by using available local materials to satisfy the demands of the climate. Where traditional raw materials were used, such as sea mud, brick, stone, and wood (Destination Jeddah, 2016).

- The type of stone used in the mosque is called coral stone or “Mangabi” stone. It is a local coral limestone extracted from the coast of the Red Sea located beside the historical Jeddah region. Mangabi stone is easy to deal with because it is a porous, light, and insulator material resistant to salty air from the Red Sea coast. Traditionally, the Mangabi stonewalls are covered with plaster (Jeddah Municipality, 2014, p.11).

- The types of wood used in the Shafei mosque are divided into two types "Gandal" and "Jawi" wood. The Gandal wood was imported from India and was used for reinforcement and flooring. On the other side, the “Jawi" wood was imported from Java, a high-quality wood used for front doors and windows (Jeddah Municipality, 2014, p.11). As a result, the mosque has elegant wooden doors that have Arabian motifs and designs. Also, there is Arabic calligraphy carved on stone panels above the main door (Destination Jeddah, 2016).

- Historically, the Shafei mosque is considered one of the ancient mosques in Jeddah, where its minaret was built in the 7th century AH, corresponding to the 13th century AD (Jeddah Municipality, 2020). The minaret is considered the oldest in the Hijaz area, which is located in the north-eastern corner of the Mosque.

  The architectural style of the minaret construction dates back to the Ayyubid era (Al Arabiya News, 2020; Destination Jeddah, 2016). Where it was designed in a round shape and was built of carved stone and consists of three octagonal floors, and it ends with a round cap surmounted by a crescent. Each floor is separated from the other by a balcony surrounded by a wooden fence based on five gradual rows of plain muqarnas that are beautifully shaped. On each floor of the minaret in two of the octagon ribs, a "Kandiliya" window, and in the third rib, there is a small door that is dedicated to the exit of the muezzin to the balcony, which is surrounded by the wooden fence, to call for prayer, see figure 4. 29 (Hareri et al., 2020, pp.127-128; Omer, S., 2020).

Figure 4. 29: *The architectural style of the Shafei mosque minaret.*
(Author, 2020)

4.5.2. Primary data

Data were collected for the five historic buildings by adopting the mixed methods in action research method as a primary resource to offer more effective and comprehensive answers to the study research question, which was 'How to create a replicable holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia'. In addition, the action research method was adopted to offer comprehensive solutions to practical problems that occur during fieldwork starting from capturing and then extracting the building element dimensions, materials, condition, and appearance by using digital recording tools including digital photogrammetry and laser scanning to determine the most appropriate recording method to capture information of a historic building. So, the process of data collection from the primary resources was also divided into two stages: 1) planning for primary data collection and 2) implementing the process of primary data collection.

- ***Stage 1: Planning for Primary Data Collection of Jeddah Historic Buildings***

Primary data is required to answer the **RQ**: Identify the most appropriate recording methods to capture information on historic buildings?
After surveying the literature and selecting the case studies of the research in the secondary data collection phase:

- The phase of action-based primary data collection started by dividing historic building recording methods into three categories: 1) Range-based, 2) Image-based, and 3) Smart stations.
- The identification of the recording methods was based on: 1) equipment availability, 2) quickness, and 3) accuracy to capture the tangible elements data of the chosen five historic buildings in Jeddah historical city.
- Also, after surveying the literature and obtaining approvals from King Abdulaziz University in Jeddah, laser scanning as a range-based method, digital photogrammetry as an image-based method, GPS, and TST as smart stations methods have been chosen as the most suitable recording methods to capture information of historic buildings in this research (Figure 4. 30).

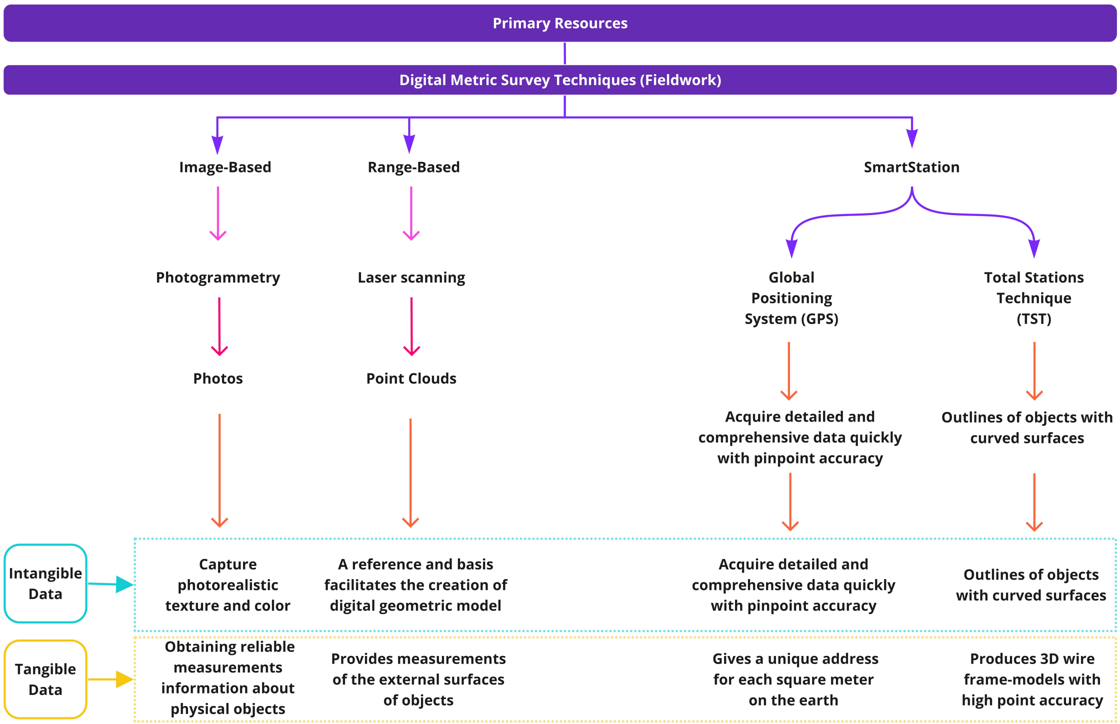


Figure 4. 30: *Primary resources to obtain tangible information about historic buildings.* (Author, 2021)

- ***<u>Stage 2: Implementing the Process of Primary Data Collection for Jeddah Historic Buildings</u>***

Different data collection methods were used to obtain information about tangible elements of this research's five chosen historic buildings. The tangible elements data collection process started by:

1) Contacting King Abdulaziz University, Faculty of Architecture and Planning, Geomatics Department, to obtain their approval to cooperate with the researcher by providing available equipment, data, and information as part of supporting the research mission for scientific research purposes. Even though accessing the university equipment was not possible due to the restrictions caused by COVID-19, faculty members in the geomatics department were collaborative and provided helpful data and information (Table 4. 3).

	Type	Description	Responsible Party
1	2D AutoCAD plans (Appendix C)	Plans, elevations, and sections of Sharif Gate	King Abdulaziz University
2	Georeferenced points clouds (Appendix F)	Data collection was done by using a Leica geosystems laser scanner for the five historic buildings, Shafei Mosque, Ribat Banajah, Jadid Gate, Makkah Gate, and Sharif Gate.	King Abdulaziz University

Table 4. 3: *The summary of the data obtained from different primary sources.*
(Author, 2021).

2) Fieldwork was another data collection method used to obtain tangible elements data of the five historic buildings which started by:

- Drawing a strategy on the buildings' plans that illustrates the path of movement to capture the data based on image capture strategies for terrestrial photography recommended by Historic England in the "Guidance for Good Practice" report (Bedford, 2017, p.38).
- Collecting data on-site to create a 3D model of tangible elements of the historic buildings by using varied tools such as:
  i. A smartphone digital camera (Photos + Videos),
  ii. Digital camera (Photos + Videos),
  iii. A smartphone digital recording app (3Dim Capture App),
  iv. Digital camera (Videos + Archival images),
  v. A smartphone digital camera (Videos) + Digital camera (Photos) + Laser scan (Points Cloud).
- Data processing by one of the methods below:

i. <u>First Method (Sharif Gate and Jadid Gate)</u>

Where photos are captured or videos converted, an additional process is followed by alignment and 3D points cloud creation. The following workflow and mitigation were used.

1. Capturing sequential photos or converting videos into sequential photos by using Adobe Premiere Pro software (Adobe, 2021, p.732),
2. Aligning the sequential photos, building a point cloud, cleaning noises, adding texture, and creating a 3D model of Sharif Gate and/or Jadid Gate in Agisoft Metashape Pro software (Agisoft LLC, 2021, pp.4-51).

ii. <u>Second Method (Makkah Gate)</u>

A separate survey for each part of the building by a smartphone application software followed by 3D point clouds creation of each part, filtration, and then application of alignment processes for merging to build 3D dense point clouds. The following workflow and mitigation were used.

1. Recording several scans by the 3Dim Capture App on a smartphone, then processing on the 3Dim cloud for creating 3D point clouds of each scan (3Dim, 2020).
2. Filtering the recorded scans to choose the best ones to be used.
3. Importing the chosen scans as XYZ files into CloudCompare software for processing (Girardeau-Montaut, 2015, pp.7-180).
4. Aligning each scan with another one by picking four equivalent point pairs each, and then merging them to build 3D dense point clouds of Makkah Gate.

iii. <u>Third Method (Ribat Banajah)</u>

Separately align photos and archival images followed by creating a 3D model of each alignment, then merge them into one single 3D model. The following workflow and mitigation were used.

1. Aligning sequential photos and archival images each one alone to process the missing parts in a historic building.
2. For each aligned group, building a point cloud, cleaning noises, adding texture, and creating a 3D model of a historic building in Agisoft Metashape Pro software was needed (Agisoft LLC, 2021, pp.4-51).
3. The two 3D models created of the building were exported as a PLY file and imported into CloudCompare software to be merged into one single 3D model to fill in the missing parts in Ribat Banajah (Girardeau-Montaut, 2015, pp.7-180).

iv. <u>Fourth Method (the Shafei Mosque)</u>

If not all the gaps were filled due to the minimum number of sequential photos captured and archival images found in the previous method, 3D point clouds data was another type of data that can be used to fill in the missing parts besides sequential photos and archival images. Survey a building with a laser scanner device, followed by processing and registration of the obtained data as 3D points cloud data. Then align the 3D model, extracted from sequential photos and archival images, and the 3D point clouds, extracted from the laser scanner, to be merged as one single 3D model. The following workflow and mitigation were used:

1. The Shafei Mosque was surveyed using a Leica ScanStation C10 device, and then the collected data was processed and registered using Cyclone software into a 3D point cloud.
2. Exporting the 3D model, extracted from sequential photos and archival images, as a PLY file, and the 3D point clouds data, extracted from the laser scanner, as a PTS file.
3. Importing them into CloudCompare software to be integrated as one single 3D model.
4. Aligning the 3D model and the 3D point clouds by picking four equivalent point pairs in each model to help integrate them together in one single 3D model of the Shafei Mosque (Girardeau-Montaut, 2015, pp.7-180).

4.6. Chapter Summary

To conclude this chapter, in comparison with the international efforts, it is noticeable that there are attempts to improve policy and governance for the protection and documentation of historic buildings by issuing laws and regulations and establishing a body responsible for conserving antiquities in the Kingdom of Saudi Arabia. This can help the country to keep on track with the enormous and fast development around the world in the field of digital and urban transformation to achieve its Vision 2030 with the purpose of improving the quality of life in the country.

It is also found in this chapter that the selection of historic buildings as case studies is dependent on the evaluation criteria, which are significant value, unique structure, accessibility of the site, and availability of data on the historic buildings to establish a holistic digital record. Some historical buildings were initially considered but later had to be rejected from this present study, despite their considerable historical value and unique structure, such as Al-Falah school and Al-Mi`mar mosque because from practical limitations Al-Falah school was not accessible for maintenance works at this time, and Al-Mi`mar mosque has not enough information to be studied in this research. Also, both buildings have large areas, so the data collection and processing will take a long time. However, the time available for this research is limited. At some point in the future, this may change, and it would be helpful to ensure that they are both thoroughly surveyed and studied to consider their future use either by the government as a museum or use their data by researchers in their historical research due to their great historical and architectural values based on UNESCO regulations. Al-Falah school and Al-Mi`mar mosque are classified as world cultural-historic buildings, located in an area registered by UNESCO (UNESCO, 2021, p.37).

The information used for selecting suitable historic buildings in Jeddah city to be studied in this research was divided into two types: secondary data and primary data, and both include tangible and intangible data. In the processing of collecting data, it was found that historical records are generally in a good state but scattered in the Jeddah municipality office, The Saudi Commission for Tourism and National Heritage office, The Saudi Commission for Tourism and Antiquities office, Masaken Engineering Consulting office, King Abdulaziz University, King Fahad Library, Saudi digital online library "online", The International Council on Monuments and Sites (ICOMOS) "online", and UNESCO "online". No single source can be referred to for understanding the physical and cultural dimensions of a historic building in Saudi Arabia. Therefore, a single digital record of historic buildings in Jeddah city that includes their tangible data and intangible data was created in this research to improve digital information management which can be a fundamental step towards a 'holistic record'.

Based on previous studies, the appropriate recording tools, methods, and processes that can be used and followed to record information about a historic building were found. However, each tool and method has several disadvantages as stated in **chapter 02**. Therefore, an integration of different tools, methods, and data was adopted to reach a better result of recording the selected historic buildings in this research, explained in detail in **chapter 05**. This is why the primary fieldwork is also undertaken. Not just to establish a principal workflow for intangible and intangible records but to create a larger system of organization for historic building information management.

Chapter 05: Data Acquisition and Processing of Selected Case Studies

5.0. Introduction

The chapter starts with a brief explanation of the Structure from Motion (SFM) approach and Neural Radiance Fields (NeRF) approach and their utilization (5.1). The general action-based workflow of Sharif Gate (5.2), the Jadid Gate (5.3), Makkah Gate (5.4), Ribat Banajah (5.5), and the Shafei mosque (5.6) is introduced, which is followed by a practice-based exploration the data acquisition processes and data processing stages of each building to examine the capability of varied digital devices in generating a three-dimensional (3D) model to identify the most appropriate recording method to capture tangible and intangible information of a heritage building for creating a holistic digital record. Issues of data acquisition and processing stages of the used method and tools in recording heritage buildings are explained. Discussion findings of the whole chapter are then clarified. Conclusions are drawn regarding this selection, which is studied in detail and digitally modelled in this research.

5.1. Structure From Motion (SFM) approach and Neural Radiance Fields (NeRF) Approach

Photogrammetry is a process of measuring, recording and interpreting photographs to create a spatial model. Dr. Albrecht Meydenbauer defined the term in 1893 and processes of photogrammetry have been applied across a range of industries. Photogrammetry of digital photographs involves the Structure From Motion (SFM) approach and, recently Neural Radiance Fields (NeRF) approach. The SFM approach is a photogrammetric range imaging technique that utilizes overlapping two-dimensional (2D) images obtained from multiple positions to create a realistic 3D mesh and point cloud (Figure 5. 1).

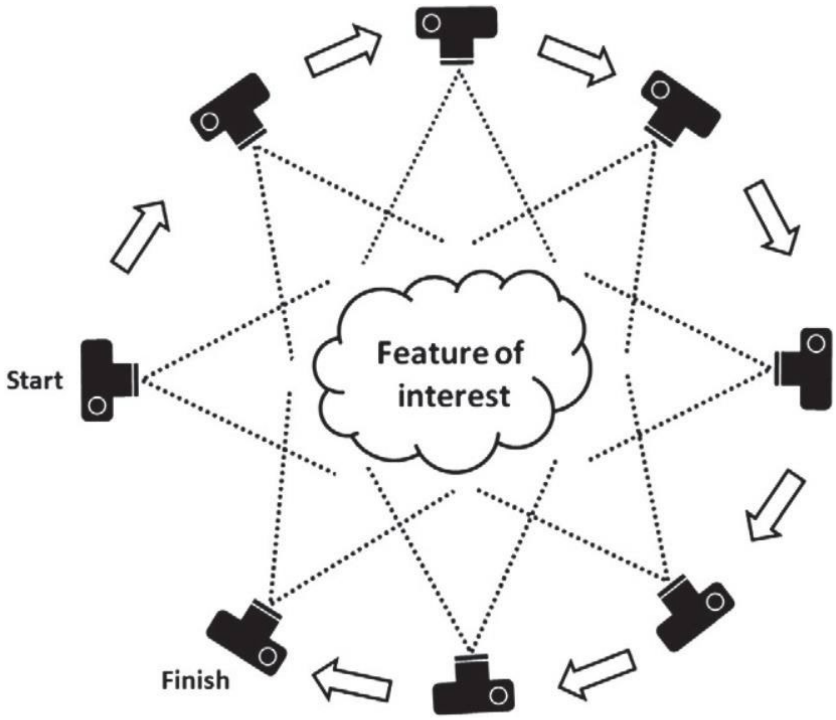


Figure 5. 1: *Structure-From-Motion (SFM) approach.*
(Westoby et al., 2012)

The Structure From Motion approach automatically identifies points of interest or "Key points" between each image. The number of key points generated depends on the image's texture and resolution, as the quality of the output point cloud data depends on the photo collection density, sharpness, resolution, and the range of natural scene textures. The high level of overlaps between photos leads to generating a high level of key points, ensuring the quality of the generated point cloud data (Nyimbili et al., 2016, pp. 27-30). However, movable objects such as people and reflective surfaces such as water and monotonous surfaces can cause holes in the generated 3D mesh, leading to further editing, modelling, and correction in the data. The popular software used in the SFM approach is Bundler, Agisoft Photoscan, Photomodeler, and Pix4D mapper software (Bedford, 2017, pp.1-124).

In recent years, a new approach called Neural Radiance Fields (NeRF) has emerged. NeRF is defined as a powerful representation approach of scenes, by capturing sequential photos of an item from various angles, as well as their opposite positions, NeRF learns to represent 3D objects to synthesise new scenes in the appropriate method, see figure 5. 2 (Cheng, 2022).

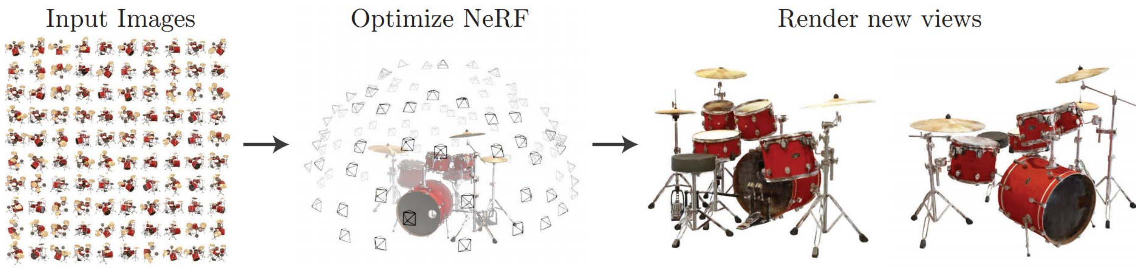


Figure 5. 2: *Considering a huge collection of photos, Neural Radiance Fields (NeRF) can represent the 3D object to synthesise new views.*
(Mildenhall et al., 2022)

For a scene representation from a collection of input images, the NeRF approach uses 5D coordinates including three spatial locations: width, height, and depth (x, y, z) and two viewing directions: polar angle θ (theta), and azimuthal angle φ (phi). The outputs are colour and density at that continuous location. Then, the volume rendering techniques are needed to collect samples of this scene representation through camera rays to render new views from any perspective (Mildenhall et al., 2022). However, a large number of images is required, training time is long-lasting, and the camera position of each image is considered essential to acquire new photorealistic views of complicated scenes with higher accuracy and appearance (Cheng, 2022).

In the field of photogrammetry, various and widely available image capture strategies can be used for terrestrial photogrammetry (Figure 5. 3). For example, DSLRs digital cameras and smartphone cameras have been used in several research studies for 3D object reconstruction capability and representing scenes for view synthesis based on the SFM approach and NeRF approach (Bedford, 2017, pp.1- 124; Yilmazturk et al., 2019, pp.1-10; Mildenhall et al., 2022).

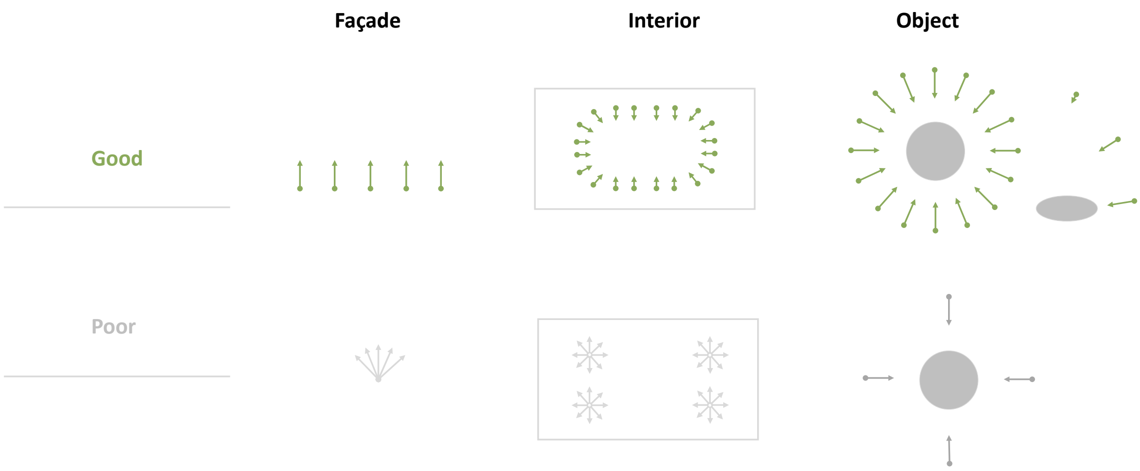


Figure 5. 3: *Strategies of image capturing for terrestrial photogrammetry for façades, interiors, and objects.*
(Agisoft user manual, 2017; Bedford, 2017)

Since this research adopted an action-based approach to collect the data, digital cameras and smartphone cameras were used with a combination of the structure from motion approach and neural radiance fields approach to generate 3D models and view synthesis of the selected heritage buildings. These contributed to a wider objective of creating a holistic 3D model, including its tangible and intangible information for digital documentation and dissemination for future works.

5.2. Case Study 1: Sharif Gate

5.2.1. Introduction

The selected heritage buildings were of three types: 1) Gates, 2) Residential Buildings ‘Ribats', and 3) Mosques. In the first category, several old Jeddah city gates built in the 15th century still survive, including Sharif, Jadid and Makkah (Jeddah Municipality,2014, p.9). Action-based research of the Sharif Gate was used in this study to examine the capability of smartphone digital cameras and the most appropriate recording method for generating a 3D model of a heritage building. The general workflow of Sharif Gate is illustrated in figure 5.4.

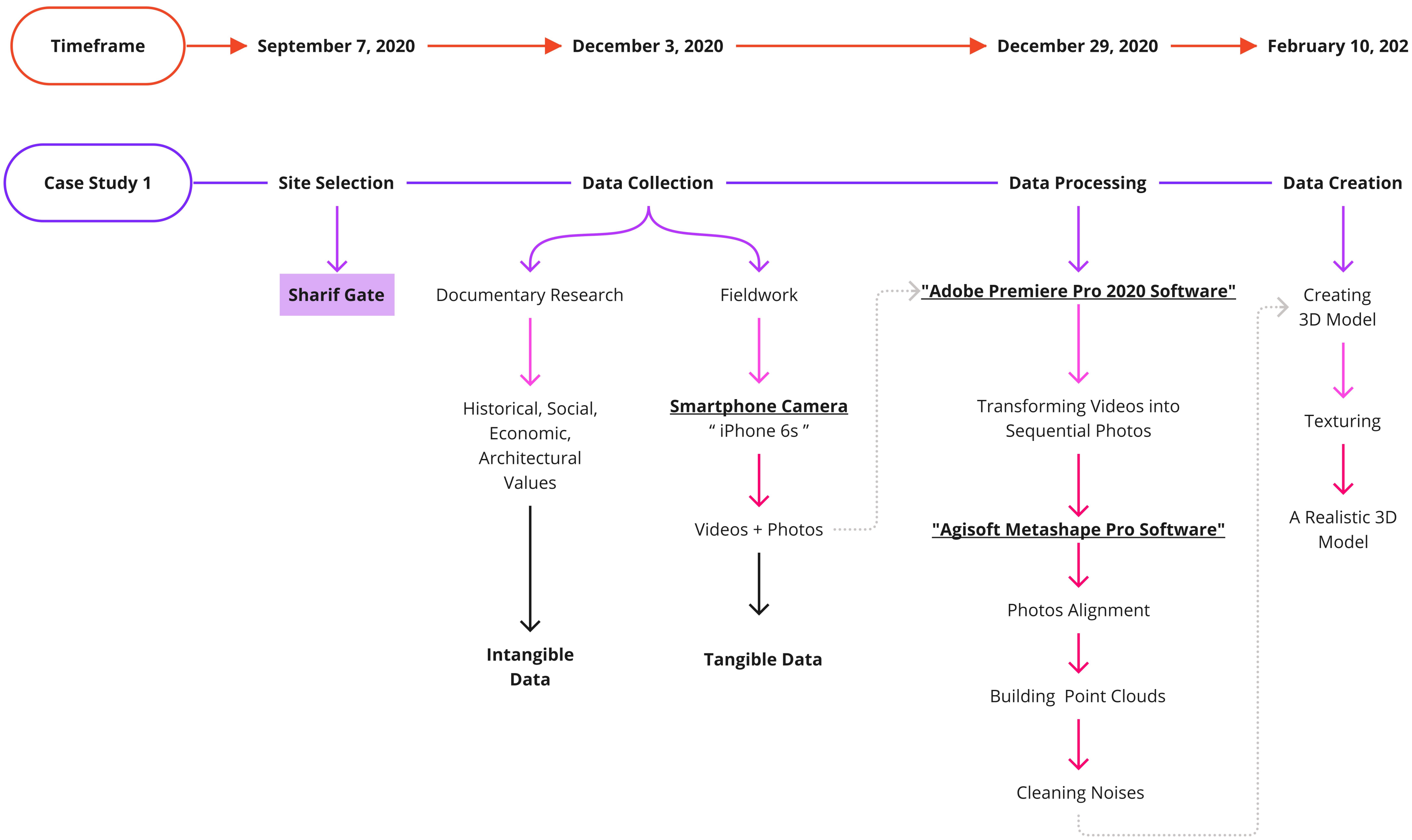


Figure 5. 4: *A diagram explanation of the general workflow of Sharif Gate.*
(Author, 2021)

The diagram explains the practical stages and methods used in Sharif Gate for digital recording and reconstruction. Many practical aspects are considered in this case study regarding timeframe, site selection, data collection, data processing, and data creation aspects. As for the time aspect, the gate lasted around five months to record and reconstruct digitally. Starting with the site selection aspect is based on the four evaluation criteria for selecting suitable buildings, including significant value, unique structures, accessibility of the site, and availability of data, which is explained in detail in **chapter 04.**

Then, the data collection is conducted based on documentary research from various resources to acquire intangible data of Sharif Gate for understanding its significant values and practice-based fieldwork using digital metric survey techniques including smartphones to acquire videos and photos of the gate's tangible data (5.2.2). A realistic 3D model of a heritage building can be generated with acceptable accuracy when data about the various tangible elements of heritage buildings are brought together by integrating images with videos from smartphone cameras (5.2.3). Some issues related to data collection, processing and creation, as well as time, technical, and geographical reference issues identified during this process, are also discussed in section 5.2.4. Followed by presenting the findings from integrating images and videos of smartphone digital cameras in a 3D model. These contributed to developing a holistic 3D model of heritage buildings (5.2.5). Based on that, questions arose about what would happen if the survey was repeated over 20 years. And having a time series of data, and what could then be drawn from this information? These queries are briefly discussed in **chapter 07**.

5.2.2. Data Acquisitions of Sharif Gate

Data acquisition pre-processes began by:

1- **Developing a practical plan based on the Sharif Gate floor plan**. This illustrates the path of movement to capture the data (Figure 5.5) using image capture strategies for terrestrial photography recommended by Historic England (Purificação et al., 2022, p. 9; Bedford, 2017, pp. 38; Hartley, 2020; Tamimi et al., 2023, p. 301). The floor plan was obtained from King Abdulaziz University.

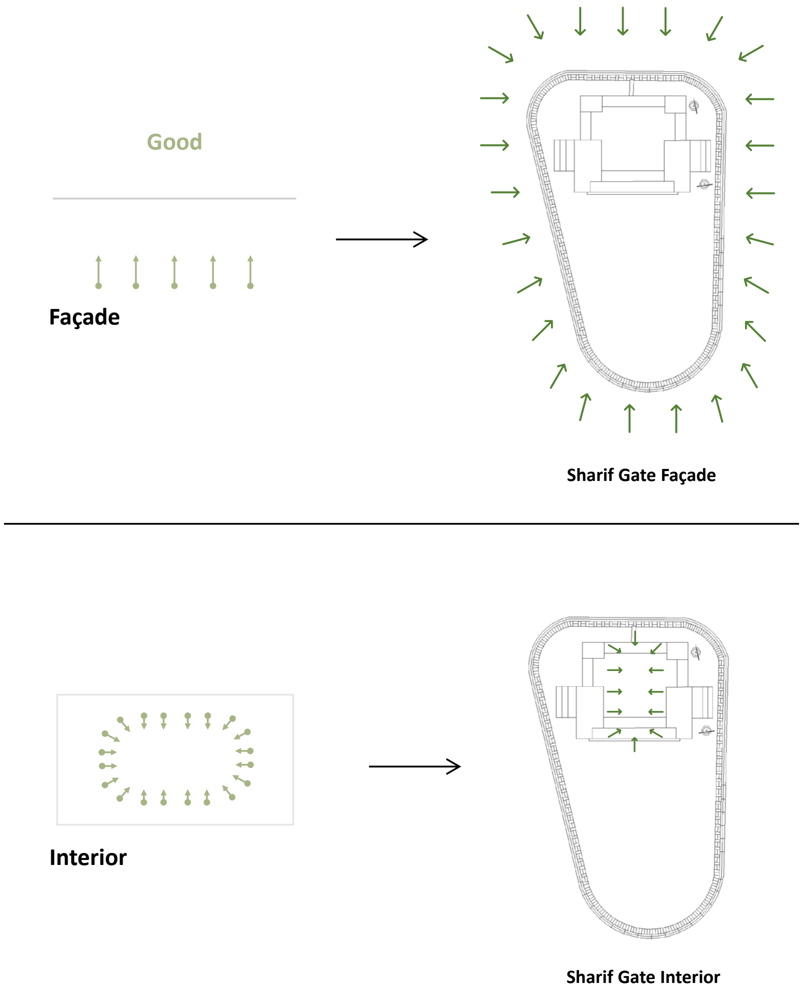


Figure 5. 5*: Photo capture strategies for terrestrial photography on the left, and the path of movement to capture photos of the Sharif Gate façade and interior on the right.*
(Bedford, 2017; Author, 2021)

2- **The available tool** that the author had at the time of this research was an iPhone 6s digital camera. This was used to conduct the practical mission of digital scanning. This revealed the ability of citizens with a smartphone could contribute images for updating various heritage areas, and the idea is to use something replicable.

3- **The practice-based action research of collecting on-site data of Sharif Gate** started by:

   a. A cloudy day was chosen as this is recommended for image capture because it provides equal light around the building (Atajwer et al., 2021, p. 6).

b. The site was checked to be accessible and free of obstacles and reflective surfaces such as mirrors and water (Hartley, 2020; Purificação et al., 2022, p. 7).
c. The smartphone camera was set at 4K resolution photos and 30 frames per second videos to obtain high-quality data.
d. Moved 360 degrees around the building as planned in the acquisition strategy (above) to capture photos and record videos simultaneously. This was done for the exterior and interior (Salvi, 2016).
e. The Sharif Gate data recording followed the recommended guidelines for scanning by smartphone digital camera. In summary, this means: scanning like painting a room with slow movement over the building and overlapping between each image to build up a complete 3D reality model of tangible elements of Sharif Gate ((Bedford, 2017, p.38; Hartley, 2020; Purificação et al., 2022, p. 18).
f. At the end of this process, 242 photos of the outer façade and the interior were taken, as well as three separate videos.

5.2.3. Practical Stages of Data Processing at Sharif Gate

The procedure of data processing practice-based to create a 3D model of an object goes through several stages:

1- Starting with loading the obtained images of the object into a 3D reconstruction of objects from image data software such as Pix4d, and Agisoft PhotoScan (Yilmazturk et al., 2019, pp.1-10)
2- Alignment photos by reorganizing the images sequentially (Ataiwe et al., 2021, p.7),
3- Building tie and dense cloud points (Ataiwe et al., 2021, p.7),
4- Noise cleaning (Agisoft, 2021),
5- Creating a 3D model of that object (Agisoft, 2021).

The practical stages of data processing at Sharif Gate are summarized in table 5. 1 below:

Sharif Gate Data Process Stages	Duration of Data Processes	No. of Data Vertices and Faces	Texture Quality	Achievable RMS Reprojection Error
1- Aligning	2.5 hours	1,755,880 tie points	Medium quality	0.2 mm
2- Building ties and dense points cloud	6 hours	75,638,004 points cloud		
3- Cleaning noises	6 hours	42,64,361 points cloud		
4- Creating a 3D model	1.40 hour	8,146,871 faces and 4,218,613 vertices		

Table 5. 1: *The summary table provides the data processing stages of Sharif Gate.* (Author, 2022)

The Sharif Gate photos and videos were processed using two software applications 1) Agisoft Metashape Pro software and 2) Adobe Premiere Pro 2020 software as supporting software. Processing was achieved using the following steps:

1- The photos were imported into Agisoft Metashape Pro software.

2- The videos were transformed into frames using Adobe Premiere Pro 2020 as follows:

   a. Three recorded videos inserted into Adobe Premiere Pro 2020 were merged as one single video.
   b. The video was exported as frames with one frame per second.
   c. 533 frames were extracted from the imported video of the Sharif Gate (Adobe, 2021).

3- These 533 frames were inserted into Agisoft Metashape Pro software along with the previous 242 photos in one chunk.

4- All photos and video frames needed to be aligned. The alignment process discovers the camera position and orientation for each photo and builds tie points (Agisoft Photoscan, 2013). The process for the Sharif Gate took 2.5 hours, with 1,755,880 tie points produced to help build dense point clouds for the next stage (Figure 5.6).

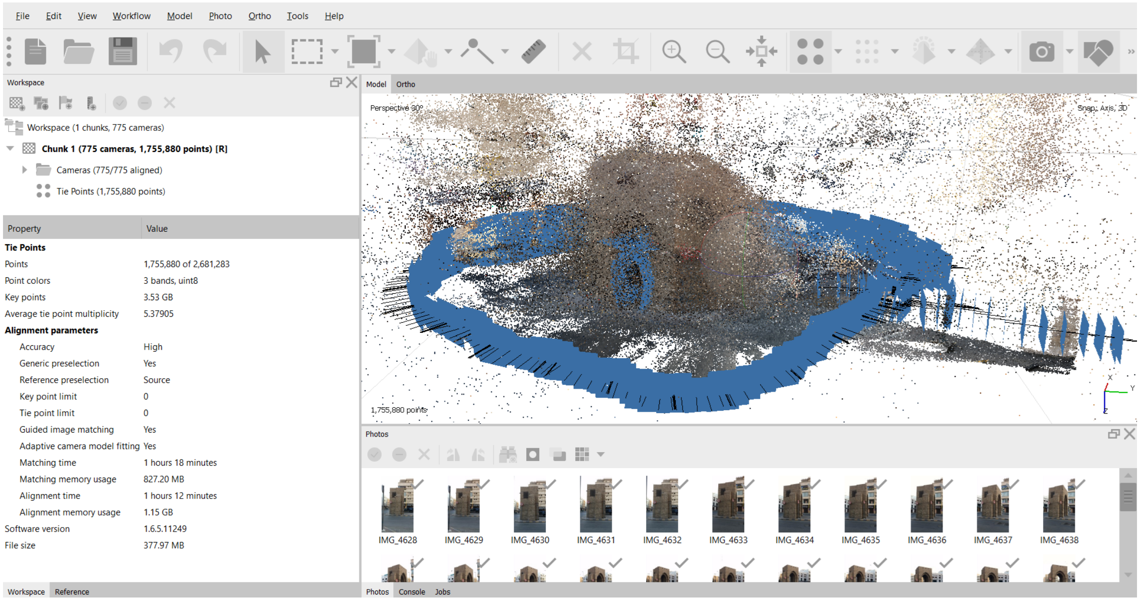


Figure 5. 6: *Aligned photos and video frames of Sharif Gate.*
(Author, 2021)

The next stage was to create dense point clouds of Sharif Gate from the aligned photos and video frames. Using the Agisoft Metashape Pro software, a command to build dense clouds for Sharif Gate was completed, where the processing time was around 6 hours with 75,638,004 points cloud (Figure 5.7). In this stage, the software calculates the information for each camera to be merged into a single dense point cloud based on the estimated camera locations to create a dense point clouds model (Agisoft Photoscan, 2013).

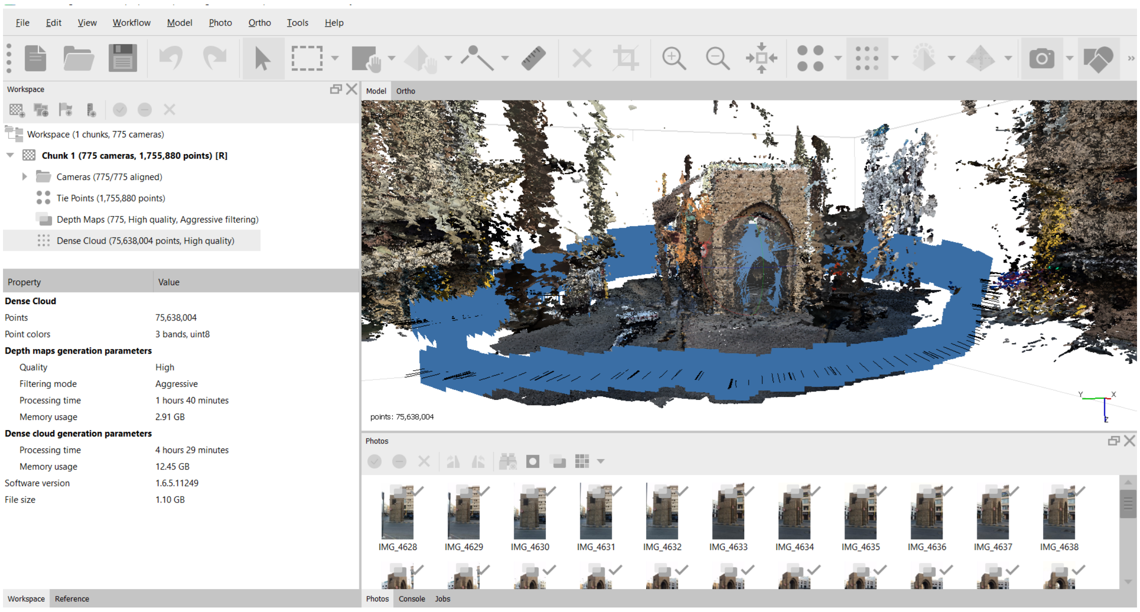


Figure 5. 7: *Built dense point clouds from aligned photos and video frames of Sharif Gate.* (Author, 2021)

A noise-cleaning stage was necessary to obtain a clear point clouds model of the Sharif Gate. Two types of points cloud filtering can be used automatic filtering and/or manual removal of point clouds (Agisoft Photoscan, 2013). In the case of the Sharif Gate, filtering of points was done by using manual points removal, which took 6 hours and led to a clear point cloud model of the gate with 42,64,361 points cloud (Figure 5.8).

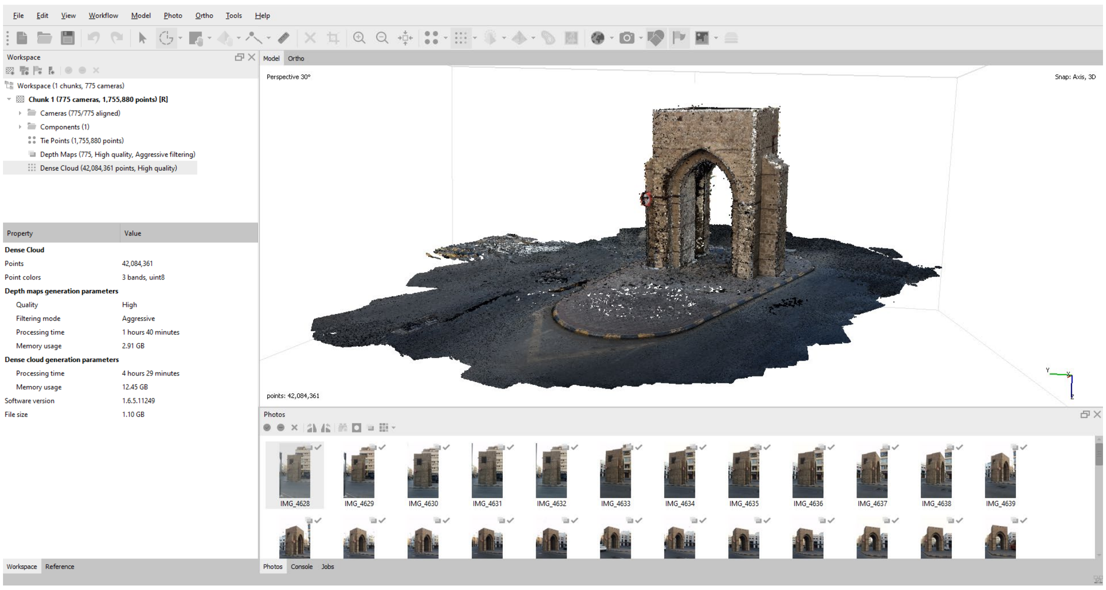


Figure 5. 8: *Filtered and cleaned point clouds model of Sharif Gate.*

(Author, 2021)

The final stage was to build a 3D mesh from the 3D point clouds. A 3D mesh is defined as “the structural build of a 3D model consisting of polygons”. 3D meshes use reference points in X, Y and Z axes to define shapes with height, width, and depth” (TechTarget Contributor,2016). Following this stage, a realistic 3D model of the Sharif Gate was built in 1.40 hours with 8,146,871 faces, 4,218,613 vertices, and medium-quality texture, with an achievable RMS reprojection error of 0.2 mm (Figure 5.9).

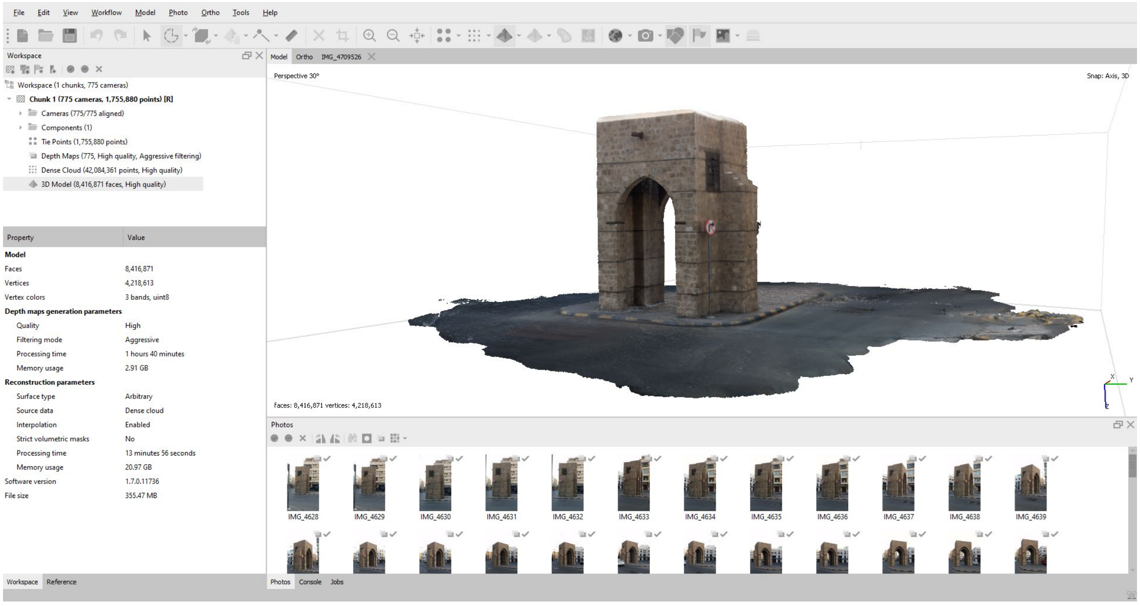


Figure 5. 9: *A 3D mesh with medium-quality texture of Sharif Gate.*
(Author, 2021)

5.2.4. Issues of Data Acquisition and Processing by Utilizing Smartphone Digital Camera

Several issues arose during practice-based data collection and data processing. Whereas, while collecting data on the site, some obstacles appeared that stopped the data collection process several times. The obstacles were as car traffic, where the Sharif Gate is located in the middle of the street. In addition, the presence of pigeons standing on the windows prevented capturing photos of some parts of the building. So, the author attempted to avoid the effect of car traffic by visiting the site early in the morning on Friday, when the traffic is low due to the closure of shops at this time and people preparing for Friday prayer, and that helped to reduce error percentage in data collection.

After acquiring photos and videos of Sharif Gate in the practice-based data collection stage, some issues occurred during the processing stage of these data. First, after doing lots of searches, it is found that no free computer software has direct support to generate a 3D model from a recorded video of an object. So, Adobe Premiere Pro 2020 software was used as a supporting software to convert Sharif Gate videos into sequential photos that can be imported into any 3D modelling program. Another issue that appeared in the data processing stage was due to the location of Sharif Gate in the middle of the street and surrounded by other buildings, where there was sparse noise of these buildings in the 3D point clouds of Sharif Gate, which needed to be removed later. In addition, there were some gaps in the floor of the 3D point clouds that appeared due to the small number of photos taken of the floor in the fieldwork. These gaps were solved by building a 3D model of the Sharif Gate, which helped to fill in these gaps. Even though a 3D model of the Sharif Gate was built with high-quality images, there were some parts of the building that were missing and had blurry texture due to the low quality of photos captured for these parts (Figure 5.10). There was a need for using aerial photogrammetry by using a drone to capture the roof in the top part of the building. However, the high cost of the equipment and the governmental restriction in this area due to its sensitivity limited the researcher from applying this step.

Figure 5. 10: *Issues in the Sharif Gate 3D model.*
(Author, 2021)

5.2.5. Discussion Findings of the Integration between Photos and Videos of Smartphone Digital Camera in a 3D Model

This section discusses the findings of the adoption of action research as a practice based on the integration between photos and videos of a smartphone digital camera for Sharif Gate. It is found that using a smartphone digital camera can help to create 3D models of heritage buildings. A realistic 3D model of a heritage building can be generated with acceptable accuracy when photos and videos are captured by a smartphone digital camera and then integrated with each other in Agisoft Metashape Pro software. For instance, a realistic 3D model of Sharif Gate was created with an achievable RMS reprojection error of 0.2 mm. It is also found that there are several advantages when using a smartphone digital camera as a recording method for recording heritage buildings. Nowadays, smartphone digital cameras are widely available to public users, so anyone can record anything, anytime, anywhere, and whenever wanted. Moreover, it is cheaper than any other surveying method, such as a professional digital camera. In addition, a smartphone digital camera is easy to use during fieldwork, where one person is enough to hold it to do a full recording of a heritage building in one day, as well as it is a small size, making it more flexible to move around the building and reach the small parts of the buildings without any obstacles.

On the other side, several disadvantages were found when a smartphone digital camera was used as a recording method of Sharif Gate to generate a 3D model. The data processing stage was time-consuming, the process of creating dense point clouds of the Sharif Gate took around 6 hours to be done. In addition, the noise-cleaning process also took 6 hours of continuous work, as well as a 3D model was built in one hour and forty minutes with medium-quality texture. Moreover, one of the disadvantages of the final 3D model is that it does not have any spatial coordinates in the global coordinate system, so it is not georeferenced. So, Ground Control Points (GCPs) are black and white checkerboards with known coordinates placed on the ground that can be used in the acquisition process to obtain a georeferenced 3D model. It is recommended to utilize around five ground control points to improve the accuracy (Pix4D, 2019). It is also, found that public users can participate in recording heritage buildings by simply following the same stages that the researcher suggested in section 5.2.2 for data acquisition. However, processing the acquired data could require technical training to generate the desired model.

In conclusion, this action research as a practice-based approach is about identifying the most appropriate recording method to capture tangible and intangible information about heritage buildings for creating a holistic digital record. So, the capability of the first selected recording method, a smartphone digital camera, was examined in generating a 3D model of a heritage building. As a result of the fieldwork, it was found that using a smartphone digital camera can help to create 3D models of heritage buildings with acceptable accuracy. In addition, it is widely available among public users, so anyone can record anything, anytime, and anywhere whenever wanted because a smartphone digital camera as a recording method is easy to use, flexible in small areas, and has a small size. However, its data processing stage was time-consuming and needed professional training. It is also found that heritage buildings can be recorded with the lowest possible costs and with the available equipment with the interested person.

The public can replicate this practice-based fieldwork to be involved in recording heritage buildings by: **Firstly, selecting the suitable site** based on: 1) Significant value, such as historical, religious, cultural and/or economic, 2) Unique structure, such as architectural styles, construction techniques, and/or materials, 3) Accessibility of site for collecting primary data, 4) Availability of secondary data in specialized government and academic depositories, including previous studies and historical records.

Secondly, conducting the process of acquiring data by: 1) Developing a practical plan for data capture movement path based on the heritage building's floor plan, 2) Selecting the available tools for digital scanning such as a smartphone digital camera, 3) Starting collecting data within practice-based on-site by capturing sequential photos or videos of the heritage building by using the available smartphone, 4) then processing them using computer software such as Agisoft Metashape Pro software PhotoScan to create a 3D model of tangible elements of the historic buildings.

The created 3D model can then be integrated with further heritage information through software and/or applications to create a holistic digital record of the heritage building. For instance, tourists can record heritage buildings by using their smartphone when visiting historical landmarks in any country they are travelling to. They can add and share the acquired information with others through software and/or applications such as Mapillary software, which provides access to up-to-date street-level images and map data. The data can be voluntarily captured by individuals with any kind of camera (Mapillary.com, 2022).

The previous approach clarifies the importance of citizen science to collect data in recording, documenting and conserving intangible and tangible cultural heritage. In addition, the significant role of Volunteered Geographic Information (VGI) in recording heritage buildings. The VGI is the use of digital tools to create, collect, and disseminate geographic data created by individual volunteers (Goodchild, 2007, p.211). Where, if the data has been shared with others through such software, illustrating some of its images and explaining its background can help to improve understanding and appreciation of the value of heritage buildings among people all over the world.

5.3. Case Study 2: the Jadid Gate

5.3.1. Introduction

Action-based research of the Jadid Gate was another case used in this study to examine the capability of digital cameras and the most appropriate recording method for creating a 3D model of a heritage building. The general workflow of Jadid Gate is illustrated in figure 5.11.

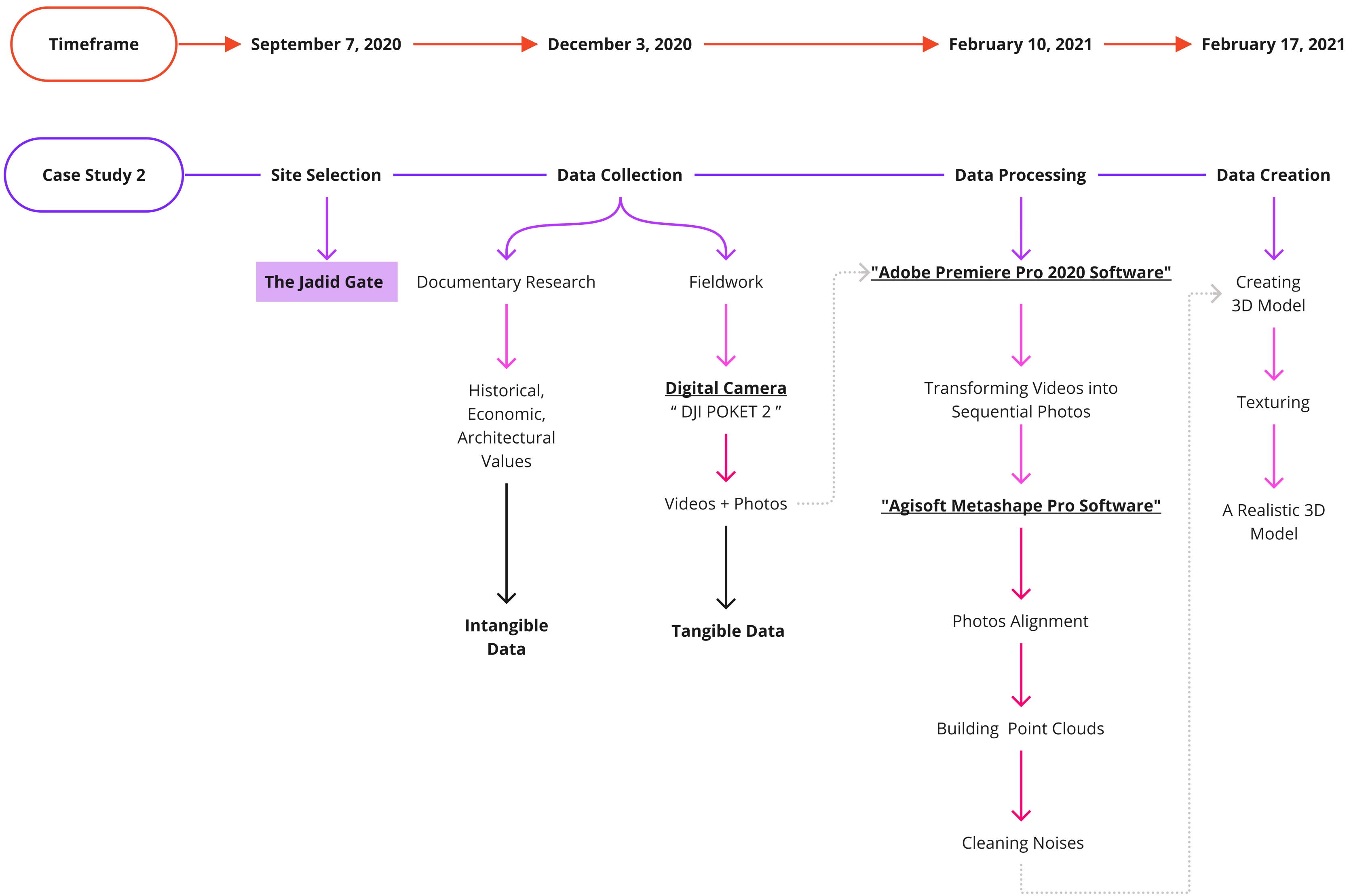


Figure 5. 11: *A diagram explanation of the general workflow of the Jadid Gate.* (Author, 2021)

The figure demonstrates the practical processes and procedures employed in Jadid Gate for digital recording and reconstruction. This case study takes into account the practical aspects of timeframe, site selection, data collecting, data processing, and data creation stages. In terms of time, the Jadid Gate required around five months to survey and rebuild it digitally. At first, the site selection stage is based on the four criteria for evaluation for choosing acceptable buildings. The data is then collected through documentary research from different resources to obtain intangible data of Jadid Gate to comprehend its important values, and practice-based fieldwork using digital metric survey techniques including digital cameras to capture videos and images of the gate to acquire its tangible data (5.3.2).

When various tangible elements' data of historical buildings are combined by integrating photos with videos from digital cameras, a realistic 3D model of a heritage building with appropriate precision could be created (5.3.3). Section 5.3.4 also discusses some of the challenges found throughout this procedure, including light, shadow, and pedestrian challenges, time and technical issues in collecting, processing, and creating the data, and geo-references. The findings from the integration of videos and images through digital cameras in a 3D model are discussed later in this chapter. These can assist in constructing a comprehensive 3D model (5.3.5).

5.3.2. Data Acquisitions of the Jadid Gate

Data acquisition pre-processes began by:

1- **Developing a practical plan based on the Jadid Gate floor plan**. This illustrates the path of movement to capture the data (Figure 5.12) using image capture strategies for terrestrial photography recommended by Historic England (Bedford, 2017, pp. 38; Agisoft Help Desk, 2022; Josephson, 2019, p. 32). The author drew the manual sketch floor plan.

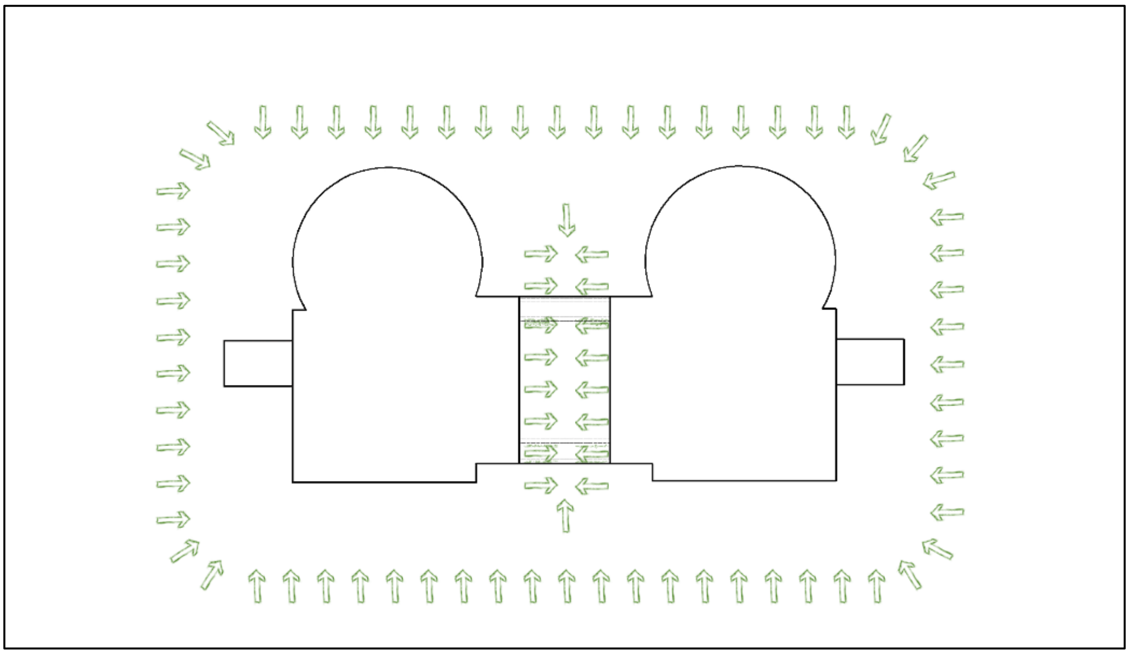


Figure 5. 12: *A manual sketch of the Jadid Gate illustrating the suggested path of movement to capture the data of the Jadid Gate.*
(Author, 2021)

2- **The available tool** that the author had at the time of this research was the "DJI POCKET 2" digital camera. This was to conduct the practical task of digital scanning to create a 3D model of tangible elements of the Jadid Gate.

3- **The practice-based action research of collecting on-site data of Jadid Gate** started by:

   a. The site was visited and checked it was clear of any obstacles and reflective surfaces while recording (Josephson, 2019, p. 25; Agisoft Help Desk, 2022).
   b. The camera settings were modified to be 4K resolution of photos, 30 frames in a single second of videos, focal length: 4.6, focal-stop: F/2, ISO: 100, auto shutter speed, and 35mm focal length (Salvi, 2016).
   c. Moved 360 degrees around the gate as planned in the acquisition strategy (above) to capture photos and record videos separately. This was done by scanning the exterior and interior spaces (Bedford, 2017. p. 38; Josephson, 2019, p. 32; Agisoft Help Desk, 2022).
   d. Scanning the Jadid Gate followed the photo capture strategies for scanning by the digital camera. In summary, this means: capturing images by overlapping between each image in order to generate a complete 3D reality model of tangible elements of the gate (Bedford, 2017, p.38).

e. At the end of this process, 122 photos had been taken of the outer façade and the interior, as well as three separate videos.

5.3.3. Practical Stages of Data Processing at the Jadid Gate

The practice-based data processing procedure of the Jadid Gate passed through several stages:

1- Inserting the captured photos and videos in a 3D reconstruction of objects from image data software such as Agisoft PhotoScan (Yilmazturk et al., 2019, pp.1-10).
2- Aligning the photos and the sequential images exported from the recorded videos sequentially (Ataiwe et al., 2021, p.7).
3- Building tie and dense cloud points (Ataiwe et al., 2021, p.7).
4- Cleaning any noises (Agisoft, 2021).
5- Creating a 3D model of the Jadid Gate (Agisoft, 2021).

The data processing practical stages of Jadid Gate are summarized in table 5. 2 below:

Jadid Gate Data Process Stages	Duration of Data Processes	No. of Data Vertices and Faces	Texture Quality	Achievable RMS Reprojection Error
1- Aligning	2 hours	2,177,677 tie points	Medium quality	0.2 mm
2- Building ties and dense points cloud	5.5 hours	52,039,173 points cloud		
3- Cleaning noises	1 hour	25,434,790 points cloud		
4- Creating a 3D model	1.40 hour	8,146,871 faces and 4,218,613 vertices		

Table 5. 2: *The summary table provides the data processing stages of Jadid Gate.*
(Author, 2022)

A DJI POCKET 2 Digital Camera was used to capture photos and record videos of the Jadid Gate. The photos and videos were processed using Agisoft Metashape Pro software and Adobe Premiere Pro 2020 software as supporting software. Processing was achieved using the following steps:

1- Adobe Premiere Pro 2020 software was used to convert the recorded videos into frames as follows:

a. Three recorded videos imported into Adobe Premiere Pro 2020 were combined as one single video.

b. The video was exported as frames with one frame per second.

c. 533 frames were extracted from the imported video of the Jadid Gate (Adobe, 2021).

2- These frames were added to Agisoft Metashape Pro software along with the 122 photos in one chunk.

3- All images and video frames needed to be aligned. The alignment process discovers each image's camera position and orientation and builds tie points. The process for the Jadid Gate took around 2 hours, with 2,177,677 tie points produced to help build dense point clouds for the next stage (Figure 5.13).

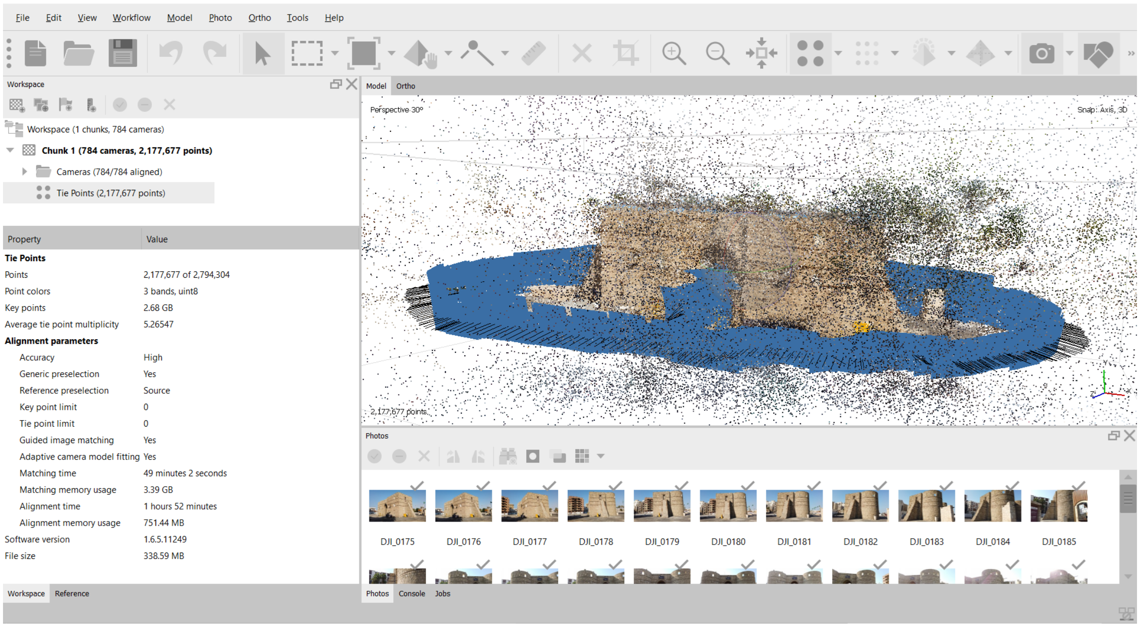


Figure 5. 13: *Aligned photos and video frames of the Jadid Gate.*

(Author, 2021)

After aligning photos and video frames of the Jadid Gate, creating dense point clouds was required. So, building dense clouds for the Jadid Gate was achieved in Agisoft Metashape Pro software, where the software calculated the data from each camera to be combined into a single dense point cloud based on camera locations to create a dense point clouds model (Agisoft Photoscan, 2013). The processing took 5.5 hours with 52,039,173 points clouds (Figure 5. 14).

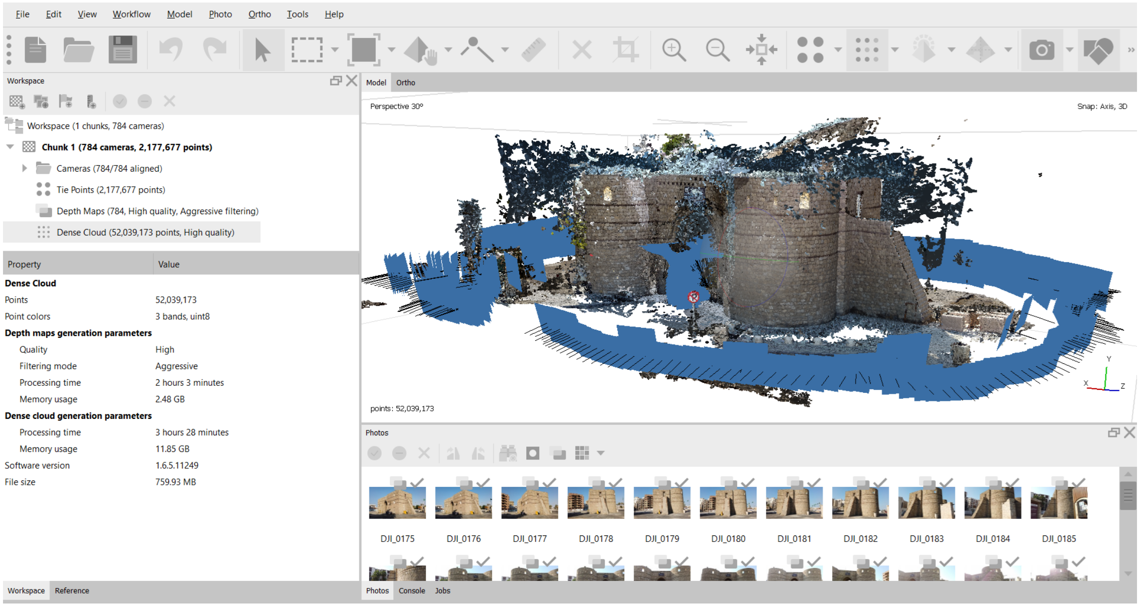


Figure 5. 14: *Built dense point clouds from aligned photos and video frames of the Jadid Gate.* (Author, 2021)

When building dense point clouds was completed, a noise cleaning process was necessary to achieve a clear point clouds model of the Jadid Gate. In the Jadid Gate, the filtering of unwanted points was finished using automatic filtering and manual removal. Automatic filtering points can help remove the points with high reprojection errors and/or those that cause high noise. In addition, manual point removal can help to delete incorrect points manually (Agisoft Photoscan, 2013). The filtering of points in the Jadid Gate was achieved using the "select confidence range" command as well as manual points removal, which led to a clear point cloud model of the gate. The cleaning process took 1 hour only until the final result of the point clouds model of the Jadid Gate was obtained with 25,434,790 point clouds (Figure 5. 15).

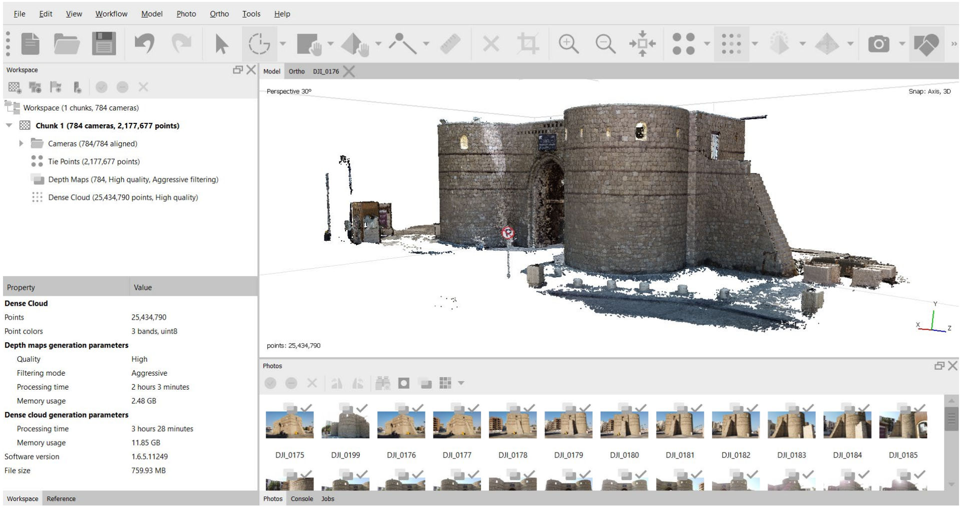


Figure 5. 15: *Filtered and cleaned point clouds model of the Jadid Gate.*
(Author, 2021)

The produced point clouds model of the gate transformed into a 3D mesh, which is the structural build of a 3D model consisting of polygons, faces, and vertices. In this stage, a 3D model of the Jadid Gate was built in 1.40 hours with 8,146,871 faces, 4,218,613 vertices, and medium-quality texture, with an achievable RMS reprojection error of 0.2 mm (Figure 5. 16).

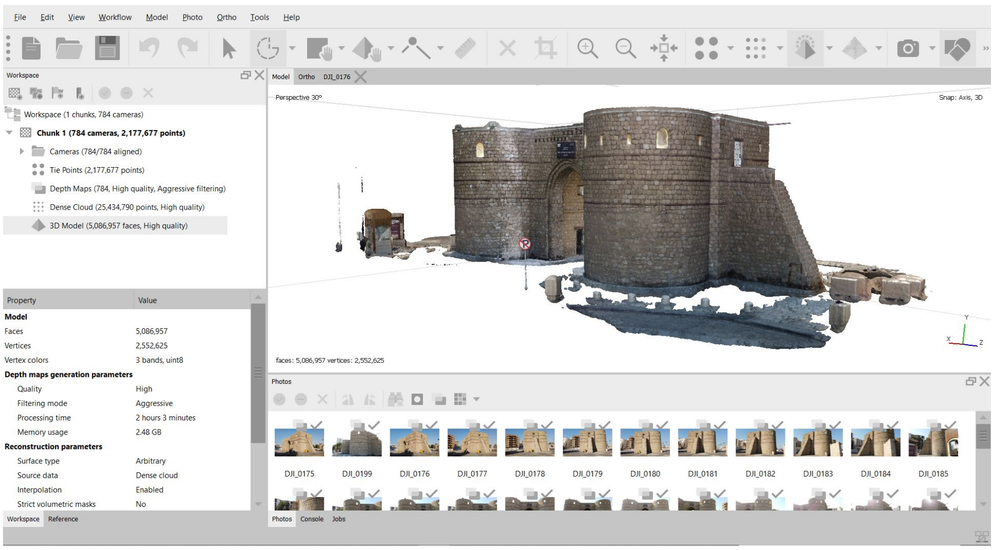


Figure 5. 16: *A 3D model with a high-quality texture of the Jadid Gate.*
(Author, 2021)

5.3.4. Issues of Data Acquisition and Processing by Utilizing Digital Camera

Several issues emerged during the time of the Jadid Gate practice-based data collection and data processing. While collecting data on the site, some challenges impeded the data collection process. The challenges, such as sunshine, trees, concrete and metal crowd barriers, signboards, and air conditioning units were casting shadows on the gate, which prevented capturing the texture of some parts of the gate wall. Another challenge was the existence of tourists and security men on site, which led to stopping recording videos and capturing images and waiting for them until they left the site.

After capturing photos and videos of the Jadid Gate in the practice-based data collection stage, some problems arose during the data processing stage. Besides the fact that there is no free computer software support generating a 3D model of an object from video recordings directly, as mentioned before in the Sharif Gate section, sparse noises showed from the surrounding trees and other objects besides the gate. The sparse noises required to be deleted to get a clear model of the Jadid Gate, as demonstrated before.

Although a 3D model of the Jadid Gate was built with high-quality photos, some parts of the gate are missing, such as gaps in the floor of the 3D point clouds because not enough photos were taken of parts of the floor during the fieldwork time. Moreover, the 3D point clouds of the Jadid Gate have blurry texture due to the sunlight intensity during the time of recording. In addition, the location of the windows is higher than the level of the planned recording path and is recessed into the wall which prevents parts of the windows from being captured (Figure 5. 17).

Figure 5. 17: *Issues in the Jadid Gate 3D model.*
(Author, 2021)

5.3.5. Discussion Findings of the Integration between Photos and Videos of Digital Camera in a 3D Model

A discussion of findings of the adoption of action research as a practice based on the use of digital cameras as a recording method for the Jadid Gate tangible elements is explained in this part. It has been discovered that digital cameras can assist in creating 3D models of any heritage building. When photos and videos are captured by a digital camera and then combined, a realistic 3D model of a heritage building can be generated with acceptable accuracy. It was also observed that there are several advantages when using a digital camera to record heritage buildings. First, its price is mid-cost and lower than other surveying methods, such as laser scanners. Second, the digital camera is as flexible as the smartphone digital camera, wherein the fieldwork during the data collection process, the digital camera was easy to carry and move from one place to another for recording the gate from all sides due to its small size. Moreover, recording videos with a digital camera is more stable when moving than a smartphone digital camera, which can help to reduce the production of inaccurate sequential photos in the data processing stage. However, when a digital camera was used as a recording method of the Jadid Gate to generate a 3D model, there were several disadvantages found. The used DJI Osmo Pocket digital camera has a quite small screen, making the recording process on-site slightly difficult. So, the iPhone 6s smartphone was attached to the DJI Osmo Pocket digital camera to obtain a bigger screen while recording, with the use of the DJI Mimo app on the iPhone app store. When the iPhone 6s smartphone was connected to the DJI Osmo Pocket digital camera, another disadvantage emerged that the digital camera has to some extent, a heavyweight when used for recording such buildings.

Moreover, the processing stage of the acquired data was time-wasting. Where computing matches and alignment between photos of the Jadid Gate lasted 2 hours to be done. Following that, reconstruction dense point cloud was reconstructed in 5 hours and 30 minutes. After that, cleaning the noise around the gate took one hour of continuous work. Finally, creating a 3D model of the Jadid Gate finished in 1.40 hours with high-quality texture. Moreover, one of the disadvantages of the final 3D model is that it does not have any spatial coordinates in the global coordinate system, so it is not georeferenced. So, to improve the accuracy, around five ground control points can be used in the acquisition process to obtain a georeferenced 3D model (Pix4D, 2019). It is also, found that public users can participate in recording heritage buildings by simply using their digital cameras by following the same stages that the researcher suggested in section 5.3.2 for data acquisition. However, processing the acquired data needs some technical training to generate the desired model. So, a practical public-facing fieldwork guide will be created in post-PhD research.

In conclusion, digital cameras were the second selected recording method as a practice-based approach to identify the most appropriate recording method to capture tangible and intangible information about heritage buildings for creating a holistic digital record. So, the capability of varied digital cameras was examined in generating a 3D model of tangible elements of a heritage building. As a result of the fieldwork, it is noticed that digital cameras can assist in creating 3D models of any tangible elements of heritage buildings. When photos and videos are captured by the digital camera and combined, a realistic 3D model of tangible elements of a heritage building can be generated with acceptable accuracy. In addition, it is found that beginner and professional photographers who use digital cameras can use this tool as a recording method of heritage building information. They can help to increase the accuracy of the generated 3D model of tangible elements of heritage buildings by using their experience in editing the camera settings to obtain high-quality images. This practice-based fieldwork can be replicated by beginners and/or professionals by involving in recording heritage buildings by following the next instructions. First, select a suitable site based on its significant value, unique structure, accessibility of the site, and availability of secondary data. Acquire data starting from drawing a manual sketch of the movement path to capture the heritage building data. Choose any available digital cameras to conduct digital scanning. Start collecting data within practice-based on-site by moving 360 degrees around the heritage building and capturing sequential photos or videos of it. Then, process the captured data using computer software such as Agisoft Metashape Pro software PhotoScan to generate a complete 3D reality model of tangible elements of the historic buildings. The generated 3D model can play an important role in preserving heritage buildings' information at a specific time describing its tangible and intangible condition when disseminating it with others. In addition, the 3D model can be combined with further heritage information through web-based software and/or mobile applications such as WikiMapia or ArcGIS Online to create a holistic digital record of the heritage building as a reference that can be used for future work such as research, investigation, or conservation activity.

5.4. Case Study 3: Makkah Gate

5.4.1. Introduction

Action-based research on the Makkah Gate was used in this study to examine the capability of using scanning software applications in smartphones and the most appropriate recording method for creating a 3D model of a heritage building. The general workflow of Makkah Gate is illustrated in figure 5. 18.

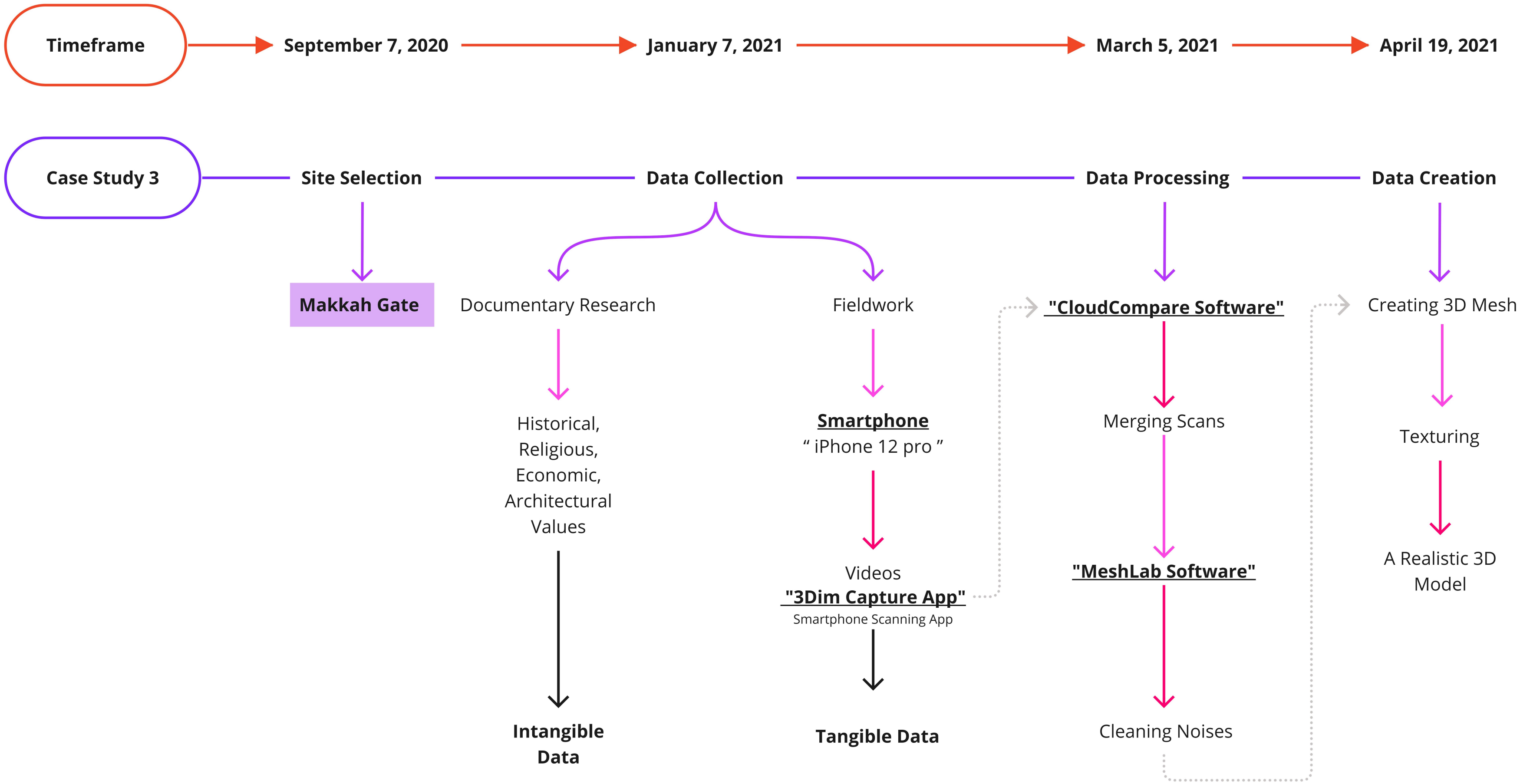


Figure 5. 18: *A diagram explanation of the general workflow of Makkah Gate.*

(Author, 2021)

The diagram shows the practical methods and techniques adopted in Makkah Gate. This case study considers the practical aspects such as time frame, site selection, data collection, data processing, and data creation. In regard to a period of time, around seven months were needed to survey and recreate Makkah Gate digitally.

In the beginning, the site selection stage is based on the four evaluation criteria for identifying the appropriate building. In order to comprehend the important values of Makkah Gate, data is collected through documentary research from several resources to obtain intangible data, and practice-based fieldwork using digital metric survey techniques including smartphone scan applications to record videos of the gate to acquire separate point clouds of its tangible data (5.4.2). Then, the integration of the point clouds recorded by the application in a smartphone is conducted to transform them into a single 3D point clouds and then convert it into a realistic 3D mesh model (5.4.3). Section 5.4.4 also highlights some of the difficulties noticed throughout this approach, such as time and technological issues regarding data collection, processing, and creation, as well as accuracy and geo-references. At last, the findings of the integration of each point cloud of scanning application software in a 3D Model are presented. These can help to develop a comprehensive 3D model of heritage buildings (5.4.5).

5.4.2. Data Acquisitions of Makkah Gate

Data Acquisition from fieldwork was done to acquire tangible information about the Makkah Gate elements. Firstly, several smartphone scan apps were tested to survey the gate. However, the best result was acquired by the 3Dim Capture app, which helps to turn the smartphone into a 3D scanner. The 3Dim Capture app is a 3D scanning technology using artificial intelligence software paired with smartphone commodity sensors. It is a tool to generate world information digitally to be accessible to everyone (3dim.ai., 2020).

So, to create a 3D model of Makkah Gate's tangible elements, the 3Dim Capture app was used on-site. In the fieldwork, data from Makkah Gate was acquired by following the 3Dim capture app team strategies for achieving good scanning results, which were explained in their capture tutorial. The recommended strategy to plan the path of movement to capture the data is to keep the smartphone steady and walk slowly in half circles around the object when scanning (3dim.ai., 2020).

Data acquisition pre-processes began by:

1- **Developing a practical plan based on the Makkah Gate floor plan**. This illustrates the path of movement to capture the data in half circles (Figure 5.19), in addition to taking into account the overlaps between each scan (Purificação et al., 2022, p. 18; Hartley, 2020; 3dim.ai., 2020). The manual sketch floor plan was drawn by the author based on on-site visits and the Google Maps application.

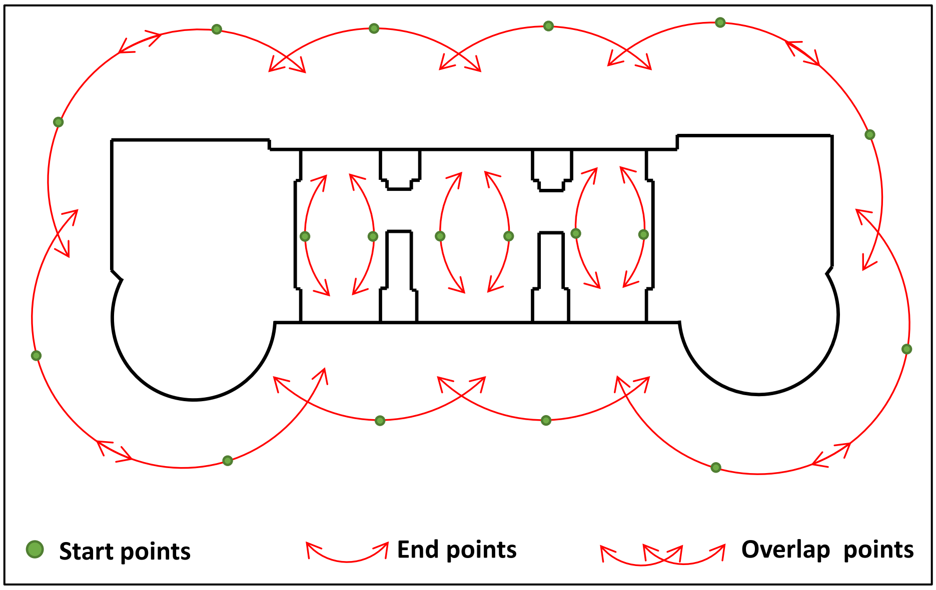


Figure 5. 19: *The planned strategy of Makkah Gate path of movement for recording.*
(Author, 2021)

2- **The available tool** that the author had at the time of this research was the iPhone 12 pro smartphone digital camera. This was used to conduct the practical mission of digital scanning.

3- **The practice-based action research of collecting data on-site at Makkah Gate** started by:

a. The 3Dim Capture App on the iPhone 12 pro smartphone was Downloaded.

b. Scanning of the Makkah Gate data followed the recommended guidelines by the team of the 3Dim Capture App in smartphones for scanning.

c. The gate was scanned in half circles back and forth, taking into account the overlaps between each scan as planned in the figure above (3dim.ai., 2020; Bedford, 2017, p.38).

d. Twenty-three scans had been recorded of the exterior and interior tangible elements of the gate,

e. At the end of this process, these scans were sent to the 3Dim cloud for processing. This is for creating a 3D points cloud of each scan (Figure 5. 20).

Figure 5. 20: *The twenty-three scans recorded for Makkah Gate tangible elements by the 3Dim capture app.*

(Author, 2021)

5.4.3. Practical Stages of Data Processing at Makkah Gate

For creating a 3D mesh of the Makkah Gate, the data processing procedure passed through several steps:

1- Filtering the twenty-three recorded scans into fifteen scans to be used for best results.

2- The fifteen scans were imported as xyz. files into CloudCompare software for processing.

3- The processing stage started by:

a. Aligning each scan with another one by picking four equivalent point pairs each.

b. Merging the aligned scans together.

The alignment process of the Makkah Gate took around two days to build a 3D dense points cloud due to the complexity and size of the gate, with achievable RMS reprojection errors of 0.003 – 0.04 mm (Figure 5. 21).

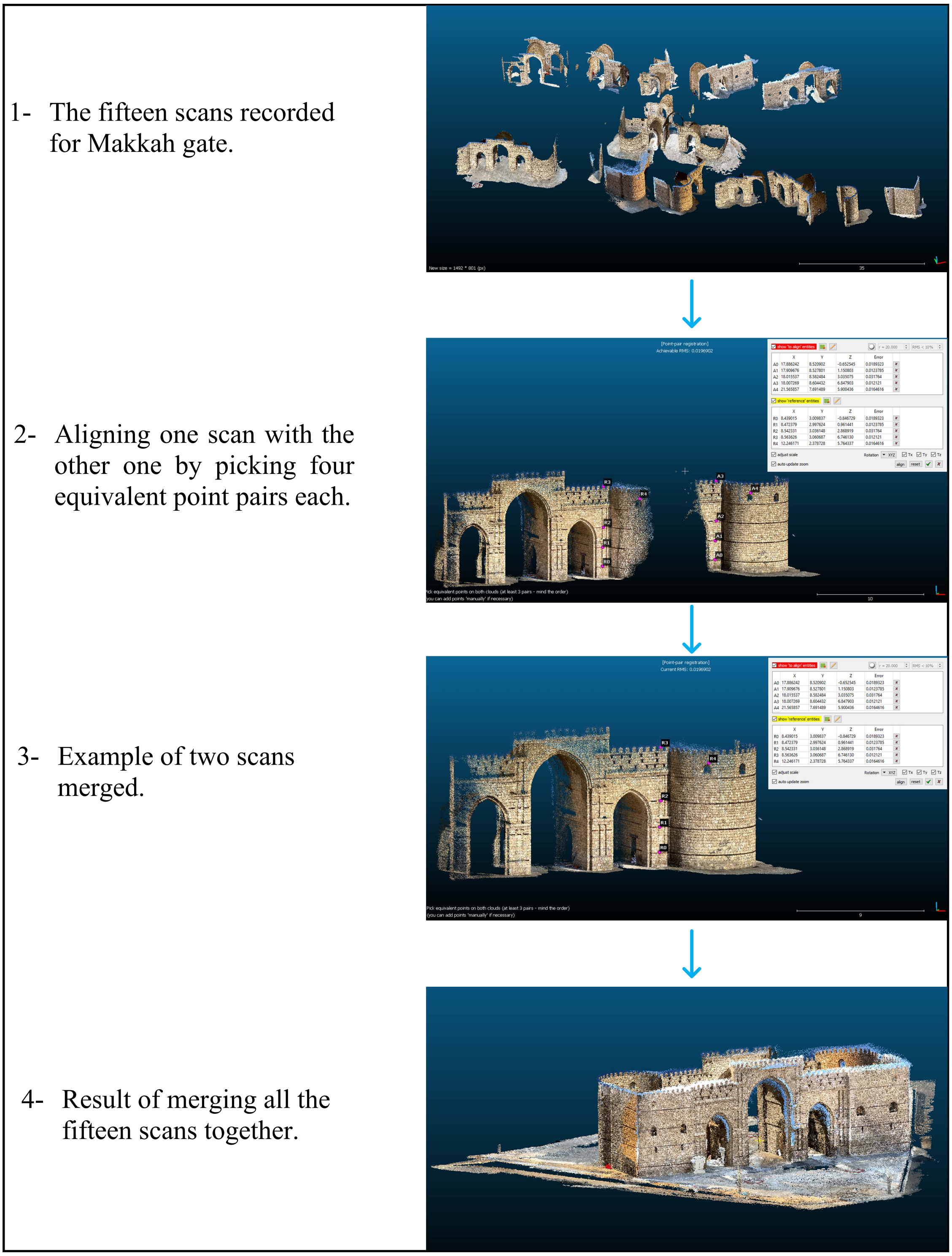


Figure 5. 21: *The final result of the 3D point cloud of Makkah Gate.*
(Author, 2021)

After building the 3D point clouds of the Makkah Gate, a cleaning noise process was finished. Removing the unwanted points was completed manually by selecting them using the segment tool in CloudCompare software and deleting them (Figure 5. 22). The cleaning process lasted for one hour only until the final result of the point cloud model of the Jadid Gate was obtained.

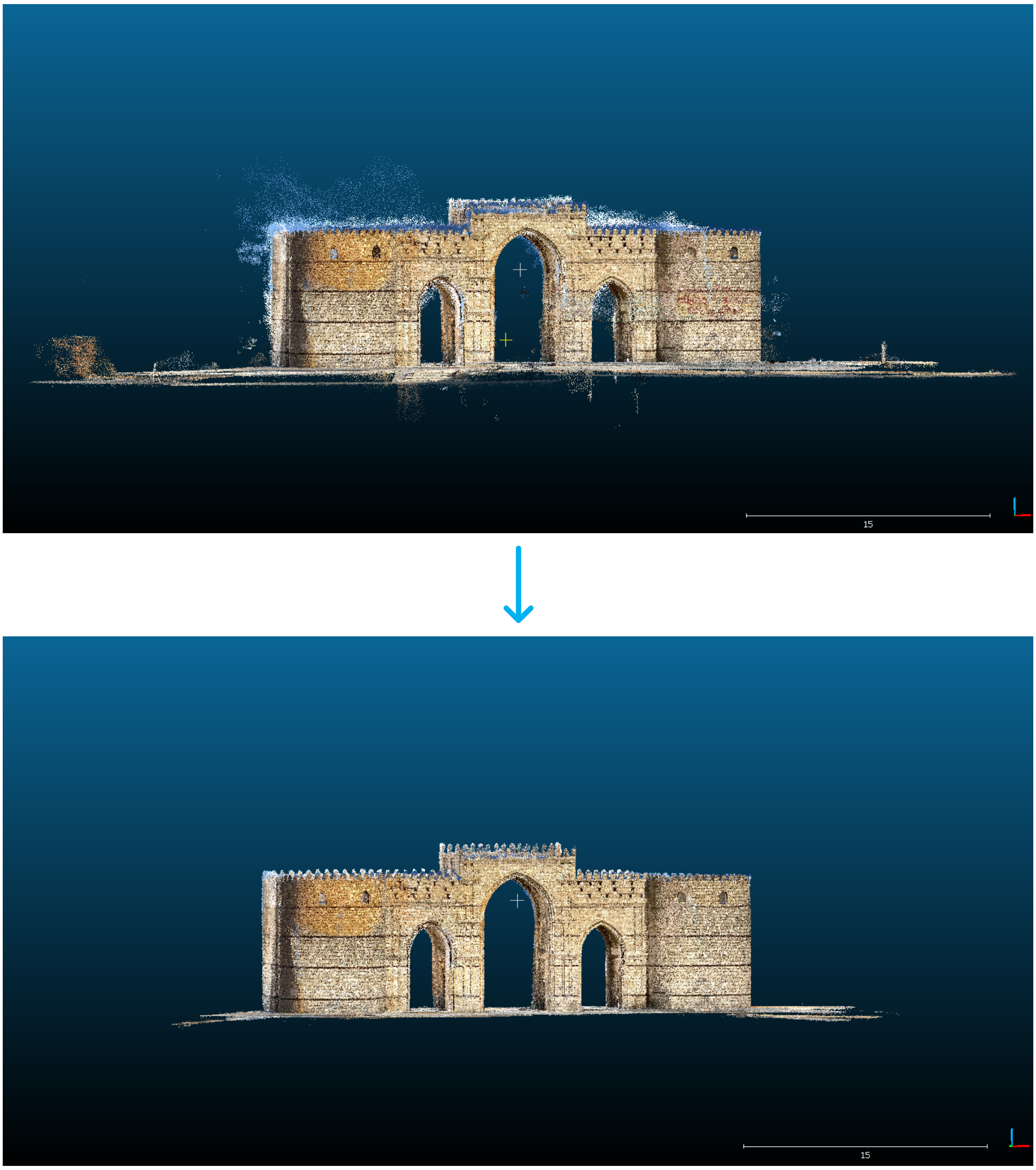


Figure 5. 22: *The produced 3D point clouds of Makkah Gate after cleaning the points noises.* (Author, 2021)

The produced 3D point clouds of the Makkah Gate were transformed into a 3D mesh. In this stage, a 3D mesh of the gate was built by using MeshLab software as recommended (Hartley, 2021; Purificação et al., 2022, p. 6).

Building the mesh started by:

1- Exporting the 3D point clouds of the Makkah Gate as a ply. file from CloudCopmare.
2- Exporting it into MeshLab software for creating a 3D mesh of the gate.
3- Computing the normals of the 3D points cloud was completed to estimate the local surface that is embodied by a point and its neighbours.
4- Surface reconstruction of points cloud was completed for creating a solid surface from oriented point sets.
5- Cleaning the surface was finished by selecting the unwanted meshes automatically and manually and deleting them to get a clear 3D mesh of the Makkah Gate.
6- Adding texture to the mesh by transferring the colours of the 3D points, which were selected as a source, to the 3D mesh, which was chosen as a target (Figure 5. 23).

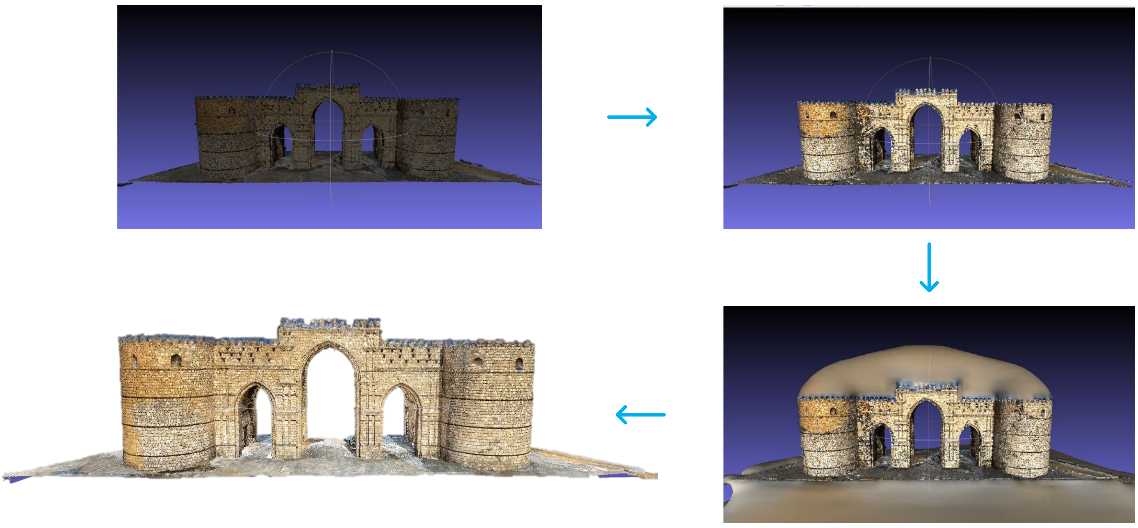


Figure 5. 23: *The process of building a 3D mesh of Makkah Gate by using MeshLab software.* (Author, 2021)

5.4.4. Issues of Data Acquisition and Processing by Utilizing Scanning Application Software in Smartphones

Several issues arose during the practice-based data collection and data processing stages of Makkah Gate. Some obstacles appeared that delayed the process of data collection on-site. For instance, car traffic, sunshine, shadows, and electric stations barred the texture to be captured of some parts of the gate wall. Other obstacles that led to stopping the process of scanning several times are the presence of homeless people and pigeons on site. As for the 3Dim Capture application software used for the scan, there were several observations on it that slowed down the process. The software has a limited time to do the scanning process, where five minutes only is allowed for one scan to generate a 3D point cloud of a part of the gate.

Therefore, the gate has been scanned 23 times to cover the entire gate's tangible elements. Then, the data was sent to the 3Dim cloud to start the processing stage, where the data was converted into 3D point clouds after 60 minutes that can be viewed on their website. For the free version of 3Dim cloud, only the first 30 seconds of scanned data can be processed. However, 302 seconds of data can be processed for the paid version, so the application software was subscribed to the value of 20 pounds for a month to complete the data processing stage for Makkah Gate.

After scanning the Makkah Gate to collect data, some difficulties arose during the data processing stage. The process of aligning fifteen scans with each other and merging them was time-consuming. Where the process took around two days to build a 3D point cloud of the Makkah Gate. In addition, there were some noises from points demonstrated around the gate which required to be removed to get a clear 3D point cloud of Makkah Gate. Furthermore, it was noticed when transforming the 3D point clouds of the Makkah Gate into a 3D mesh, the generated 3D mesh had low texture accuracy.

5.4.5. Discussion Findings of Using Scanning Application Software in Smartphones

In this section, the findings of utilizing scanning application software in smartphones are discussed based on the adoption of action research. Firstly, it is found that using scanning application software in smartphones can help create 3D point clouds of a heritage building. These points can be integrated altogether by utilizing CloudCompare software and then transferred into a 3D mesh in MeshLab software for future work.

In addition, it is noticed that there are several benefits when utilizing scanning application software in smartphones as recording tools for digitally creating heritage buildings. Firstly, smartphones are popular devices among public users, light in weight and small in size, that can be carried at any time by a single person to capture data in the data collection stage. The 3Dim capture application software used in the processing data stage has several advantages, including a cheap cost tool for scanning, a fast reconstruction processing of 3D point clouds, 3D models and 3D mesh models, that can be reviewed online on computer desktops and/or smartphones via the application cloud website. These models can be imported into Computer-Aided Design (CAD) and 3D design software such as Sketchup to import 3D point, cloud models, Blender to import colour XYZ and PLY point cloud models, MeshLab for visualizing the 3D mesh or point cloud models, or/and CloudCompare to merge several 3D points clouds models.

However, there are several disadvantages found while utilizing scanning application software in smartphones as a tool for digitally recording and reconstructing the Makkah Gate heritage building. The data processing stage was time-consuming, requiring several software products to create the 3D mesh, such as CloudCompare and MeshLab software. The process of merging point clouds together took around two days to create one 3D point cloud of Makkah Gate. Moreover, the noise-cleaning process also took 4 hours of continuous work. Although the 3D mesh was built in only three minutes, the accuracy of the materials was weak. Moreover, one of the disadvantages of the final 3D mesh is that it does not have any spatial coordinates in the global coordinate system, so it is not georeferenced. So, to improve the accuracy, around five ground control points can be used in the acquisition process to obtain a georeferenced 3D model (Pix4D, 2019). It is also, found that public users can participate in recording heritage buildings by simply using their smartphone digital cameras by following the same stages that the researcher suggested in section 5.4.2 for data acquisition. However, processing the acquired data needs some technical training to generate the desired model.

In conclusion, action research as a practice-based approach was used in the third selected recording method to identify the most appropriate recording method by using smartphone applications to capture tangible and intangible information about heritage buildings for creating a holistic digital record. So, the capability of smartphone applications was examined in generating a 3D model of tangible elements of a heritage building. As a result of the practice-based fieldwork, it is noticed that it is possible to create a realistic 3D mesh of a heritage building's tangible elements by utilizing scanning application programs in smartphones. Also, it was found that utilizing scanning application software in smartphones can help to create a 3D point cloud of heritage building elements. These points can be integrated by utilizing CloudCompare software and transferred into a 3D mesh in MeshLab for future work.

It was noticed that there were several benefits when utilizing scanning application software on smartphones. Where smartphones are popular devices among public users, light in weight, and small in size. In addition, a 3Dim capture application software used in the data collection stage has several advantages such as providing a cheap cost tool for scanning, a fast reconstruction processing of 3D point clouds, 3D models and 3D mesh models that can be reviewed online on computer desktops and/or smartphones via the application cloud website. These models can then be imported into CAD and 3D design software for further work.

However, there were several disadvantages found while utilizing scanning application software in smartphones, such as the data processing stage being time-consuming and needing professional training, especially for high-rise and large-sized buildings, where it was needed to use various software to create the 3D mesh.

So, the overall conclusion of this section is that it is found that public users can participate in recording low-rise or small-sized heritage buildings information by replicating this fieldwork via utilizing their smartphone digital cameras without the need for special training. Users can replicate this fieldwork by following the four evaluation criteria in selecting a suitable site: significant value, unique structure, accessibility of the site, and availability of secondary data. Then, following the data acquisition plan stated in section (5.4.2) the data processing plan stated in section (5.4.3), by using a smartphone scanning application such as 3Dim capture application software to generate a 3D model of a heritage building's tangible elements.

The generated 3D model can be then developed by adding additional heritage information to it to create a holistic digital record of heritage buildings and then sharing the information via various computer software. This process states the significance of disseminating VGI and citizen science in promoting the involvement of the public in recording heritage buildings' geographic information, which can be then disseminated through web-based software such as WikiMapia, GoogleMaps, Google Earth (Elwood, 2008; Phillips, 2022; Castilla et al., 2021, p. 12), ArcGIS Online, QGIS software, OpenStreetMap website, OpenAerialMap, ArcGIS StoryMaps (Hartley, 2021; Coppinger, 2023; Kwon, 2024), and Mapillary web, mobile, and/or desktop applications (Mapillary.com, 2022).

5.5. Case Study 4: Ribat Banajah

5.5.1. Introduction

Action-based research of the Ribat Banajah was used in this study to examine the capability of two different digital camera devices and data combined and the most appropriate recording method for creating a 3D model of a heritage building. The general workflow of Ribat Banajah is illustrated in figure 5. 24.

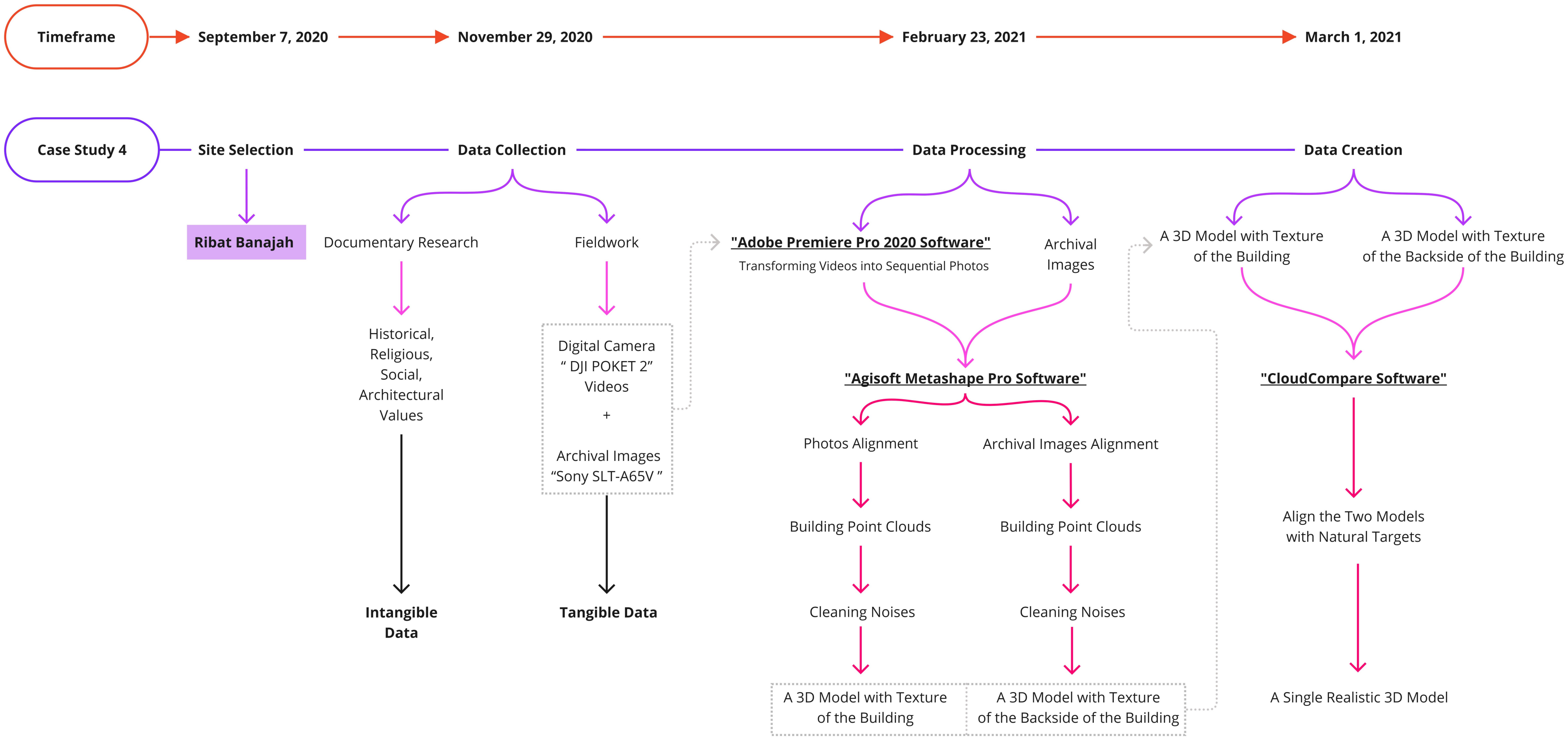


Figure 5. 24: *A diagram explanation of the general workflow of Ribat Banajah.*

(Author, 2021)

The figure displays the practical processes and techniques utilised in the Ribat Banajah. This case study considers the practical aspects of timeframe, site selection, data collection, processing, and creation. In terms of time, it took approximately six months to survey and digitally rebuild Ribat Banajah. The site selection stage is initially based on the four evaluation criteria to identify the appropriate building.

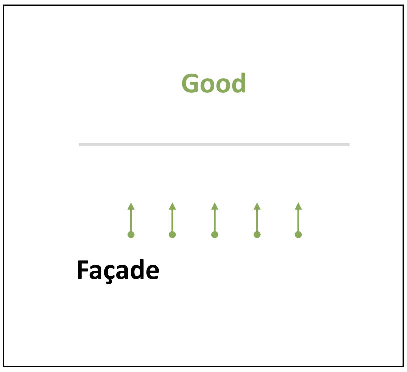
To understand Ribat Banajah's key values, data was collected by documentary research from multiple sources for obtaining intangible data and practice-based fieldwork using digital metric survey techniques including two different digital camera devices to acquire recent and archive images of its actual data (5.5.2). The integration of recent and archive images captured through two different digital camera devices is then conducted with the goal of turning them into a single realistic 3D model (5.5.3).

Some of the challenges found throughout this method, such as time and technology issues in data collecting, processing, and creation, as well as accuracy and geo-references, are also underlined (5.5.4). Furthermore, the findings of integrating recent and archive images into a 3D model are presented. These aid in the creation of a comprehensive 3D model of heritage building (5.5.5).

5.5.2. Data Acquisitions of Ribat Banajah

Data acquisition pre-processes began by:

1- **Developing a practical plan based on the Ribat Banajah floor plan.** This illustrates the path of movement to capture the data (Figure 5. 25) using image capture strategies for terrestrial photography recommended by Historic England (Bedford, 2017, pp. 38; Agisoft Help Desk, 2022; Josephson, 2019, p. 32). The floor plan was obtained from King Abdulaziz University and was recorded by aerial photogrammetry.



The image capture strategies for terrestrial photography recommended by historic England in "Guidance for Good Practice" report (Historic England, 2017).

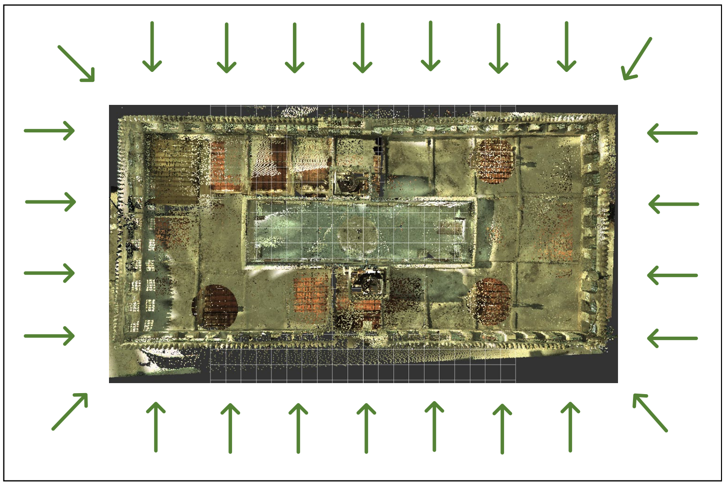


Figure 5. 25: *Image capture strategies for terrestrial photography on the left, and the path of movement to capture videos of Ribat Banajah façade on the right.*
(Bedford, 2017; Author, 2021)

2- **The available tool** was a (DJI POCKET 2) digital camera to conduct the practical mission of digital scanning.

3- **The practice-based action research of collecting on-site at Ribat Banajah data** started by:

a. The site was visited and checked it was clear of any obstacles and reflective surfaces while recording (Josephson, 2019, p. 25; Agisoft Help Desk, 2022).

b. Moved 360 degrees around the building as planned in the acquisition strategy (above) to record the façade (Bedford, 2017. pp.38; Josephson, 2019, p. 32; Agisoft Help Desk, 2022).

c. Two videos were recorded with 4K resolution and 30 frames in a single second to create a complete 3D model. However, the inaccessible parts of the Ribat Banajah could not be recorded during the data collection stage.

d. Archival images of Ribat Banajah were obtained from King Abdulaziz University to search for images related to the inaccessible parts.

e. The device used to capture the archival images was a Sony SLT-A65V digital camera with a focal length: 18, focal-stop: F/10, ISO: 400, and 35mm focal length. The images' horizontal and vertical resolutions are 350 DPI.

5.5.3. Practical Stages of Data Processing Stages at Ribat Banajah

Ribat Banajah passed through several practice-based data processing procedures. It initiated with:

1- Converting two recorded videos into 553 sequential photos by using Adobe Premiere Pro 2020 software (Adobe, 2021).
2- Loading all the sequential photos into Agisoft Metashape Pro software.
3- Aligning the sequential photos.
4- Building a 3D points cloud.
5- Cleaning noises.
6- Adding texture.
7- Creating a 3D model of Ribat Banajah (Agisoft, 2021).

The practical data processing stages of Ribat Banajah are summarized in table 5. 3 below:

Ribat Banajah Data Process Stages	Duration of Data Processes	No. of Data Vertices and Faces	Texture Quality	Achievable RMS Reprojection Error
1- Aligning	1.40 hour	1,516, 720 tie points	Ultra-high-quality	0.2 mm
2- Building ties and dense points cloud	8 hours	174,960,847 points cloud		
3- Cleaning noises	30 minutes	106,422,265 points cloud		
4- Creating a 3D model	6.15 hours	21,096,202 faces and 10,578,401 vertices,		

Table 5. 3: *The summary table provides the data processing stages of Ribat Banajah.* (Author, 2022)

The alignment process took around 1.40 hours with 1,516, 720 tie points generated (Figure 5. 26). As for the building dense point cloud stage, the processing was around 8 hours with 174,960,847 points cloud (Figure 5. 27). The noise-cleaning process for unnecessary points was filtered using automatic filtering and manual removal tools. The cleaning process lasted for 30 minutes to obtain the point clouds model of Ribat Banajah with 106,422,265 points cloud (Figure 5. 28). The final stage was building a model with texture for Ribat Banajah to acquire a realistic 3D model. Building the model and texture lasted for 6.15 hours with 21,096,202 faces, 10,578,401 vertices, and with ultra-high-quality texture, with an achievable RMS reprojection error of 0.2 mm (Figure 5. 29).

Figure 5. 26: *Aligned images and video frames of Ribat Banajah.*
(Author, 2021)

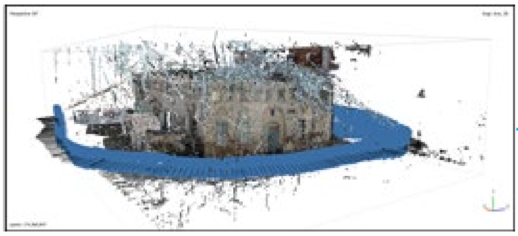


Figure 5. 27: *Built dense point cloud from aligned images and video frames of Ribat Banajah.*
(Author, 2021)

Figure 5. 28: *Filtered and cleaned point cloud model of Ribat Banajah.*
(Author, 2021)

Figure 5. 29: *The built model with ultra-high-quality texture for Ribat Banajah.*
(Author, 2021)

There were some parts of the 3D point cloud model missing due to access limitations, specifically behind the electric station and the backside of the building (Figure 5. 30). Archival images of Ribat Banajah, taken from King Abdulaziz University, were used to process the missing parts. The process of filling in missing parts started with:

1- Adding the archival images in the same software but on a new chunk.

2- Aligning, building dense point clouds, cleaning noise, and creating a model with texture were completed for these archival photos with an achievable RMS reprojection error of 0.2 mm (Figure 5. 31).

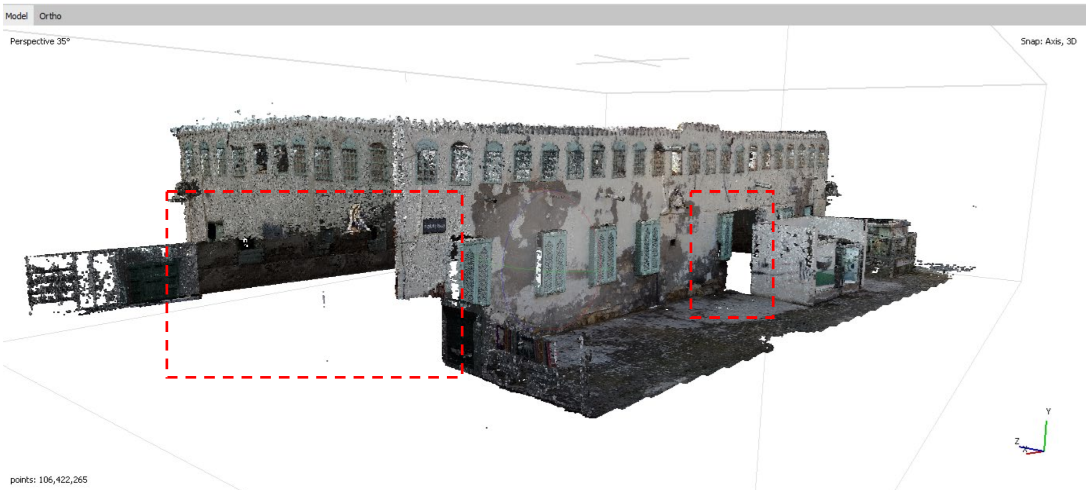


Figure 5. 30: *The missing parts of the point cloud model behind the electric station and the backside of Ribat Banajah.*
(Author, 2021)

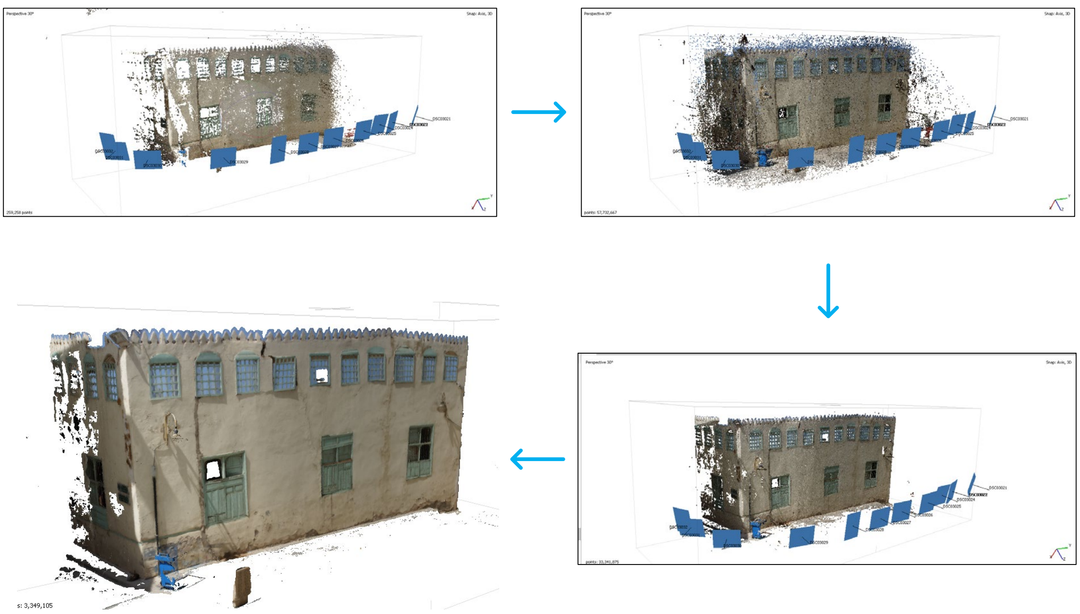


Figure 5. 31: *The process of building a model of Ribat Banajah backside from archival images.*
(Author, 2021)

3- A combination of the backside 3D model with the frontside 3D model of Ribat Banajah was achieved to fill in the gap. The two 3D models of the building were exported as a ply. files and imported into CloudCompare software to be merged into one single 3D model (Figure 5. 32).

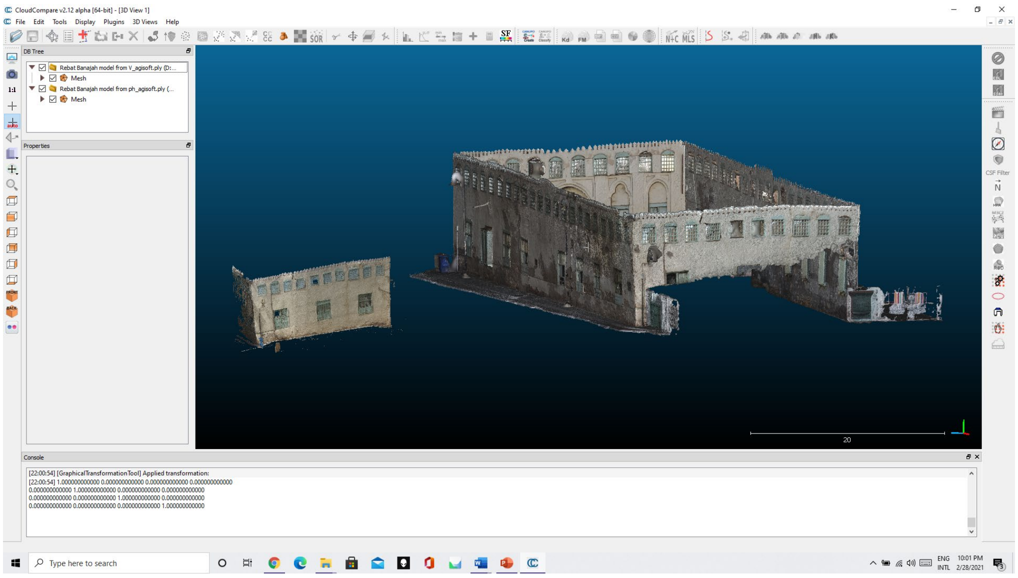


Figure 5. 32: *The backside 3D model with the frontside 3D model of Ribat Banajah in CloudCompare software.*
(Author, 2021)

4- Around six natural targets were picked for each one, such as the corners on the floor, windows, and wooden beams to align these two models (Figure 5. 33).

5- Alignment was completed with a final RMS error of 0.04, and the final result is shown in figure 5. 34.

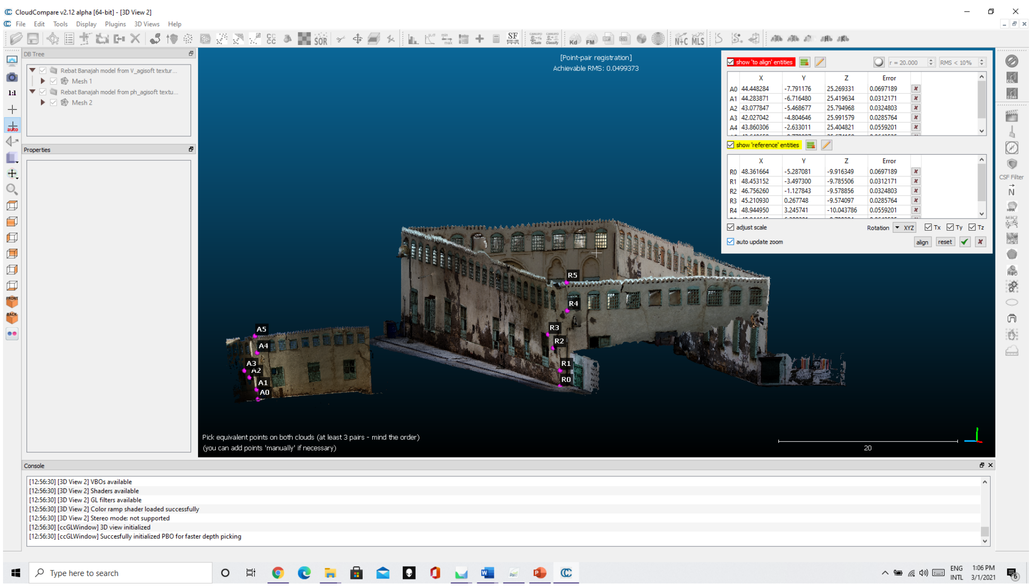


Figure 5. 33: *The picked natural targets in the backside 3D model with the frontside 3D model of Ribat Banajah.*
(Author, 2021)

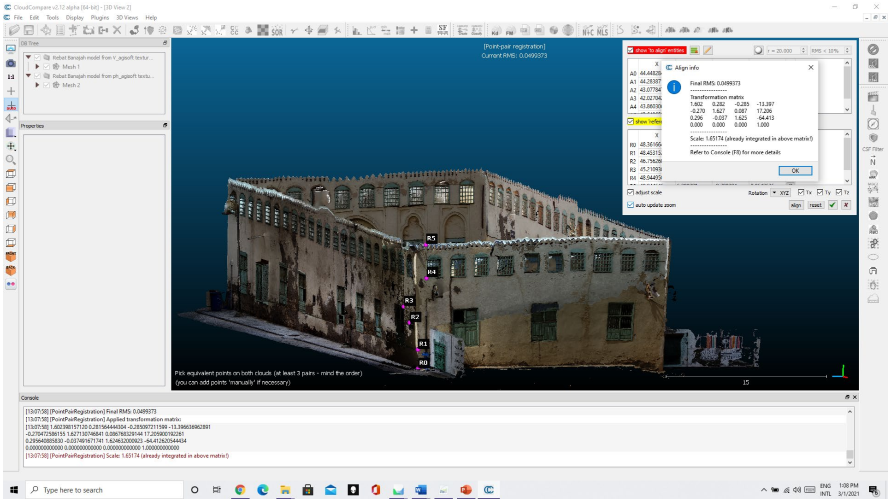


Figure 5. 34: *The final result of the 3D model of Ribat Banajah.*
(Author, 2021)

5.5.4. Issues of Data Acquisition and Processing by Utilizing Various Digital Camera Devices

In Ribat Banajah case study, several issues emerged during the practice-based data collection and data processing stages. As for data collection on-site, there were some obstacles appeared that blocked some parts of the building from being captured. These obstacles are electric stations located beside the building and metal fencing in the backside (Figure 5. 35).

Figure 5. 35: *Electric stations and metal fencing located beside and backside the building.*
(Author, 2021)

In addition, there was difficulty in accessing Ribat Banajah due to the sensitivity of the building and security restrictions during the time of the COVID-19 pandemic. As for the data processing stage, there were some problems that arose, such as noises from the surrounding buildings appearing around Ribat Banajah. In addition, there was a missing part of the backside of the building due to the access restriction, which was solved by integrating the new images extracted from videos with images obtained from the archive in CloudCompare software.

5.5.5. Discussion Findings of the Integration between Varies Data from Varies Digital Cameras Devices in a 3D Model

The findings of the adoption of action research as a practice based on integrating data from different digital camera devices are discussed in this section. Previously in this study, it was mentioned that digital cameras could assist in creating 3D models of any heritage buildings. In addition, it could also be stated that Ribat Banajah case study helped to discover that using different digital camera devices and different types of data such as videos from a DJI camera and archival images from a Sony camera can also assist in generating a realistic 3D model of any heritage buildings with acceptable accuracy by integrating these data together and process them using, for example, CloudCompare software. It was also found that there are several advantages when using different digital camera devices as recording methods and different types of data for constructing heritage buildings. The archival images combined with recent images of a heritage building can assist in completing the missing parts and gaps in the created 3D model. This means that any heritage building can be reconstructed as a 3D model with the help of previously recorded images only.

However, several disadvantages appeared while using digital camera devices and different data types for recording and digitally reconstructing heritage buildings. Each digital camera device has its specifications and features, so the resolution of the extracted images varies from one device to another. Also, the variation of image scales led to having various sizes of the produced 3D point clouds of each part of the heritage building. These 3D point clouds of different sizes needed to be resized to match each other for better results. In addition, it was found that the archival pictures do not reflect the current state of the heritage building, where there was a difference between them and the recent images either in the physical material or condition. Where some changes can take place on the heritage building, whether from natural erosion factors or maintenance operations by the competent authorities. Moreover, one of the disadvantages of the final 3D model is that it does not have any spatial coordinates in the global coordinate system, so it is not georeferenced. So, ground control points can be used in the acquisition process to obtain a georeferenced 3D model (Pix4D, 2019).

It is also, found that public users can participate in recording heritage buildings by simply using their digital cameras and old images by following the same stages that the researcher suggested in section 5.5.2 for data acquisition. However, processing the acquired data needs some technical training to generate the desired model.

In conclusion, action research as a practice-based approach was used in the fourth selected recording method to identify the most appropriate recording method by using two different digital camera devices to capture tangible and intangible information about heritage buildings to create a holistic digital record. So, the capability of two different digital camera devices and data was examined in generating a 3D model of a heritage building's tangible elements.

As a result of the practice-based fieldwork, it is noticed that creating a 3D model of Ribat Banajah's tangible elements with two different digital camera devices and data is capable. Where it is found that using different digital camera devices and different types of data such as videos and archival images can assist in generating a realistic 3D model of any heritage building's tangible elements. Also, when archival images combined with recent images of a heritage building can help to complete missing parts and gaps in the created 3D model.

On the other side, using various digital camera devices and different types of data for recording and digitally reconstructing heritage buildings such as the data processing stage was time-consuming and needed professional training. Where, the variation of image resolution from one device to another, image scales, and 3D point cloud sizes needed to be resized to match each other for better results. Moreover, it is found that the archival images do not reflect the current state of the heritage building, where there was a difference between them and the recent images either in the physical material and condition due to the natural erosion factors or maintenance operations by the competent authorities.

The replication of this fieldwork can be conducted by others such as amateur photographers by initially following the four evaluation criteria in selecting a suitable heritage building for recording which are significant value, unique structure, accessibility of the site, and availability of secondary data. Then, following the data acquisition steps mentioned in section 5.5.2 by utilizing two digital cameras, and then the captured data can be processed by following the steps in section 5.5.3 via Agisoft Metashape Pro software and CloudCompare software to create a 3D model of tangible elements of a heritage building. There is a possibility of adopting citizen science for updating the model annually to observe the changes that occurred over time to the heritage buildings, and individual volunteers can develop a model by adding extra heritage tangible and intangible information via web-based software, Geo-browser software, or smartphone applications to create a holistic digital record of heritage buildings.

5.6. Case Study 5: The Shafei Mosque

5.6.1. Introduction

Action-based research of the Shafei mosque was used in this study to examine the capability of using a smartphone digital camera and digital camera device combined with a laser scanner and the most appropriate recording method for creating a 3D model of a heritage building. The general workflow of Shafei mosque is illustrated in figure 5. 36.

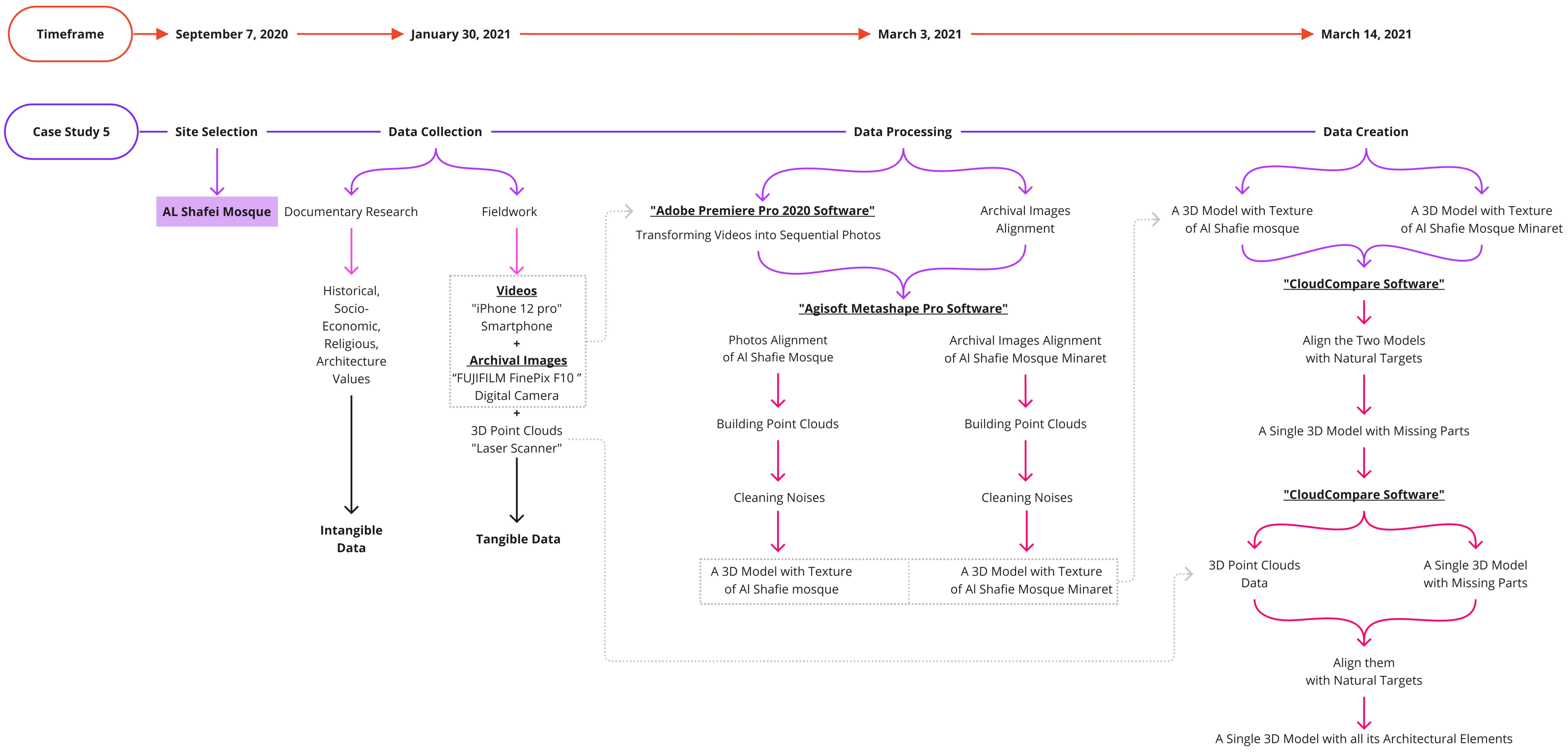


Figure 5. 36: *A diagram explanation of the general workflow of the Shafei mosque.*

(Author, 2021)

The diagram illustrates the Shafei mosque's practical methods and techniques utilised. In this case study the timeline, location selection, data collection, data processing, and data creation are taken into account. The Shafei mosque was surveyed and digitally rebuilt over the course of six months. The four evaluation criteria are used to determine the appropriate building during the site selection stage.

To explore Shafei mosque's important values, data is collected through documentary research from various sources for intangible data, and via practice-based fieldwork using digital metric survey techniques including a smartphone digital camera and digital camera device combined with a laser scanner to acquire videos, archived images, and point clouds of the Shafei mosque tangible data (5.6.2). The integration of videos and archived images, which are captured by two different digital camera devices, and point clouds extracted from laser scanners is completed to create a single realistic 3D model (5.6.3).

This section also identified some of the challenges that were experienced throughout the process, such as time and technical limitations in data collection, processing, and creation, as well as accuracy and geo-references (5.6.4). Furthermore, the findings of integrating videos, archived images, and point clouds into a 3D model are presented. These contributed to the development of a holistic 3D model of heritage buildings (5.6.5).

5.6.2. Data Acquisitions of the Shafei Mosque

Data acquisition pre-processes began by:

1- **Developing a practical plan based on the Shafei mosque floor plan.** This illustrates the path of movement to capture the data (Figure 5.37) using façade, interior, and object image capture strategies for terrestrial photography recommended by Historic England (Bedford, 2017, pp. 38; Hartley, 2020; Castilla et al., 2021, p. 7; Agisoft Help Desk, 2022; Josephson, 2019, p. 32) due to the different architectural elements that the mosque has in its front elevation (Figure 5.38). The floor plan was obtained from King Abdulaziz University.

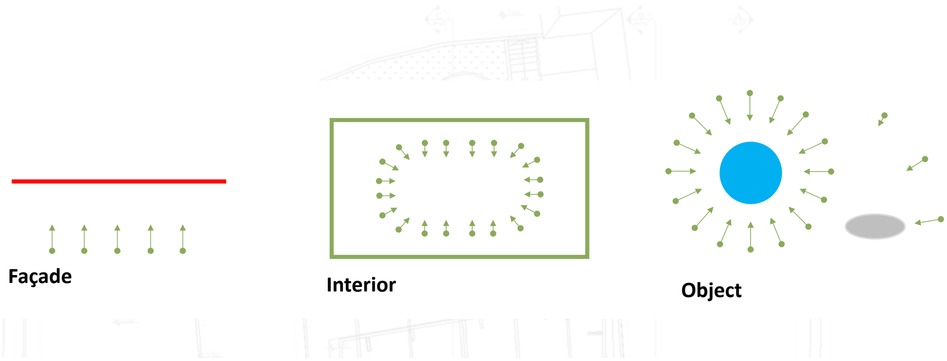


Figure 5. 37: *The image capture strategies for terrestrial photography recommended by Historic England in the "Guidance for Good Practice"report.*
(Bedford, 2017)

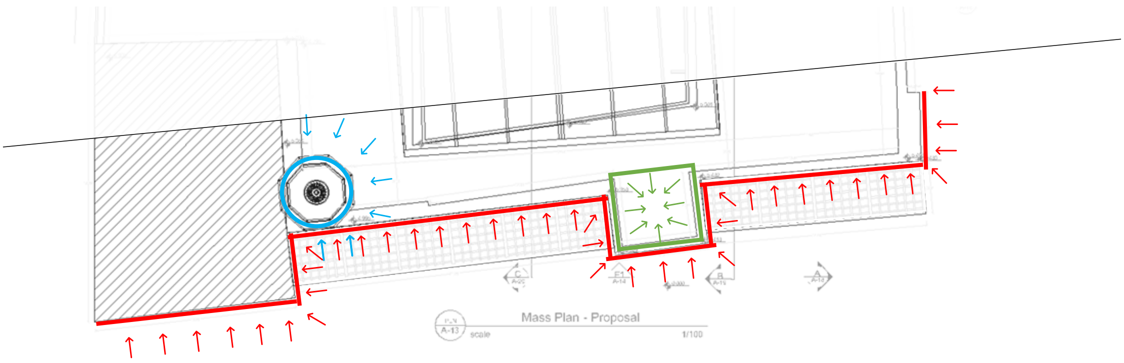


Figure 5. 38: *The path of movement to capture the: façade in red, the entrance in green, and the minaret in blue.*
(Author, 2021)

2- **The available tool** was the iPhone 12 Pro for the practical task of digital scanning,

3- **The practice-based action research of collecting on-site data of the Shafei mosque** started by:

a. The site was checked to be accessible and free of movable and reflective objects to start recording (Purificação et al., 2022, p. 7; Hartley, 2020; Josephson, 2019, p. 25; Agisoft Help Desk, 2022).

b. The iPhone 12 pro digital camera video sitting was edited to be 4K resolution and 30 frames in a single second.

c. A record of the building was done in one single video as planned in the acquisition strategy (above) to scan the mosque's tangible elements to create a 3D model.

d. Archival images of the mosque were obtained from King Abdulaziz University to process the missing parts that could not be acquired during the data collection stage on-site due to governmental restrictions.

e. These images were captured by FUJIFILM FinePix F10 digital camera with a focal length: 8 mm, focal-stop: F/6.4, and ISO: 200. The images' horizontal and vertical resolutions are 72 DPI.

f. Points cloud extracted from the laser scanner of the Shafei mosque were obtained from King Abdulaziz University of inaccessible sides that could not be recorded during the data collection stage of the mosque.

5.6.3. Practical Stages of Data Processing Stages at the Shafei Mosque

The Shafei mosque has gone through several practical data processing phases:

1- Inserting the recorded video into Adobe Premiere Pro 2020 software and then transforming it into 2924 sequential images (Adobe, 2021).

2- Loading the sequential images into Agisoft Metashape Pro software PhotoScan (Yilmazturk et al., 2019, pp.1-10).

3- All the sequential images were matched in 4.10 hours and then aligned to produce tie points (Ataiwe et al., 2021, p.7).

4- A dense points cloud was built (Ataiwe et al., 2021, p.7).

5- Noises of points cloud were cleaned using automatic filtering only, and that reduced the amount of points cloud (Agisoft, 2021).

6- The texture was added, and a 3D model of the Shafei mosque was created, see Figure 5. 39, 5. 40, 5. 41, and 5. 42. (Agisoft, 2021).

The practical data processing stages of the Shafei mosque are summarized in table 5. 4 below:

The Shafei Mosque Data Process Stages	Duration of Data Processes	No. of Data Vertices and Faces	Texture Quality	Achievable RMS Reprojection Error
1- Aligning	3.28 hours	11,337,825 tie points	High-quality	0.3 mm
2- Building ties and dense points cloud	4.65 hours	242,339,762 points		
3- Cleaning noises	cleaning 2 minutes	158,824,289 points cloud		
4- Creating a 3D model	8.64 hours	31,750,254 faces and 15,913,167 vertices		

Table 5. 4: *The summary table provides the data processing stages of the Shafei mosque.* (Author, 2022)

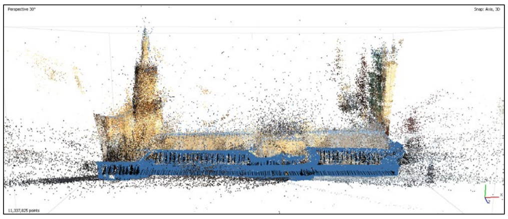


Figure 5. 39: *Aligned images and video frames of the Shafei mosque.* (Author, 2021)

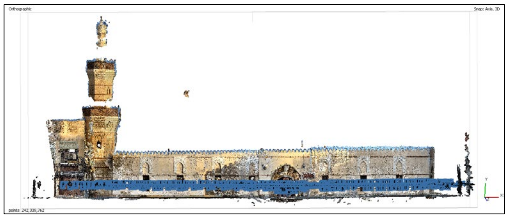


Figure 5. 40: *Built dense point cloud from aligned images and video frames of the Shafei mosque.* (Author, 2021)

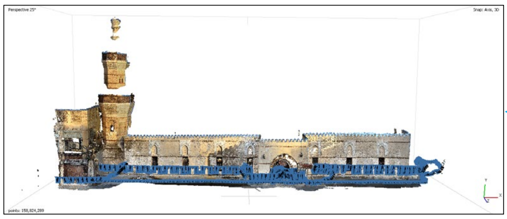
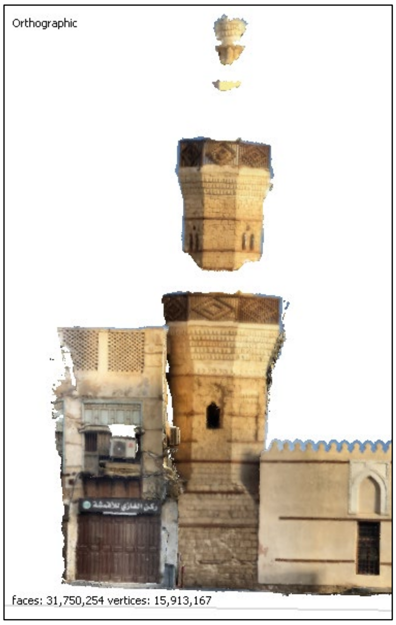


Figure 5. 41: *Filtered and cleaned point cloud model of the Shafei mosque.* (Author, 2021)

Figure 5. 42: *The built mesh with high quality texture for the Shafei mosque.* (Author, 2021)

There were some elements of the Shafei mosque 3D points cloud model missing due to entry restrictions during the COVID-19 pandemic. The missing elements were some parts located on the top side of the minaret, and the entrance walls and ceiling (Figure 5. 43).



Entrance wall gaps

Minaret gaps **Entrance ceiling gaps**

Figure 5. 43: *The missing elements are located on the top side of the minaret and entrance walls and ceiling.*
(Author, 2021)

Processing the missing parts of the minaret, archival images were acquired from King Abdulaziz University. These images were used to fill in some of the gaps in the minaret model by following the same process starting with alignment into creating a 3D model of the minaret missing parts, with an achievable RMS reprojection error of 0.2 mm (Figure 5. 44).

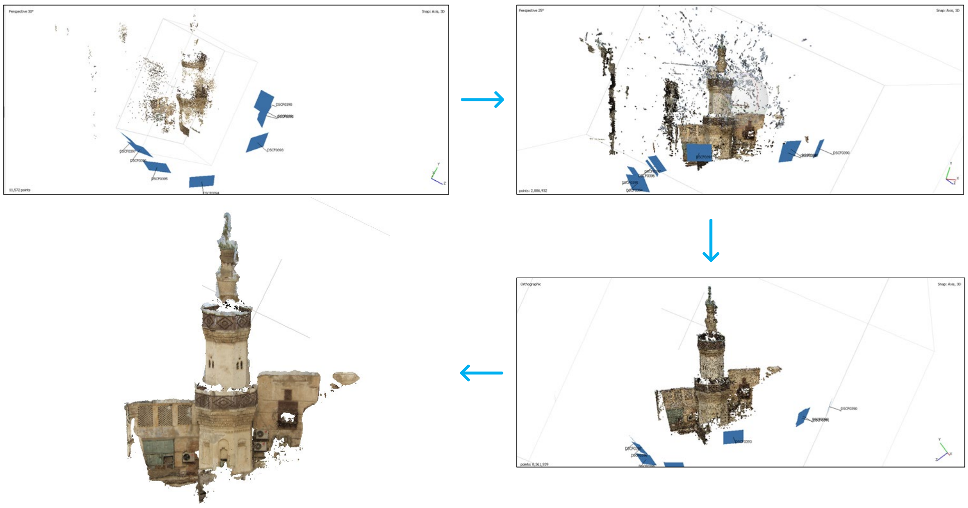


Figure 5. 44: *The process of building a mesh of the Shafei mosque minaret from archival images.*
(Author, 2021)

The mosque 3D model, which was built from videos, and the minaret 3D model, which was built from archival images, were combined to fill in the gaps in the minaret in CloudCompare software with an achievable RMS reprojection error of 0.04 mm. However, not all the gaps were filled due to the minimum number of archival images found (Figure 5. 45).

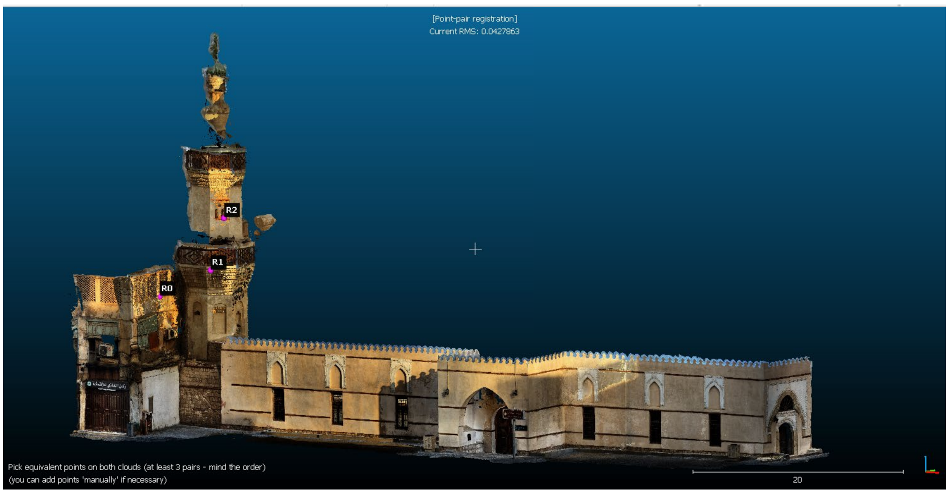


Figure 5. 45: *The result of combining the mosque 3D model built from a video and the minaret 3D model built from archival images for filling in the gaps in the minaret in CloudCompare software.*
(Author, 2021)

Therefore, another type of data was added to fill in the missing parts, which was using 3D points cloud data for the Shafei Mosque, which was obtained from King Abdulaziz University. The Shafei Mosque was surveyed by using a Leica ScanStation C10 device with 360 degrees horizontally × 270 degrees vertically of a wide field of view, and up to 50,000 pts/s pulse repetition rate, with between 2 to 6 mm/50 m of 3D scan precision. Then, the point clouds data obtained were processed by using Cyclone software to process and register the collected data into a 3D point cloud (Figure 5. 46).

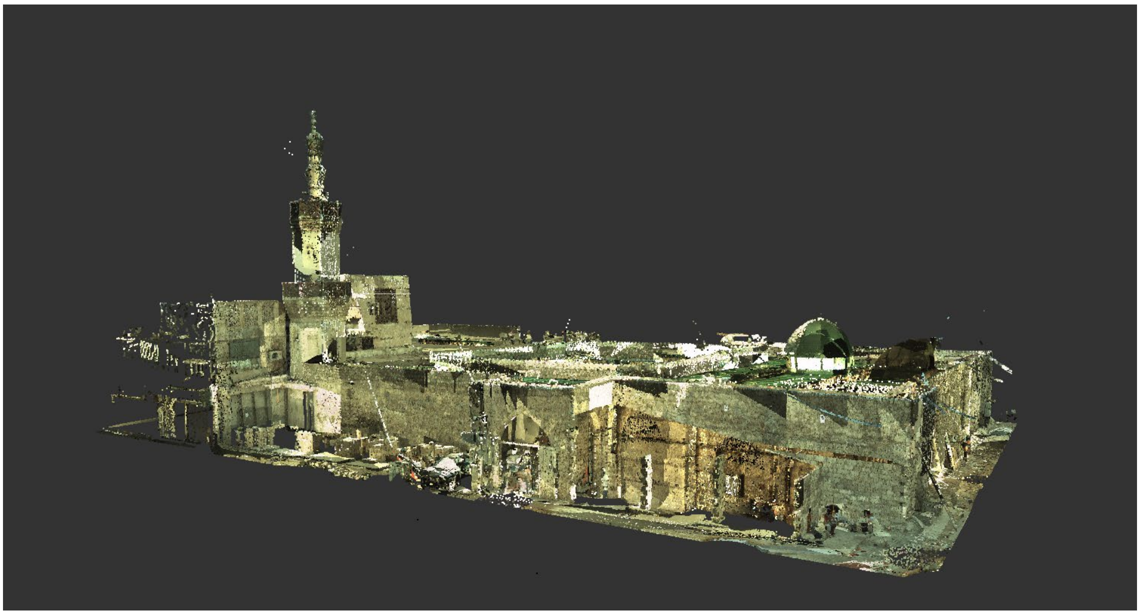


Figure 5. 46: *A 3D point cloud extracted from the laser scanner of the Shafei Mosque.*
(King Abdulaziz University, 2016)

To do so, export the 3D model of the Shafei mosque as a ply. file and the 3D points cloud data as a pts. file was completed. Then, imported them into CloudCompare software to be integrated as one single 3D model was finished. Following that, aligning the 3D model and the cloud by picking four equivalent point pairs in each model to help integrate them with final RMS error 0.03 (Figure 5. 47, 5. 48, and 5. 49).

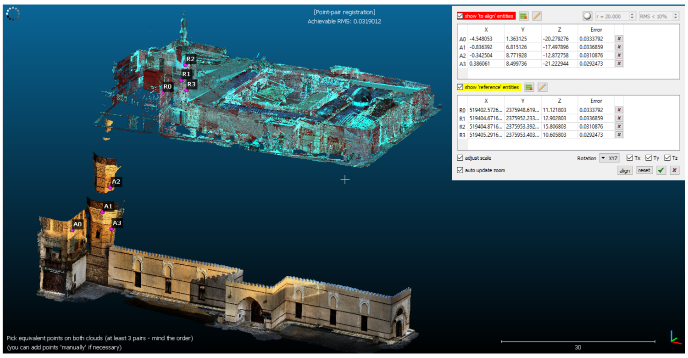


Figure 5. 47: *Exporting the 3D model of the Shafei mosque as a .PLY file and the 3D point cloud data as a .PTS file.*
(Author, 2021)

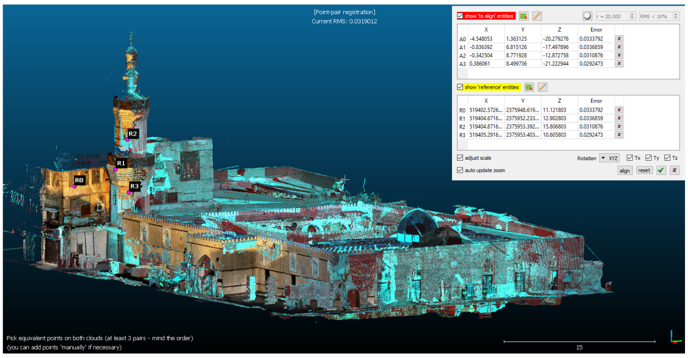


Figure 5. 48: *Aligning the 3D model and the cloud by picking at least four equivalent point pairs from each model.*
(Author, 2021)

Figure 5. 49: *Alignment information shows the final RMS error of the integrated models.*
(Author, 2021)

5.6.4. Issues of Data Acquisition and Processing by Utilizing Various Digital Devices

Several problems emerged during the practice-based data collection and data processing phases of the Shafei Mosque. In the data collection phase, sunshine and shadows were the main problems that the researcher faced due to the complex design of the building and the protrusion of some parts to the outside, such as the main entrance.

As a result, high-accuracy data were not obtained for the mosque materials due to the shadows casting (Figure 5. 50). Moreover, access inside the mosque was restricted due to the COVID-19 pandemic for health security. In addition, it was difficult to record the mosque's minaret from all sides because of its height, so archived data was used in which the minaret was recorded completely by a laser scanner.

As for the data processing phase, there were missing parts located at the top of the minaret, the entrance walls, and the ceiling due to either the height of the minaret and ceiling or the plane material that the facade has. The missing parts on the entrance walls and the ceiling were solved by integrating 3D point cloud data with the 3D model to fill in the gaps in CloudCompare software. As in the creating 3D model data phase, there was a need for a fee-based short training course on using 3D software to gain accurate results of the minaret.

Figure 5. 50: *The height, shadow casting, and plane material on the Shafei Mosque elements.* (Author, 2021)

5.6.5. Discussion Findings of Data Integration from Various Digital Devices in a 3D Model

In this section, the findings of the adoption of action research as a practice based on integrating data from different devices are discussed. Firstly, it is found that smartphones and digital camera data in conjunction with laser scanner data can help to create georeferenced and realistic 3D models of any heritage buildings where these data can be integrated altogether by utilizing CloudCompare software and then transformed into a 3D model by using Revit software. In addition, it is discovered that there are several benefits when using different digital devices and different types of data as recording tools for digitally creating a realistic 3D model of a heritage building with acceptable accuracy. When integrating videos recorded by smartphones and images captured by digital cameras with points cloud extracted from a laser scanner of a heritage building can help to fill the missing parts and gaps in the created 3D model. Moreover, using laser scanner data that used Global Positioning System (GPS), and Total Stations Technique (TST) as smart station methods during the data acquisition process can help to get georeferenced points cloud of a heritage building. Point clouds extracted from a laser scanner with georeferenced information are defined as the integration of point clouds with the other spatial data in a geodetic coordinate system, which is considered fundamental in planning and visualization and for responding to spatial queries (Altuntas et al., 2014). So, using laser scanner data that used GPS, and TST as smart station methods during the surveying process can help to get georeferenced points cloud of any heritage building. Another benefit that was discovered is that multiple models which are either created by sequential photos extracted from videos, archival images, or laser point cloud can be compared to provide information on structural degradation and weather erosion of its details through time.

Nevertheless, there are several disadvantages shown while using various devices and different types of data for digitally recording and constructing heritage buildings. Each digital device has its specifications and features; consequently, the data extracted from smartphones and digital cameras vary from the one from laser scanner devices. Where smartphones and digital cameras produce photos and videos, while laser scanners produce point clouds data. Therefore, the data scales differed, too, due to the difference in the types of data extracted. So, the variety of scales in the created 3D point cloud or the 3D model of the heritage building needs to be re-adjusted to improve the matching result between them, making the data processing stage time-consuming and needing professional training. In addition, it is found that the point clouds do not illustrate clear details and realistic textures of the heritage building, where there is a difference between the 3D point clouds and the 3D model in the physical material and colours (Figure 5. 51).

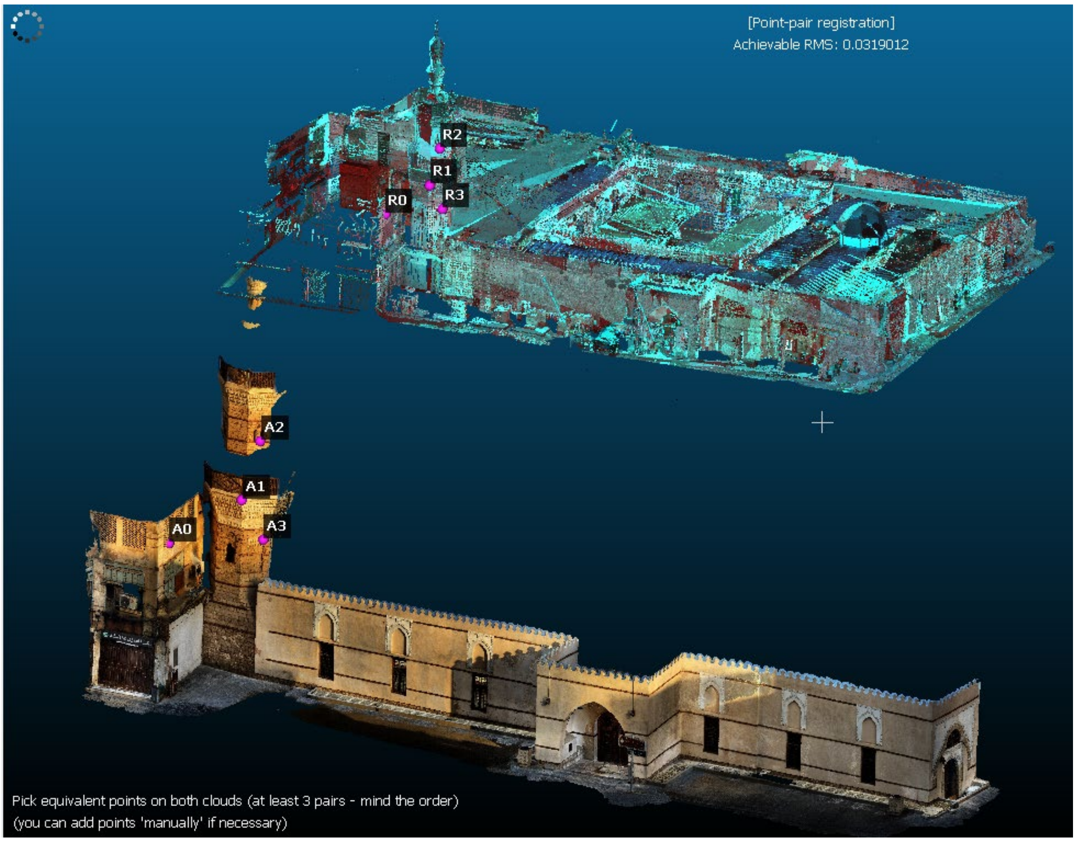


Figure 5. 51: *The differences between the 3D point cloud and the 3D model in their scales, physical material, and colours.*
(Author, 2021)

In conclusion, action research as a practice-based approach is used in the fifth selected recording method to identify the most appropriate recording method was a smartphone digital camera and digital camera device combined with a laser scanner to capture tangible and intangible information about heritage buildings for creating a holistic digital record. So, the capability of various devices and data was examined in generating a 3D model of tangible elements of a heritage building. As a result of the practice-based fieldwork, it was noticed that it was possible to create a realistic 3D model of any heritage building's tangible elements with acceptable accuracy by using various types of devices and data. A smartphone digital camera and digital camera device combined with a laser scanner can be used to create a realistic 3D model of a heritage building's tangible elements. It is also discovered that integrating smartphone and laser scanner data can help create georeferenced and realistic 3D models of heritage buildings' tangible elements. In addition, it was found that integrating videos recorded by smartphones, images captured by digital cameras, and points clouds extracted from a laser scanner of a heritage building can help to fill the missing parts and gaps in the created 3D model. Moreover, using laser scanner data that used GPS, and TST as smart station methods during the data acquisition process can help to get georeferenced point clouds of a heritage building. However, there were several disadvantages demonstrated while using various devices and different types of data for digital recording and reconstructing heritage buildings. The data extracted from smartphones varies from those from laser scanner devices because each digital device has specifications and features. Smartphones and digital cameras produce photos and videos, while laser scanners produce point cloud data. Due to the difference in the types of data extracted, the data scales differed too. So, the variety of scales in the created 3D point clouds or the 3D model of the heritage building needs to be re-adjusted to improve the matching result between them. In addition, it was found that the point clouds do not illustrate clear details and realistic textures of the heritage building, where there was a difference between the 3D point cloud and the 3D model in the physical material and colours.

In addition, this practice-based fieldwork can be replicated by the public to be involved in recording heritage buildings by: **Firstly, selecting the suitable site** based on: 1) Significant value, such as historical, religious, cultural and/or economic, 2) Unique structure, such architectural styles, construction techniques, and/or materials, 3) Accessibility of site for collecting primary data, 4) Availability of secondary data in specialized government and academic depositories, including previous studies and historical records. **Secondly, conducting the process of acquiring data** by: 1) Developing a a practical plan for data capture movement path on the heritage building's floor plan, 2) Selecting the available tools for digital scanning such as smartphone digital cameras, digital cameras, laser scanners 3) Start collecting data within practice-based on-site using available tools, and then processing them using computer software such as Agisoft Metashape Pro software PhotoScan and CloudCompare software, or smartphone applications.

It is possible then to add other heritage features such as texts, images, hyperlinks, ...etc. When disseminating the recorded information through web-based software such as WikiMapia or ArcGIS online, or Geo-browser software such as Google Earth or ArcGIS Pro (Elwood, 2008; Hartley 2021) or smartphone applications such as Mapillary application, that is classified as VGI to create a holistic digital record of a heritage building that includes its tangible and intangible information. Where there is a possibility of utilizing citizen science for updating the digital record information by individual volunteers monthly or annually to observe the changes that occurred over time to the heritage buildings as a result of climate factors, and natural and/or human disasters.

5.7. Chapter Summary

In conclusion, this chapter used action-based research to identify the most appropriate recording method to capture tangible and intangible information about heritage buildings for creating a holistic digital record by examining smartphone digital cameras, digital cameras, and laser scanners. The public beginners, amateurs, and/or professionals can replicate this practice-based fieldwork to involve in recording heritage buildings by: **Firstly, selecting the suitable site** based on: 1) Significant value, such as historical, religious, cultural and/or economic, 2) Unique structure, such architectural styles, construction techniques, and/or materials, 3) Accessibility of site for collecting primary data, 4) Availability of secondary data in specialized government and academic depositories, including previous studies and historical records.

Secondly, conducting the process of acquiring data by: 1) Developing a practical plan for data capture movement path based on the heritage building's floor plan, or if it is not available drawing a manual sketch of the building's plan to draw the movement plan on it 2) Selecting the available tools to conduct the practical mission of digital scanning such as a smartphone digital camera, a digital camera, an integration of two digital cameras, or an integration of smartphone digital cameras, digital cameras, and laser scanner 3) Starting collecting data practice-based on-site around the heritage buildings and capture sequential photos, videos, and/or point cloud of the heritage building by using the available tools 4) then processing them using computer software such as Agisoft Metashape Pro software PhotoScan, CloudCompare software, and Cyclone software, or using smartphone scanning applications such as 3Dim capture application software and its cloud software to generate a complete 3D reality model of tangible elements of the historic buildings.

The overall conclusion is that the created realistic 3D models of tangible elements of heritage buildings can be improved by creating a digital record that includes realistic 3D models of heritage buildings integrated with tangible and intangible information to have a holistic 3D model of heritage buildings. This digital record can be used for future investments such as improving understanding and appreciation of the historical, architectural, religious, cultural, and/or economic values of heritage buildings in Saudi Arabia or any other city in the world. Also, can help to conserve heritage buildings' information at a specific time describing its tangible and intangible condition as a reference that can be used for future work such as research, investigation, or conservation activity. Moreover, it can provide a unified digital record to access all tangible and intangible information about the heritage building, for instance, through smartphone applications or the record's website. There is also the ability to share the digital record with whoever, however, wherever, and whenever it is needed, as well as the possibility of updating the digital record by individual volunteers monthly or annually to observe the changes that occurred over time to the heritage buildings as a result of climate factors, natural and/or human disasters.

The generated 3D model can be then developed by adding additional heritage information to it and then sharing the information via various computer software to create a holistic digital record of heritage buildings. This requires data to be captured voluntarily by individuals with any kind of camera at first, generates a 3D model, and then adds heritage features to the model such as texts, images, hyperlinks, ...etc before disseminating the recorded information. For instance, tourists can record heritage buildings by using their smartphones when visiting historical landmarks in any country they are travelling to. They can add and share the acquired information with others through software and/or applications such as Mapillary application, which provides access to up-to-date street-level images and map data (Mapillary.com, 2022).

This approach clarifies the importance of citizen science to collect data in recording, documenting and conserving cultural heritage. In addition, the significant role of Volunteered Geographic Information (VGI) in recording heritage buildings. The VGI is the use of digital tools to create, collect, and disseminate geographic data created by individual volunteers (Goodchild, 2007, p.211). Where, if the data has been shared with others through such software, illustrating some of its images and explaining its background can help to improve understanding and appreciation of the value of heritage buildings among people all over the world. This process states the significance of disseminating VGI and citizen science for promoting the involvement of the public in recording heritage buildings' geographic information, which can be then disseminated through web-based software, Geo-browser software, or smartphone applications such as WikiMapia, GoogleMaps, Google Earth (Elwood, 2008; Phillips, 2022; Castilla et al., 2021, p. 12), ArcGIS online, QGIS software, OpenStreetMap website, OpenAerialMap, ArcGIS StoryMaps (Hartley, 2021; Coppinger, 2023; Kwon, 2024), and Mapillary web, mobile, and/or desktop applications (Mapillary.com, 2022).

Chapter 06: The Creation of a Holistic Digital Record for Heritage Buildings for Documentation and Dissemination

6.0. Introduction

The chapter starts with a brief explanation of the origin of the Historic Building Information Modelling System (HBIM) and its importance for heritage building documentation (6.1). It then provides the best practices used by HBIM in the digital documentation of heritage buildings. The implementation processes of digital documentation for a heritage building in the Jeddah historical district are illustrated. The chapter then introduces a brief of the development stages of the disseminating process (6.2). It explains the importance of the digital dissemination of heritage buildings. It presents the methods used and best practices in the digital dissemination of heritage buildings. It then illustrates the implementation of digital dissemination for the Shafei ' 'Mosque's Minaret, a heritage building in Jeddah (6.3). It ended with the creation of a framework for a holistic digital record of the Shafei ' 'Mosque's Minaret that integrates its tangible and intangible information in order to develop the recording process of heritage buildings in the Kingdom of Saudi Arabia, which can help in attempting to fulfil the direction of the Kingdom of Saudi Arabia 2030 vision in the culture and heritage sector in section 6.4 (Vision2030.gov.sa, 2020, p.4).

6.1. Digital Documentation of Heritage Buildings

The heritage buildings' digital documentation definitions, importance, methods, best practices, and previous studies were discussed previously in the literature review in **chapter 02**, sections 2.4, 2.5., 2.6., and 2.7. In this section, the author focuses on one of the recent widespread methods used in documenting heritage buildings which is HBIM for creating, documenting, and managing heritage information including its geometric and non-geometric attributes and relationships (Megahed, 2015, pp.130-147). In this research, digital documentation of a heritage building with a high level of detail was developed for future conservation and management with the help of Building Information Modelling (BIM).

6.1.1. The Origin and Importance of BIM for Digital Documentation of Heritage Buildings Records

BIM is a process that has been in the field for at least 15 years and was developed during the early stages of Computer-Aided Design (CAD) (the late 1970s – early 1980s) (Eastman et al., 2011, p.36). According to the National BIM Standard-United States, BIM is a digital representation of a facility's physical and functional characteristics and a shared data resource for information about a facility, shaping a reliable basis for decisions during its life cycle; defined as existing from the earliest conception to demolition. While BIM has been used for contemporary architectural buildings, it has been adopted recently for preserving and managing heritage buildings due to the absence of information that helps them survive (Garagnani et al., 2013, pp.87-92). HBIM is a modern methodology that supports documenting heritage buildings (Fai et al., 2011; Garagnani et al., 2013; Volk et al., 2014). It is a method for creating, preserving, documenting, and managing complete engineering drawings and information for heritage buildings (Megahed, 2015). In addition, HBIM provides an understanding of the current state of repair, informing schedules, and changes, forming renovations and conservation policies and planning (Megahed, 2015).

6.1.2. BIM Best Practice in Digital Documentation of Heritage Buildings

Several cases lead to adopting the HBIM process in the heritage sector. For instance, in Edinburgh, Scotland, the listed ticket office and adjacent staff areas in Edinburgh Waverley Station were surveyed to provide a three-dimensional (3D) model to adopt BIM workflow. This adoption minimises the reduced cost and minimises time through communication among all team members. A FARO® laser scanner was used to capture the 3D data, and total station technology was used to coordinate all registration targets. After registration, a 3D points cloud was obtained with high accuracy. A 3D model was generated by Revit® (Autodesk®), which includes the geometry parameters and the materials, as well as blank fields to add manufacturer details and costs of components and any information needed. Interaction, filtering, and scheduling out the items of the model were essential to be available for the users in a single standard data environment (Antonopoulou et al., 2017, PP.39-41). In the United Kingdom, Durham Cathedral Chapter House has been used as a case study to explore radical solutions to the restoration process by adopting BIM processes and technologies. Laser scanning was used to capture the interior of the church, and it transformed into a geometric 3D model. The main purpose is to obtain accurate information about its present condition and layout as a single accessible and reliable reference. Scenario planning and mobile virtual tours were provided through the model, as well as Condition surveys and maintenance schedules were created for the team to save time and cost. The generated model is for understanding, managing, preserving, and maintaining the building for future generations and for raising awareness of the important role that BIM plays in this heritage sector (Tapponi et al., 2015, pp.106 -114)

Also, Manchester City Council adopted the BIM process to renovate the town hall extension and central library located in the heart of Manchester city. Due to their national significance, they are listed by Historic England as grade-two buildings. In addition, they are considered the highest-level architectural model because of their high standards of innovation, sophistication, and construction. The main objective of the renovation was to help Manchester City Council develop its entire asset and facilities management approach. There are many benefits when adopting BIM for heritage buildings, such as providing interactive demonstrations of complex design, testing design options, exporting geometry data from the designed model for construction elements to be manufactured off-site, and asset management through transforming data to the Facility Management (FM) team (BIMCommunity, 2015).

The Sydney Opera House is one of Australia's 20th century's most unique buildings. It was listed in the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage in June 2007. In addition, it was chosen for the application of BIM for FM purposes due to its construction importance and complexity. Sydney Opera House was chosen by the Australian ' 'Government's Facilities Management and the Cooperative Research Centre (CRC) for Construction Innovation as a case study for their FM Exemplar Project. The project was for creating "a precise, reliable, and appropriate integrated building model to support operational management, building and service system changes and additions, and asset and maintenance management". Adopting BIM in the project is a suitable and valuable technology that can store and retrieve maintenance and management data for the Sydney Opera House (Ballesty et al., 2007, pp.1-19).

6.1.3. Implementation of Digital Documentation for a Heritage Building in Jeddah

In this research, the author adopted HBIM for the Shafei ' 'mosque's minaret. This adoption was to create, document, and manage its heritage information, including its geometric and non-geometric attributes and relationships (Megahed, 2015, pp.130-147). After obtaining 3D point cloud data with high accuracy of the minaret by the integration between digital photogrammetry, laser scanner, and documentary research in **chapter 05**, section 5.6 (Figure 6.1), a generic 3D model was created by using Autodesk Revit software, a BIM software, to assists in extracting geometric information such as plans, sections, elevations, etc. easily of the minaret (Figure 6.2), as well as non-geometric attributes such as descriptions from a particular time about its current status; this latter information can serve as a reference for decision making for future work, such as research, investigation, or conservation activity (Figure 6.3).

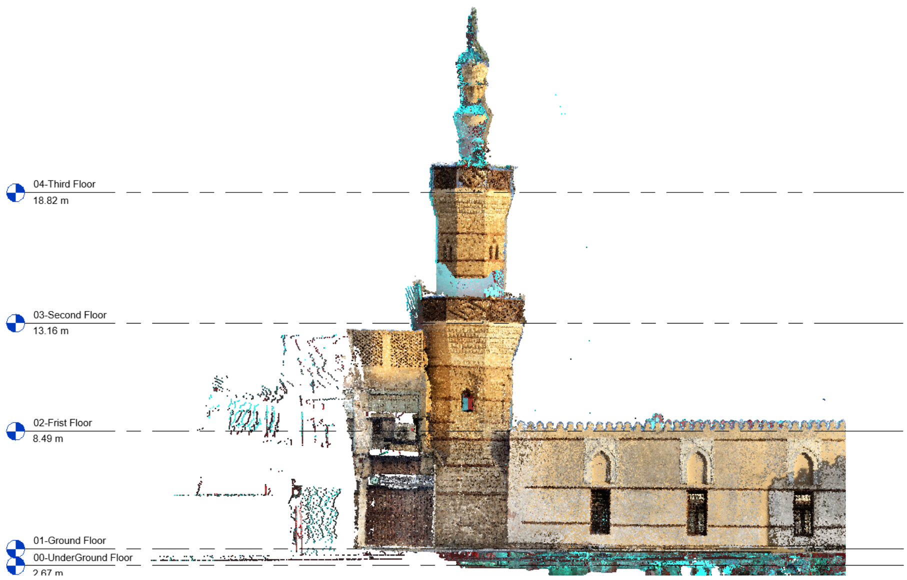


Figure 6. 1: *A 3D point cloud model of the Shafei ' 'mosque's minaret created by sequential photos extracted from videos, archival images, and laser point cloud (Data were exported as e57. file from CloudCompare software to ReCap software, and then exported as RCP. file to Revit software).*
(Author, 2021)

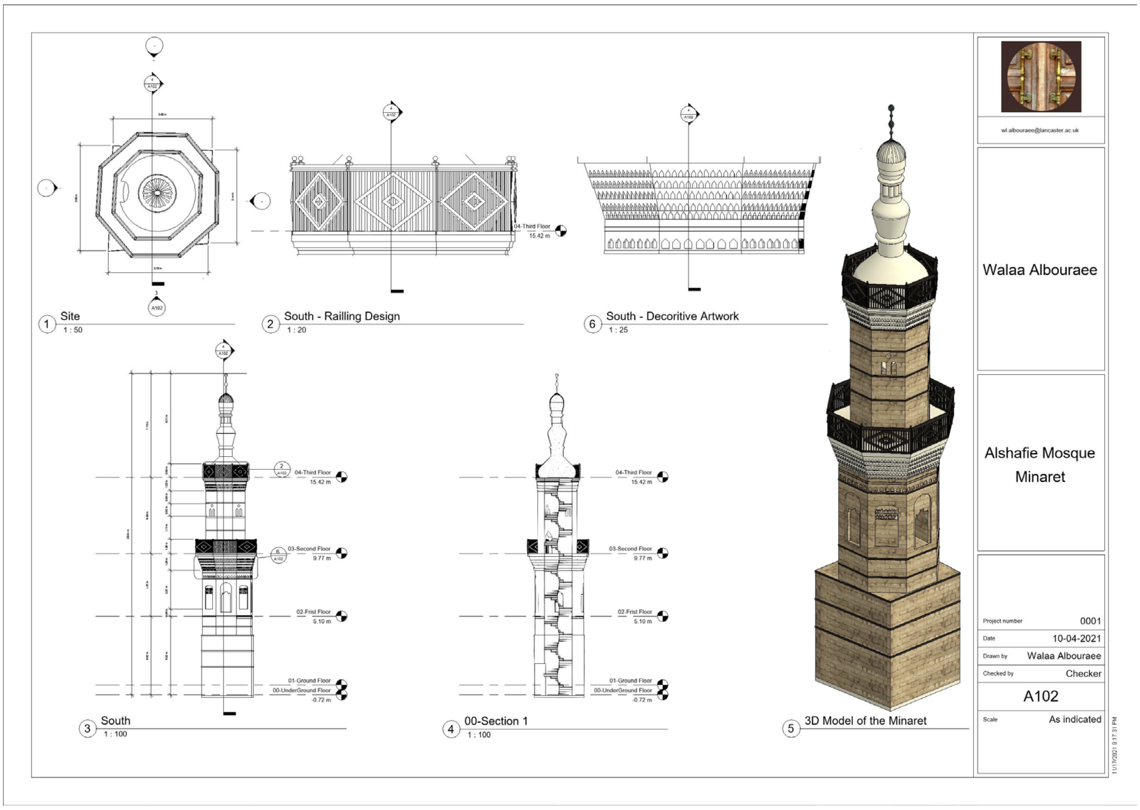


Figure 6. 2: *A generic 3D model of the Shafei mosque minaret with its architectural drawings.*
(Author, 2021)

<Alshafie Mosque Report>

A	B	C	D	E
Category	Family	Material: Area	Description	Model
Windows	wl minaret window opening	1.30 m^2		
Windows	wl minaret window opening	1.30 m^2		
Windows	wl minaret window opening	1.30 m^2		
Windows	wl minaret window opening	1.30 m^2		
Windows	wl minaret window 2	5.99 m^2		
Windows	wl minaret window 2	5.99 m^2		
Windows	wl minaret window 1	6.42 m^2		
Walls	WL INSIDE WALLS1	114.74 m^2	The two of the octagon ribs in the minaret, has a "kandiliya" window, and in the third rib there is a small door that is dedicated to the exit of the muezzin to the balcony	
Windows	wl decorative work 2	6.46 m^2		
Windows	wl decorative work 2	6.46 m^2		
Windows	wl decorative work 2	6.46 m^2		
Windows	wl decorative work 2	6.46 m^2		
Doors	M_Single-Flush	3.38 m^2		
Doors	M_Single-Flush	2.02 m^2		
Doors	M_Single-Flush	3.38 m^2		
Doors	M_Single-Flush	2.02 m^2		
Floors	Floor	13.53 m^2		
Floors	Floor	5.37 m^2		
Floors	Floor	7.19 m^2		
Walls	Alshafie Mosque Third Floor Wall part 1	3.52 m^2		
Walls	Alshafie Mosque second Floor Wall Part 1	88.99 m^2	The two of the octagon ribs in the minaret, has a "kandiliya" window, and in the third rib there is a small door that is dedicated to the exit of the muezzin to the balcony	
Walls	Alshafie Mosque Frist Floor Wall Part 17	13.58 m^2	Fiv gradual rows that are beautifully shaped	
Walls	Alshafie Mosque Frist Floor Wall Part 16	11.75 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 15	11.65 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 14	33.12 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 10	20.00 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 9	0.00 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 7	21.68 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 6	23.41 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 5	25.69 m^2		
Walls	Alshafie Mosque Frist Floor Wall Part 4	29.14 m^2	Five gradual rows that are beautifully shaped	
Walls	Alshafie Mosque Frist Floor Wall Part 3	29.53 m^2		
Walls	Alshafie Mosque Fourth Floor Wall Part 3	2.79 m^2	the Al Shafei mosque is considered as one of the ancient mosques in Jeddah, where its minaret was built in the 7th century AH, corresponding to the 13th century A	The minaret ends with a round cap
Walls	Alshafie Mosque Fourth Floor Wall part 2 1	0.54 m^2	The architecture style of the minaret construction dates back to the Ayyubid era	The crescent
Walls	Alshafie Mosque Elevation Wall	117.90 m^2		
Walls	Alshafie Mosque 3ed Floor Wall Part 4	2.69 m^2		
Walls	Alshafie Mosque 3ed Floor Wall Part 2	2.12 m^2		
Walls	Alshafie Mosque 3ed Floor Wall Part 1	29.13 m^2	The minaret was designed in a round shape and was built of carved stone	

Figure 6. 3: *The Shafei Mosque's minaret intangible and tangible information description schedule.*
(Author, 2021)

In conclusion, research revealed that numerous digital libraries of architectural elements had been created in English, Chinese, German, French, Czech, Italian, Japanese, Korean, Polish, Portuguese, Russian, Spanish, and Traditional Chinese styles. However, these digital libraries have only described the physical characteristics of the architectural elements and neglected to explain their inhabitants' histories, experiences, and cultures.

Furthermore, although the HBIM method has been adopted to digitise the building information in a digital record, it does not demonstrate any spatial data for the building. Geographical data cannot be visualised or understood if a map does not show relationships, patterns, and trends. Consequently, there is a need to merge between HBIM and the Historic Geographic Information System (HGIS), which are common practices and methods for managing building data. HBIM and HGIS are systems which have the potential to host heritage buildings' information, which can help reconstruct and conserve the buildings' data. Recently, This integration has been used for obtaining references of more detailed information, which can help create an information model of a whole city referred to as the City Information Model (CIM).

6.2. Digital Dissemination of Heritage Buildings Digital Documents

Digital documentation of cultural heritage enables digital dissemination, which can be accessible to the targeted audiences. The digital dissemination of cultural heritage is one of the popular topics in recent times (Jiang et al., 2021, p.2632). Previously, the dissemination of information was based on traditional methods such as paper materials in libraries (Suduc et al., 2010, p.2814). While now, with the development of technology, the dissemination of information has become digital and is represented virtually in local museums and exhibitions or educational environments as well as online sharing platforms (Brumana et al., 2013, p.497; Peinado-Santana et al., 2021, p.3; Jiang et al., 2021, p.2632). In this section, the author discussed the importance, methods used, and best practices for the digital dissemination of heritage buildings.

6.2.1. The Importance of Digital Dissemination of Heritage Buildings

There is an urgent need to digitise cultural heritage data for preservation and utilisation in the future, either for analysis or digital documentation (Meyer et al., 2007, p. 396). In the cultural heritage field, digital documentation helps with the digital dissemination of data and its access to all the different members of society if it is published in several ways that suit the targeted groups. Dissemination of cultural heritage is a social imperative to improve the knowledge of society in this field, to understand the danger exposed to monuments, and/or to raise awareness about the care that should be provided (Ortiz et al., 2018, p.1). Digital dissemination helps enrich the scientific content in the digital open sources, making the data accessible to all demographics based on a large set of heterogeneous historical data resulting from digital documentation.

6.2.2. Methods Used in Digital Dissemination of Heritage Buildings

Various digital dissemination methods in cultural heritage can be divided into computer-based, cloud-based, and web-based. Computer-based applications method includes Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) applications, and Game Engine platforms. The disadvantage of these applications is that they need expensive tools and require scientific and practical experience, otherwise, there can be misuse, misinterpretation, and poor visualisation (Billger et al., 2017, p.1024). On the other hand, cloud services can provide massive storage, applications, and hardware, which users can control at a low cost. Cloud-based applications are software that can be utilised online without the need to install it on 'users' personal computers (Daniel, 2011). Cloud-based application functions can include data collection, storage, sharing, management, and/or processing. These functions can be completed on a local computer or workstation, and an internet connection is only required for downloading or uploading data, such as Slack, Dropbox, and Evernote (Jay, 2019; Shore, 2021). On the other hand, the Web is an assortment of information and data stored on various servers worldwide, which can be researched and recovered but cannot be controlled (Daniel, 2011). Web-based applications are run on a web browser, which relies on the elements of the webserver installed in the device to allow the online web services to function. Web-based apps can be used from anywhere at any time as long as ' 'there's an internet connection, such as websites like YouTube, Facebook, and Wikipedia. Web-based apps work as transaction platforms such as data-sharing websites (Jay, 2019).

6.2.3. Best Practices in Digital Dissemination of Heritage Buildings

There are several methods in cultural heritage dissemination, which can be presented in:

6.2.3.1. The Use of Real-Life and Virtual-Life Methods

- **Real life** in libraries through books, audio tapes, etc. (Al-Barakati, A., 2012, pp.10-11) as well as three-dimensional printing for heritage education, dissemination, and conservation (Suduc et al., 2010, p.2814); (Peinado-Santana et al., 2021, p.4).
- **Virtual life** in local museums and exhibitions or educational environments such as VR, AR, MxR, and Game Engine platforms (Brumana et al., 2013, p.497; Peinado-Santana et al., 2021, p.4; Cui et al., 2021, P.490). In recent years, online digital dissemination has become more and more popular, and the creation of information-sharing platforms is becoming increasingly prosperous (Jiang et al., 2021, p.2633).

6.2.3.2. The Use of Web-Services and Open-Source Software, such as:

a) **EUROPEANA** is a digital humanities website that provides digital access to European cultural heritage material for enthusiasts, professionals, teachers, and researchers to use for inspiration, to create new things, to share and enjoy the rich data of cultural heritage (Peinado-Santana et al., 2021, p.6; Europeana.EU., 2022).
b) **3DHOP** is open-source software for generating high-resolution, interactive web displays for three-dimensional heritage (3dhop.net., 2022; Peinado-Santana et al., 2021, p.4).

6.2.3.3. The Use of Building Information Modelling (BIM) to disseminate heritage for:

- **Preserving** in recent decades, methods, and techniques of the BIM system for allowing 3D digital access to architectural heritage have been studied. For instance, recent work in Italy generates an open-source HBIM database of built heritage information for dissemination between professionals in various disciplines (García et al., 2018, p.100).

- **Visualisation**, a combination of HBIM models with immersive visualisation techniques, is adopted to improve the visualisation of heritage data, raise the understanding of cultural heritage, and enrich scientific research (García et al., 2018, p.101). HBIM approach can be used to illustrate the different structural elements and construction technologies for the walls, the roof, etc., and the decorative elements from a two-dimensional approach to a three-dimensional representation (Brumana et al., 2013, P.497).

- **Dissemination for educational purposes and virtual tourism,** for instance, via creating an HBIM library for explanation and education about structural elements and the used construction and decoration systems (Brumana et al., 2013, p.497), or for allowing interaction for a virtual tour to obtain information about the heritage elements (Barazzetti et al., 2015, p.35; García et al., 2018, p.p.100-102).

6.2.3.4. The Use of Geographic Information System (GIS) to disseminate heritage for:

- **Visualisations in an interactive web map**. The 3D city model of the city of Zurich displays exact virtual spatial data of the current buildings, trees, bridges, pipes, roads, etc. for achieving people's perception with a high level of detail, building materials, or the integration of buildings, see figure 6.4 (Stadt-zuerich.ch., 2022; Schrotter et al., 2020, p.p.102-104).

- **Analyses and simulations**, when additional information is added to the 3D city model, analyses and simulations can be achieved regarding noise spread, solar, shadow, etc (Caprari, 2022, p.9).

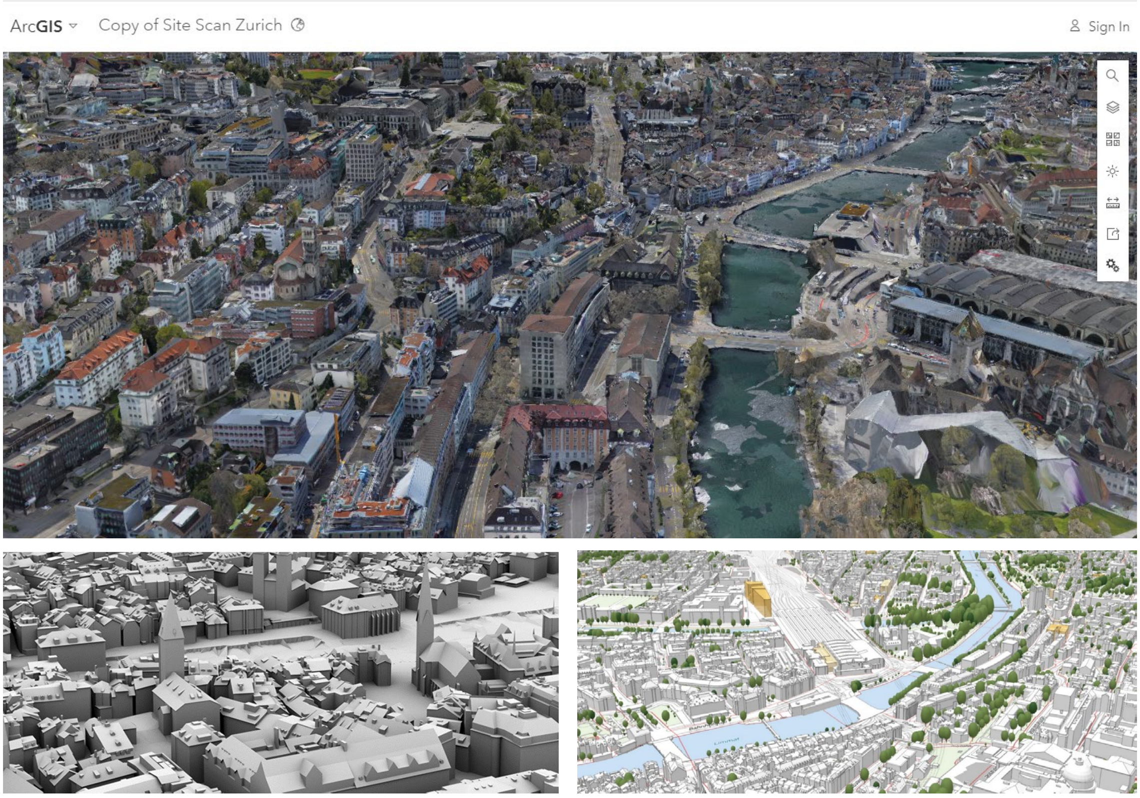


Figure 6. 4: *A 3D model of the City of Zurich in Switzerland.*
(Stadt-zuerich.ch., 2022)

- **Monitoring Smart City Performance.** Maps, graphs, charts, gauges, 3D models, and other dynamic, interactive, and interconnected visual analytics are used in dashboards to visually organise and interact with data (Building City Dashboards, 2017). For instance, the Dublin dashboard is an interactive geospatial platform that provides real-time information about the whole city's aspects. These data are presented using visualisations, data stories, maps, and interactive tools (Figure 6.5). The purpose of using dashboards is to integrate numerous data from various resources to display it through interactive maps, and historical and real-time data visualisations (Mattern, 2015). Citizens, public sector workers, and companies can gain detailed and up-to-date information from dashboards which can help achieve a holistic view of city performance that covers the social, environmental, and economic dimensions. Dashboards are for monitoring smart city performance and provide synthetic analysis and visualization of urban data, which can help for future decision-making and enhance information analysis (Building City Dashboards, 2017; Jing et al., 2019, p.13). Dashboards are tools that can help to integrate heterogeneous tangible and intangible data of heritage buildings in Jeddah's historical city to create a detailed and up-to-date holistic digital record that includes their different aspects in interactive and visualisations forms. Easy access to the historic city dashboards' information can allow the public and professionals to utilize it for future decision-making or for improving the monitoring, analysis, and visualization of the historic city performance.

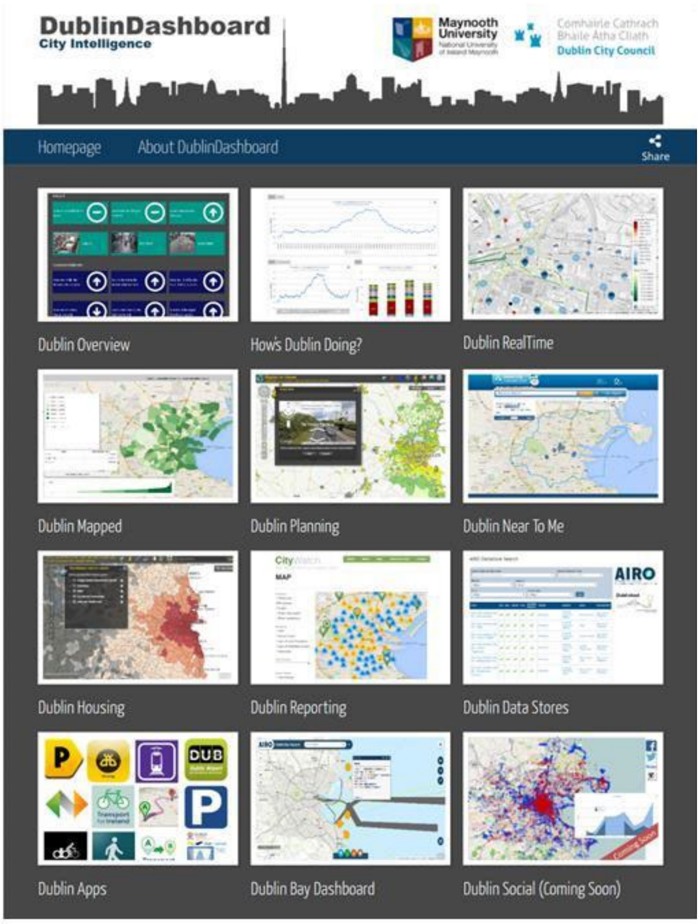


Figure 6. 5: *Dublin city dashboard developed by Maynooth University.*
(Creame, 2018)

- **Reaching as many people as possible for new utilisation experience.** A digital twin is a live digital synchronization in the virtual world to represent the state of the physical structure in the real world (Boyes et al., 2022, p.17). It employs and integrates heterogeneous data with the physical city for understanding and improving, and it also intends to monitor the current status of the construction phases and predict potential future scenarios of a particular block (Scalas et al., 2022, p. 343). The Kalasatama in Helsinki ' 'project's primary goal is to produce digital twins of the Kalasatama an open platform for designing, testing, applying, and servicing the entire lifecycle of the built environment, as well as smart city development (Figure 6.6). The produced reality mesh model and the CityGML city information model of Kalasatama in Helsinki are shared as open data to reach as many people as possible for new utilisation experiences. For instance, educational institutions and developer communities can use the model to create their environments for game engine streaming, analysis, and simulation (Helsinki Region Infoshare, 2019, p.p.1-60).

Figure 6. 6: *The Kalasatama digital twins project in Helsinki, Finland.*
(Helsinki Region Infoshare, 2019, p.1)

So based on the previous dissemination methods, the author adopted different digital dissemination strategies in this research for sharing cultural heritage tangible and intangible data using free platforms and low-cost tools such as cloud-based apps and web-based apps to:

1- Raise awareness and appreciation of the importance of the data of digitally conserved historical buildings.
2- Allow accessibility for reaching a larger audience of society to increase public engagement to improve digital records.

To reach the previous goals, the fusion of Geographic Information Systems (GIS) with BIM, which has increasing attention in publications and projects (Laat et al., 2011, p.1), is discussed in the following section.

6.2.3.5. The Integration of Geographic Information Systems (GIS) and Building Information Modelling (BIM)

In recent years, there has been a significant increase in the integration between BIM and GIS. When they are integrated, digital cities can be generated to visualise new buildings or conserve historic buildings and improve communication or participation between stakeholders. To fully benefit from the GeoBIM, it is necessary to understand in brief the concept of BIM and GIS (Das, 2020). The most famous semantic 3D modelling formats used in the Architecture, Engineering, and Construction (AEC) industry for buildings are 1) Industry Foundation Classes (IFC), used in the BIM field, and 2) City Geography Markup Language (CityGML), used in GIS field. IFC is an open-BIM data exchange format used in the AEC industry to exchange 3D building design data among various BIM software (Das, 2020; Antonopoulou et al., 2017, p.16).

In BIM, IFC has six Levels of Details (LoDs) for building models, each level illustrates the required geometric and semantic representations, and levels are shown in Figure 6.7 (Antonopoulou et al., 2017, p.16). However, in metric survey specifications for cultural heritage, BIM has four levels of details specifically for heritage buildings. levels are shown in Figure 6.8 (Andrews et al, 2015, p.126).

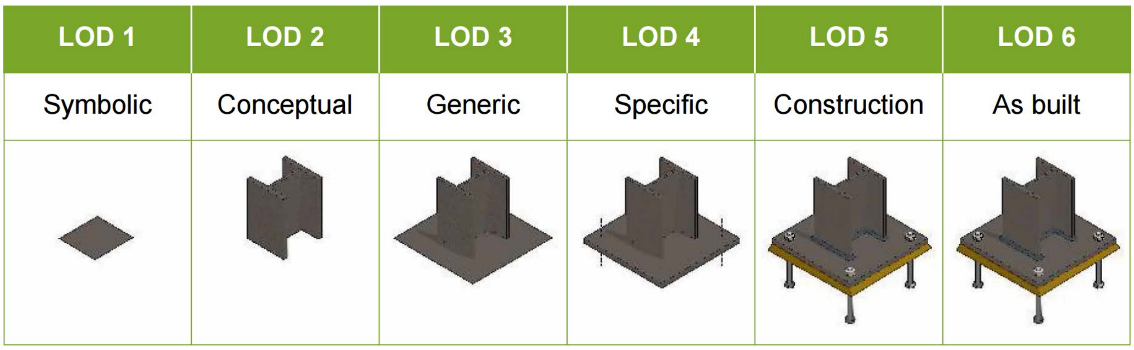


Figure 6. 7: *BIM Levels of Detail (LODs) by AEC (UK) BIM technology protocol.* (Antonopoulou et al., 2017, p.16)

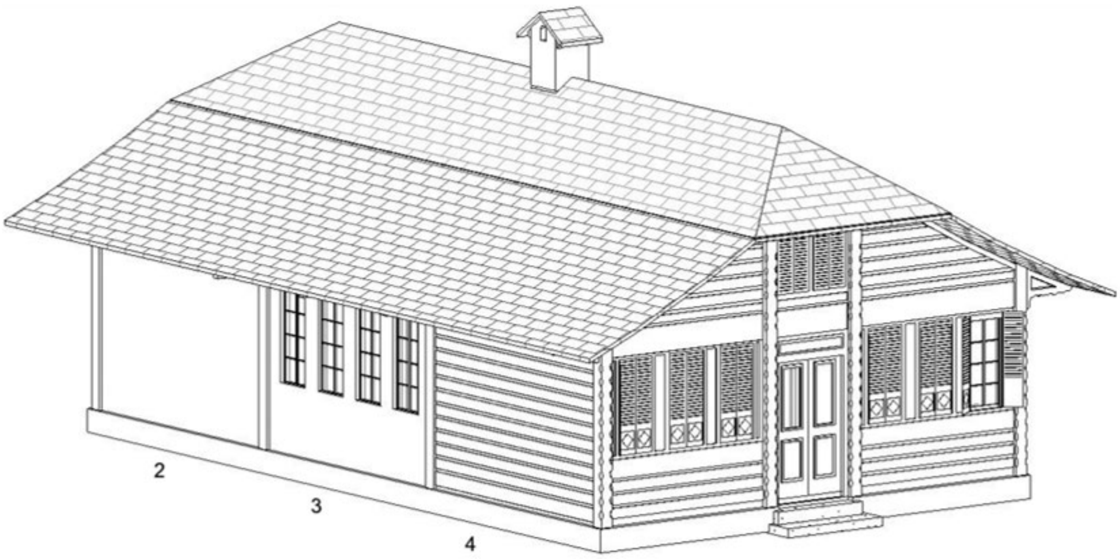


Figure 6. 8: *HBIM levels of detail level 2 at the back, level 3 in the middle, and level 4 at the front.*
(Andrews et al, 2015, p.130)

As for CityGML, it is an open data model and exchange format that is used to store digital 3D city models for individual buildings and landscapes. It helps to define cities' 3D features and objects and their relationships, such as buildings, roads, rivers...etc. In GIS, CityGML has five LoDs for the 3D objects to present them based on the implementations and purposes, levels are shown in Figure 6.9 ((Borrmann et al., 2012, p.2; Malhotra et al., 2021, pp.3-5).

The LoDs consent of five different levels. LoD0 is a two-dimensional digital model that represents an aerial image, a map, or a landscape scale with the low accuracy of the building. LoD1 is a single geometry model representing the building height and flat roof structures but with no textures. A building in LoD2 has detailed roof structures, and plant objects and textures possibly represented. LoD3 denotes architectural models with detailed wall and roof structures, balconies, bays, and projections. High-resolution textures can be mapped onto these structures. In addition, detailed vegetation and transportation objects are components of a LoD3 model. LoD3 represents buildings the exterior architecture and landscape scale of a model in detail, including information about walls, windows, openings, roof structures, balconies, bays, projections, and exterior installations for various buildings. LoD4 is complementary to LoD3. It represents the detailed interior architecture of a building, such as rooms, interior doors, stairs, and furniture (Kolbe et al., 2005, p.4; Kolbe, 2009, p.4; Malhotra et al., 2021, p.4).

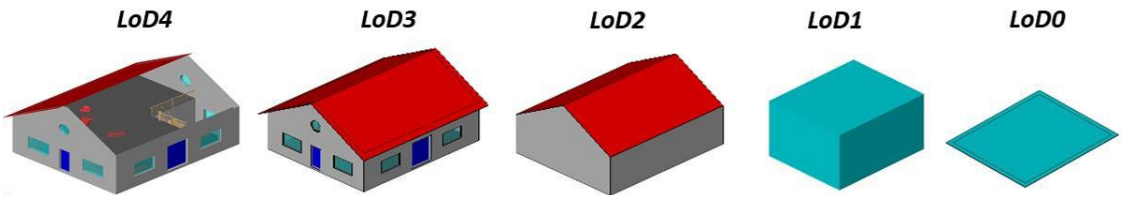


Figure 6. 9: *CityGML five Levels of Detail (LoD) in GIS.*
(Malhotra et al., 2021, p.5)

LoD2 models are often chosen for representing cities and urban areas (Malhotra et al., 2021, p.4). One example is the Lancaster City Information Model (LCIM) project (Figure 6.10). The LCIM project is an open-source web application that can display the first output of 3D (LOD2) geospatial data of Lancaster City, Morecambe, Lancaster University, and Heysham (Cureton et al., 2023). Based on this example, the digital record creation of individual buildings can be the first step toward CIM. CIM is a combination of BIM and GIS, which are well-known methods for managing building data (Lu et al., 2020, p.4).

Figure 6. 10: *Lancaster city information model project (LoD2).*
(Cureton et al., 2023)

Previously, research and applications often considered BIM and GIS as separate or integrated digital methods. Separate methods, such as utilising BIM only to create detailed and highly semantic 3D data, such as ticket office and staff areas in Waverley station in Edinburgh, Cathedral Chapter House in Durham, Town hall extension and central library in Manchester, and Sydney Opera House in Australia projects discussed earlier in this chapter in section 6.1.2, or utilising GIS only to determine the geographical location of objects using real-world coordinates, such as the City of Zurich in Switzerland project discussed earlier in this chapter in section 6.1.1.4. As for integrated methods, such as integrating between BIM and GIS by placing the three-dimensional building created in BIM in the GIS programs or creating geospatial building data in BIM programs such as creating streets, terrain...etc (Laat et al., 2011, p.2). However, this integration is not considered to be holistic without paying attention to the importance of integrating BIM and GIS data of buildings with their tangible and intangible information in a single place. Here comes the role of the GeoBIM domain to create a single source of building information where the tangible and intangible data can be added to achieve the integration between all the heterogeneous data in one place. Therefore, the researcher focused on developing the recording process of heritage buildings in the Kingdom of Saudi Arabia by creating a new framework model for integrating heterogeneous datasets for heritage buildings by adopting CIM approaches as a source for creating a holistic digital record of heritage buildings including their tangible and intangible heritage data to conserve and promote them in a single digital format. Then the author disseminated and allow accessing the created digital record easily through cloud-based applications such as ArcGIS Online software without the need for expensive devices or high technical skills, which can help recognise the importance of heritage buildings and enhance the educational process in societies.

6.3. Implementation of Digital Dissemination for the Shafei ' 'Mosque's Minaret in Jeddah

Based on surveying the literature and the previous studies, the HBIM (LoD4) of the Shafei ' 'mosque's minaret was created previously in this chapter. So, before starting the integration between BIM and GIS of the heritage buildings in Jeddah city, it was necessary to identify the benefits of this integration for the digital record system created in this research. The digital record system of Jeddah heritage buildings can be used by researchers, historians, archaeologists, and academics. The benefit of this system is that the recorded data can be integrated into maps using a wide variety of layer configurations. Maps can contain layers illustrating the heritage buildings in their exact location linked with their numerical data and descriptive, including text, tables, and images through the ArcGIS online website (this is a particular type of GIS public interface). Experts and non-experts widely use it for creating, managing, analysing, sharing, and collaborating on any type of data to improve communication, management, and decision-making (Traynor et al. 2001, pp. 116; Esri.com., 2021). For instance, via the ArcGIS online website, several layers were created of Sharif Gate, Jadid Gate, Makkah Gate, Ribat Banajah, and Shafei Mosque, and their exact locations are identified on the map (see ArcGIS Layers of the Five Heritage Buildings in a Map). Tangible and intangible information was then added as pop-ups, including texts, images, and hyperlinks for more information about the Hijazi Region Intangible Cultural Heritage Domains. This type of comprehensive approach allows for a better understanding of the sites for future management and decision-making (Figure 6.11).

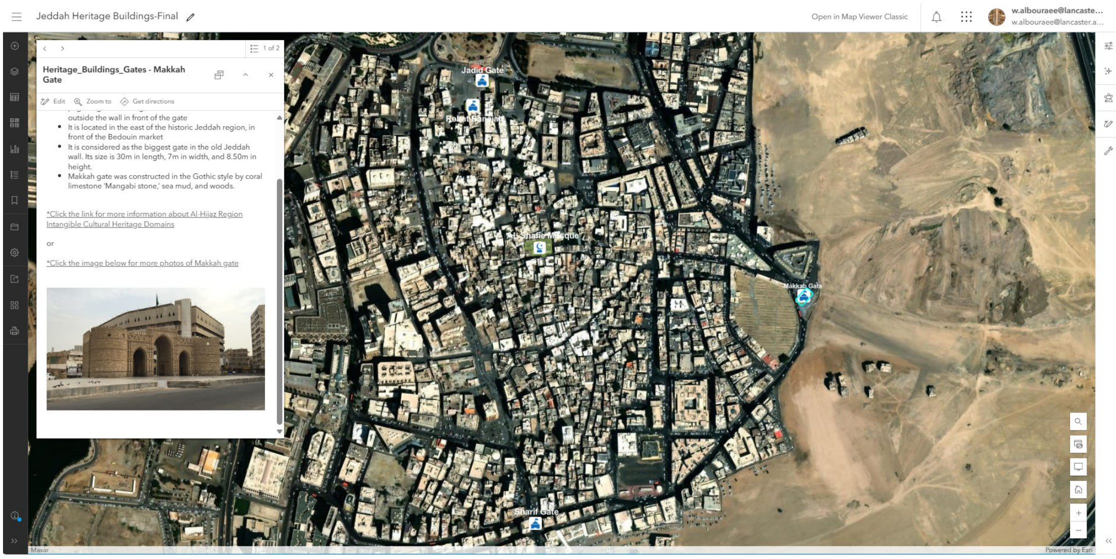


Figure 6. 11: *ArcGIS online layers of Sharif Gate, Gate, Makkah Gate, Ribat Banajah, and Shafei Mosque.*
(Author, 2021)

Maps are a tool that can also tell stories and provide the user with an experience to build upon and share (Harder et al., 2015, p.39). Moreover, story-builder tools can be used to enter and develop stories about heritage buildings based on the created digital record system. One of these tools is ArcGIS StoryMaps, a web-based application that can be used to create a map that includes text, lists, images, videos, and other media. The created story can be viewed on desktop computers and mobile devices. It can also be shared through social media and includes a link that can be shared anywhere (Esri.com, 2021). This application was used here to create a story map of Jeddah's heritage buildings. A story was entered for each of the five heritage buildings chosen in this research, thus contributing to a guided tour map. The location of each building, images, and information were added, and the story map was published, making it available to the public. This allows for a better understanding and appreciation of the heritage aspects because they are presented within a unified digital record that provides access to all tangible and intangible information about ' 'Jeddah's heritage buildings (Figure 6.12). After publishing the story map of the selected five heritage buildings in Jeddah, a URL link for the Jeddah heritage buildings map was obtained: Story Map of Jeddah Heritage Buildings, Saudi Arabia. This site illustrates the story through smartphone applications on the record's website. In addition, there are different internet mapping technologies such as Google Earth, a Geo-browser software, and location-based mobile apps that can be used for presenting the current state of history (Gregory et al., 2018, p.2).

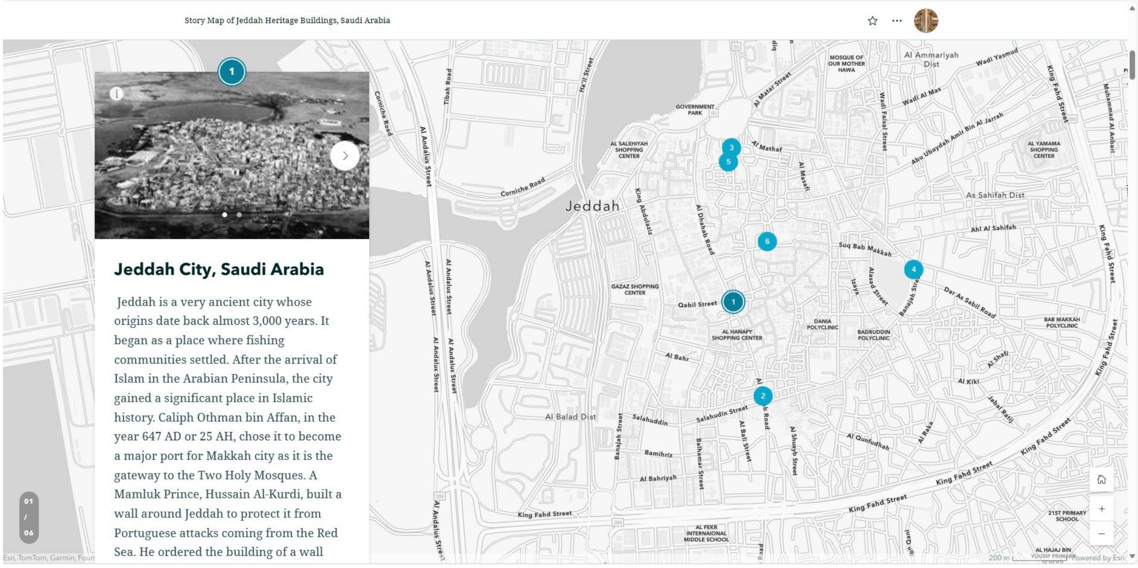


Figure 6. 12: *A story map for five heritage buildings in Jeddah city.*
(Author, 2021)

To sum up, it was found that digital heritage records can be utilised with GIS, whereby GIS can provide different types of information that can enhance the record, such as reports, charts, locations, images, texts, and tables. In addition, it can record stories of a ' 'building's history, region, city, or country. It was also found that the 3D record can be used in 'Geobrowser' software like Google Earth (App-Website- Google Earth Pro on desktop) which can help visualise building elements and understand their relationship with surrounding buildings, streets, sidewalks…etc. (Figure 6.13).

Figure 6. 13: *Example of 3D model of Jeddah heritage buildings in Google Earth software.*
(Abu Inabah, 2021)

6.4. The Creation of a Framework for Holistic Digital Records of Heritage Buildings

This chapter discusses the establishment of a framework to improve the recording process for the creation of a holistic digital record of heritage buildings of the Kingdom of Saudi Arabia by integrating information about their intangible and tangible heritage to conserve and promote them locally and internationally in a digital format; various systems were employed to achieve this integration. This framework can help achieve the direction of the Kingdom of Saudi Arabia's 2030 vision of the third-level targets assigned to the quality of life program in the area of culture and heritage (Vision2030.gov.sa, 2020, p.4). The creation of the holistic digital record starts with identifying the goal of the creation, followed by selecting the sites to be included in the digital record. It then clarifies the targeted audiences and tools used to create the digital record in this research. Next, it systematically explains the data collection, processing, and creation methods. It then clarifies the integration phase between tangible and intangible data in various digital platforms. Finally, it explains how to save and share the digital record with others for future work (Figure 6.14). Finally, conclusions are drawn regarding adopting this framework in creating the holistic digital record.

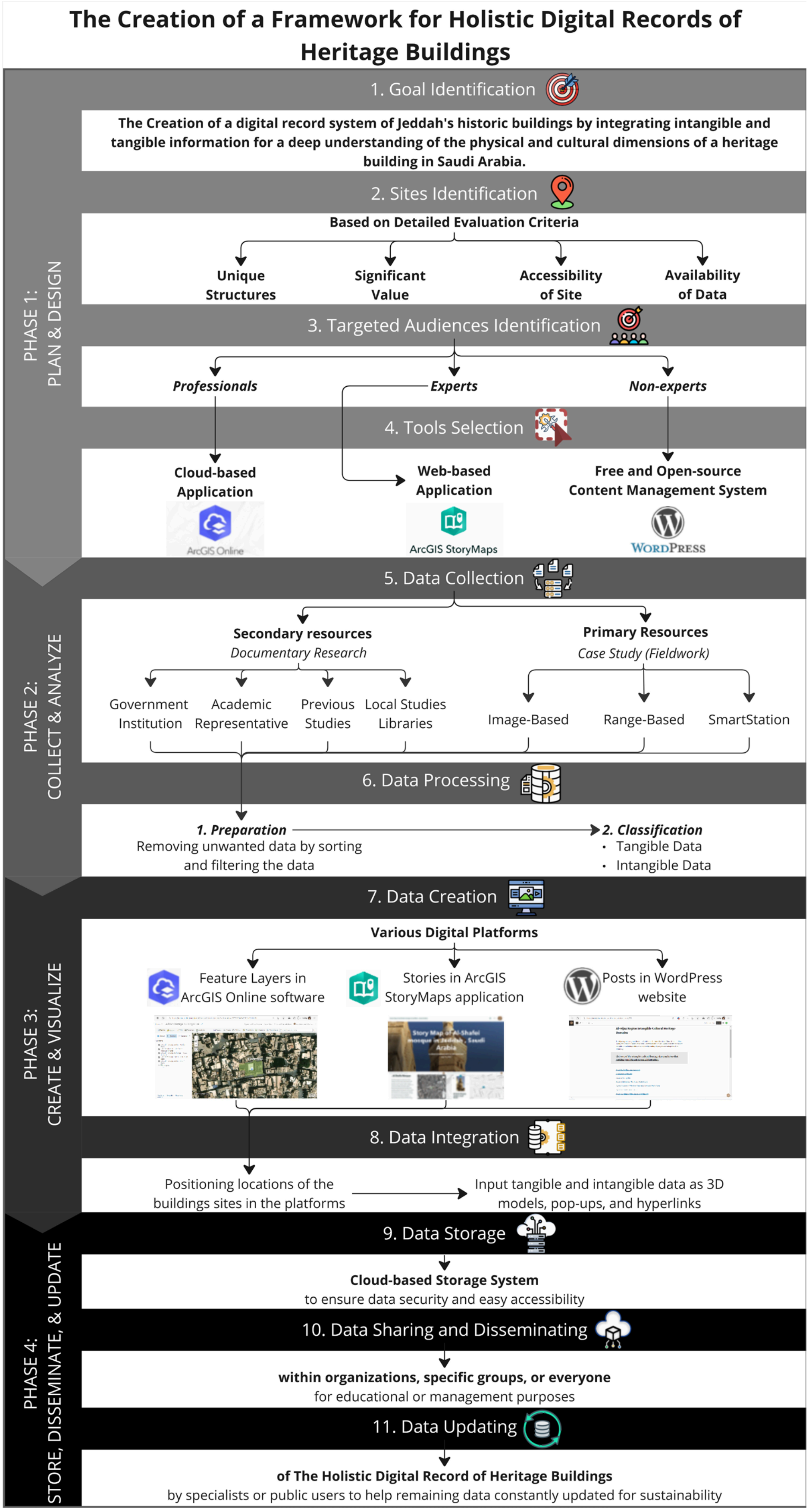


Figure 6. 14: *A Framework for holistic digital record system of heritage buildings.* (Author, 2022)

6.4.1. The Framework Phases

Based on the literature review, previous studies, methodologies, and implementations, as well as data acquisition and processing of selected case studies in heritage building recordings explained in previous chapters in this research, a framework is created. It is for drawing the steps of actions followed to create a holistic digital record of heritage buildings anywhere by anyone interested in the heritage field. The proposed framework consists of four main phases 1) Plan and Design, 2) Collect and Analyse, 3) Create and Visualize, and 4) Store, Disseminate, and Update. Each phase consists of several steps to achieve the desired goal, which are as follows:

1) Goal Identification Step**:** there is a need to focus on one specific goal and then explain the reasons for adopting this goal in digital heritage recording.

2) Sites Identification Step**:** the historical sites or monuments that are included in the digital record should be determined based on their 1) significant values, such as historical, architectural, aesthetic, economic, cultural, and social values...etc., 2) Unique structures, such as architectural styles, construction techniques, and/or materials, 3) Accessibility of site for collecting primary data, 4) Availability of data in specialized government and academic depositories, including previous studies and historical records.

3) Targeted Audiences Identification Step**:** defining who benefits from the created holistic digital record. For instance, the target audiences can be professionals, experts, and/or non-experts, and this depends on the desired goal from the beginning.

4) Tools Selection Step**:** Their choice can depend on availability, cost, accuracy, speed, and/or accessibility, …etc. as well as the targeted audience such as cloud-based application, web-based application, and a free and open-source content management system to carry out creating the holistic digital record.

5) Data Collection Step**:** after selecting the appropriate tools, the step of collecting historical buildings or site data comes from various information sources. For instance, in documentary research and/or fieldwork case studies, these data can come in various forms, visual or audible.

6) Data Processing Step**:** two stages must be taken in this step. First, prepare the data by sorting and filtering it by excluding unimportant data. Second, classify them according to tangible or intangible data type.

7) Data Creation Step**:** in digital format and form it in the shape of a map, a story, a website, etc., or any other form that fits with the main objective of the study using different applications that suit the target audiences such as *ArcGIS Online software*, *ArcGIS StoryMaps*, and *WordPress.*

8) Data Integration Step**:** different shapes created from the data can be combined in a digital platform and include tangible and intangible data to obtain an integrated digital record of the heritage building that includes all its data from varied aspects.

9) Data Storage Step**:** saving the data is a significant step. Where saving all kinds of data digitally in certain types of storage systems can ensure data security and easy accessibility to be used for future investment.

10) Data Sharing and Disseminating Step**:** can grant access to the holistic digital record within organisations, specific groups, or everyone interested in the heritage field to benefit from it, for instance, for educational or management purposes.

11) The Data Updating Step allows specialists or public users to carry out the processes of updating, which is an essential step in creating a holistic digital record of historic buildings, which can help keep them constantly updated for sustainability.

The author follows all these steps in this research to create a holistic digital record of heritage buildings in the Kingdom of Saudi Arabia, which are discussed in detail in the following section.

6.4.2. Creating a Holistic Digital Record of the Shafei ' 'Mosque's Minaret in Jeddah

Based on the created framework, in terms of the goal identification step, the author focused the goal on the creation of a holistic digital record system of Jeddah's historic buildings by integrating intangible and tangible information for a deep understanding of the physical and cultural dimensions of heritage buildings in Saudi Arabia. Then, the heritage buildings that were suggested to be included in the digital record were selected based on their significant values, unique structures, accessibility of the site, and availability of data, such as Sharif Gate, Jadid Gate, Makkah Gate, Ribat Banajah, and Shafei Mosque. The targeted audiences identified for this study are 1) professionals, such as architects, designers, restorers, archaeologists, and archivists; 2) experts, such as researchers, historians, and academics; and 3) non-experts means anyone interested in cultural heritage can benefit from this digital record. Suitable tools were selected based on the availability of use, ease of accessibility, free and low-cost tools, and the targeted audience to carry out creating the holistic digital record of Jeddah's historic buildings, such as *ArcGIS Online software*, a cloud-based mapping, and analysis solution, *ArcGIS StoryMaps*, A web-based application to enter and develop stories about heritage buildings, and *WordPress*, A free and open-source content management system that allows to host and build websites. Then the author collected the data obtained from various sources such as documentary research in government institutions, academic representatives, previous studies, local libraries …etc., and from data created in various forms based on the obtained data from the fieldwork stage through Image-based, Range-based, and Smart-stations techniques. These data can come in all visual or audible forms, including texts, images, videos, hyperlinks…etc. The processing of the data started by preparing them by removing the unwanted ones through sorting and filtering them, and then classifying the data into tangible and intangible data. Creating the holistic digital record of a heritage building and then integrating tangible and intangible data in diverse shapes were undertaken on different platforms. In ArcGIS Online Software a feature layer of the Shafei mosque was created and its exact location was identified on the map (Figure 6.15). Then, its tangible and intangible information was added as pop-ups, including texts, images, and hyperlinks to better understand the building for future management and decision-making (see Jeddah Mosque - the Shafei Mosque Minaret).

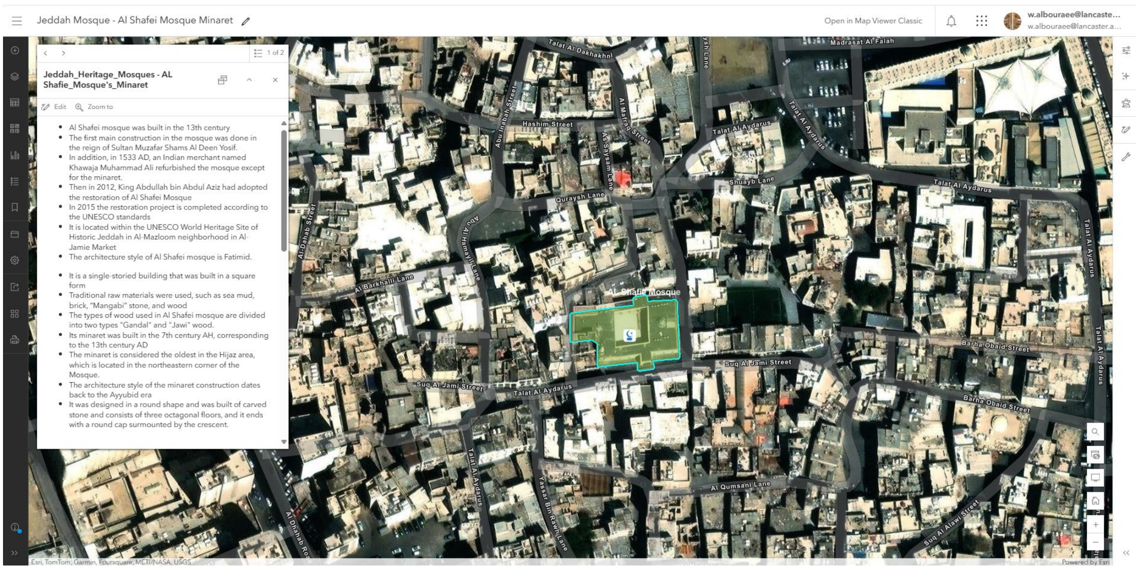


Figure 6. 15: *ArcGIS feature layers of the Shafei Mosque's minaret in a map.*
(Author, 2022)

Also, in the ArcGIS StoryMaps application, a story was created to present a story map of the Shafei mosque (Figure 6.16) to allow for a better understanding and appreciation of the heritage aspects within a unified digital record that provides access to all tangible and intangible information of a building, see Story Map of the Shafei Mosque in Jeddah, Saudi Arabia.

Figure 6. 16: *A Story map of the Shafei mosque in Jeddah, Saudi Arabia.*
(Author, 2022)

As for the WordPress website, the Hijazi Region Intangible Cultural Heritage Domains website was created to allow the publication and dissemination of information to be accessed by all demographics for better understanding and discovery of the hidden heritage (Figure 6.17).

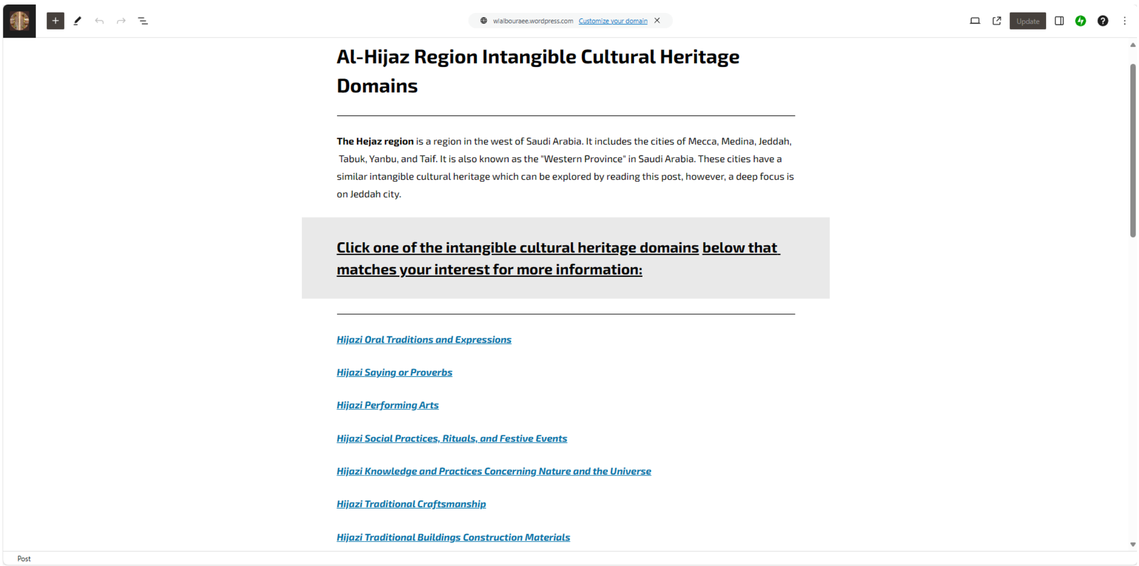


Figure 6. 17: *Hijazi region intangible cultural heritage domains.*
(Author, 2022)

Following on from this, all types of data were saved digitally in a cloud-based storage system to ensure data security and easy accessibility to be used for future investment. These data can be then shared and disseminated within organisations, specific groups, or everyone for education and/or management purposes. Giving access to the digital record allows specialists or public users to proceed with the processes of updating the created holistic digital record of historical buildings to keep them up to date for sustainable purposes.

6.5. Conclusion

The increasing attention to digitising tangible and intangible information about heritage buildings is a great chance for digital conservation, documentation, and dissemination. In this chapter, it is found that the Shafei mosque's information has a lack of digital documentation. Therefore, there is a need to utilize HBIM, the latest method in the digital documentation of heritage buildings. HBIM can assist in distinguishing and categorising architectural elements of heritage buildings including geometric and non-geometric characteristics to obtain a comprehensive generic 3D model. The model can be utilized as a reference for decision-making in future, such as research, investigation, or conservation works. Although prior studies have used the HBIM method to create digital libraries of architectural elements of various styles of heritage buildings for digital documentation purposes, at most these studies only describe the tangible aspects of the elements and ignore demonstrating the heritage characteristics and indicate any spatial data for the building. In light of the presented information, this comes to the conclusion that employing the HBIM method alone is insufficient for producing a comprehensive digital record of heritage buildings. Therefore, it is important to digitally document architectural elements for the Shafei mosque by integrating the HBIM and GIS methods. This resulted in a holistic digital record that includes tangible and intangible data and displays the building's spatial data. Furthermore, this holistic approach can grant a better understanding of the heritage building to improve management and decision-making processes in future. According to the documentary research that was done, it can be said that the Shafei mosque's cultural heritage information is recorded, but it is not shared with others or accessible because of its sensitiveness. Therefore, it is necessary to guarantee that heritage buildings with huge areas are thoroughly surveyed, examined, and—perhaps most importantly—then disseminated via a variety of free digital apps to ensure sharing, increase knowledge and appreciation, and provide access to cultural heritage data.

Another conclusion is that the Shafei mosque's recorded heritage cultural information is frequently in good condition but scattered, and no single digital source can be referred to for understanding the physical and cultural aspects of a heritage building. Therefore, a single digital record of the heritage building must be created that includes both tangible and intangible information and spatial data for conservation and future use by the government and researchers. It has been concluded that there is a need to improve the process of recording information about heritage buildings. As a result, a framework for developing a holistic digital record system of heritage buildings by integrating their intangible and tangible heritage information was presented. The framework enables the information to be displayed in ways that may help increase awareness of the value of cultural heritage conservation and the opportunities provided by digital approaches, both locally and worldwide. For instance, digital information about heritage buildings can be disseminated by creating an open access and interactive experience of a historical site's information. The use of cloud-based, web-based, and/or free open-source content management systems can assist in improving analytics and visualisation of the historical sites' data.

In this chapter, it is found that the holistic digital record can lead to a CIM Model. The LCIM project is a great example that proves this ambition. However, the LCIM project can be improved by attaching more tangible and intangible data, including historical, cultural, economic, social, architectural, aesthetic, artisanry, environmental, and religious values of the landmark buildings and sites. Therefore, it is suggested that a Jeddah Historic City Information Model (JHCIM) and, eventually, a Saudi Arabia Countrywide Information Model (SACIM) be built as an open web application that includes 3D geospatial models and their tangible and intangible aspects. It would be a valuable reference for future investment before responding to changes, renovations, and repairs, ensuring that no negative impact occurs during the work. It is also discovered that there is a lack of up-to-date geographic information on heritage buildings in Saudi Arabia. Therefore, there is a need to use GIS which can help update a city's geographical data by adding more layers with a variety of information types through community participation. For instance, participants from the community can help develop Jeddah's geographic information system to enhance its geospatial databases. To conclude, it is recommended that before creating a digital record of a heritage site in Jeddah, it would be beneficial to explore the importance of Volunteered Geographic Information (VGI), in which geospatial information is created by individuals using open mapping systems on the internet such as OpenStreetMap (Center of Excellence for Geospatial Information Science, 2021). This system enables individuals to generate their own data by setting marks on locations with certain features or events that do not exist on the main map of the city (Lu et al., 2016, p.19). This method also requires caution as there is concern over the credibility and authority of the data (O'Brien et al., 2016, p. 88). It is also recommended to recognise the importance of the participation of volunteer community members in updating and publishing their recorded geographic information to observe the changes that occurred over time to the heritage buildings to include them in the digital record in future works to develop the digital record system for ensuring its sustainability.

Chapter 07: The Overall Conclusion, the Overview of the Research Aim and Objectives, Research Findings, Original Contribution to Knowledge, Limitations of the Study, and Recommendations for Further Studies

7.0. Introduction

This final chapter provides the overall conclusion of the research (7.1) and is followed by restating the research aim and objectives (7.2). It also summarizes the main research findings (7.3) and explains the research's original contributions to knowledge (7.4). This is followed by acknowledging the potential limitations resulting from the adopted research methods (7.5). It then provides recommendations for further research in the future (7.6).

7.1.The Overall Conclusion

Initially this research, it was looked at how to conserve heritage buildings digitally for educational purposes. Many areas were considered, including heritage building recording, documentation, and methods used in recording, mapping, and modelling heritage buildings. Based on this initial literature review, the research direction was developed: digitally recording heritage buildings. Consequently, the literature examined: what are heritage buildings recordings? The importance of heritage buildings recording, traditional survey techniques used in recording historic buildings, digital metric survey techniques used in recording historic buildings, best practices in heritage buildings recording internationally, and previous studies in heritage buildings recording in Saudi Arabia (**Chapter 02**).

The literature review found that digital recording is considered the first step in heritage preservation, conservation, and documentation. It can also be conducted for both tangible elements and intangible information of heritage buildings. Subsequently, the research question was narrowed further to focus more specifically on: How to create a digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia? Based on this question, the research objectives were developed, and methodology, including the research philosophy, design, and methods and their capability to produce effective results to meet the aims and objectives of this study, were presented. The advantages and disadvantages of each method used in this research were discussed (**Chapter 03**).

Wide geographic information about the Kingdom of Saudi Arabia and its policy and governance, heritage and timelines for the protection and documentation of historic buildings in an international comparison were examined. The Kingdom's historic buildings to elaborate on vernacular characteristics were discussed. The historic buildings of Jeddah City, in particular, were explored. The criteria for selecting a suitable sample to be studied in detail in order to determine the complexity of intangible and tangible information and the range of approaches to fieldwork were explained. The processes and information used to select five historic buildings were explained (**Chapter 04).**

Structure from Motion (SFM) approach and Neural Radiance Fields (NeRF) approach and their utilization in the recording process were briefly explained. The general workflow of Sharif Gate, the Jadid Gate, Makkah Gate, Ribat Banajah, and the Shafei mosque were introduced, which was followed by an explanation of the data acquisition processes and data processing stages of each building to examine the capability of varied digital devices in generating a three-dimensional (3D) model to identify the most appropriate recording method to capture tangible and intangible information of a heritage building for creating a holistic digital record. Issues of data acquisition and processing stages of the used method and tools in recording heritage buildings were explained (**Chapter 05**).

The origin of the Historic Building Information Modelling System (HBIM) and its importance for heritage building documentation was briefly explained. The best practices used by HBIM in the digital documentation of heritage buildings were provided. The implementation processes of digital documentation for a heritage building in the Jeddah historical district were illustrated. The development stages of the disseminating process were briefly introduced. The importance of the digital dissemination of heritage buildings was explained. The methods used and best practices in digitalising heritage buildings were presented. The implementation of digital dissemination for the Shafei ' 'Mosque's Minaret, a heritage building in Jeddah, was illustrated. A framework for a holistic digital record of the Shafei ' 'Mosque's Minaret that integrates its tangible and intangible information in order to develop the recording process of heritage buildings in the Kingdom of Saudi Arabia, which can help in attempting to fulfil the direction of the

Kingdom of Saudi Arabia 2030 vision in culture and heritage sector was created in **chapter 06**.

7.2.The Overview of the Research Aim and Objectives

The main aim of this research was to create a replicable holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia.

The research question was the starting point for exploring the research objectives and methodology through surveying documentary research and fieldwork for this study. The research objectives centre around the following:

1- Determine what type of information will be included in the digital record and why.
2- Identify the most appropriate recording method to capture information about a heritage building.
3- Understanding the relationships between tangible and intangible information.
4- Establish and experiment with process-based methods of integrating tangible and intangible information.
5- Verify the effectiveness of the integration of information and stakeholder interactions.

In relation to the author's objectives, the following sections discuss: the main research findings, original contribution to knowledge, limitations of the study, and recommendations for further areas of research beyond the thesis.

7.3.The Main Research Findings

This research found that secondary data acquisition was required to view and determine available information about the buildings in the historical area of Jeddah, including their tangible and intangible information, for understanding the physical and cultural dimensions of a historic building in Saudi Arabia.

1- This research found that secondary data acquisition from different parties was required to view available information about buildings located in the historical area of Jeddah, including their tangible and intangible information for understanding the physical and cultural dimensions of a historic building in Saudi Arabia, which helped to determine what type of information will be included in the digital record and why (**Chapter 04**).

2- This study has shown that the selection of case studies was dependent on the evaluation criteria, which are significant value, unique structure, accessibility of the site, and availability of data on the historic buildings to establish a holistic digital record. (**Chapter 04**).

3- These experiments confirmed that it would be useful to ensure buildings with large areas are thoroughly surveyed and studied to consider their future use either by the government as a museum or use their data by researchers in their historical research due to their great historical and architectural values (**Chapter 04**).

4- It is found that to obtain rich, reliable, and accurate information about tangible elements and intangible attributes of Jeddah's historic buildings, utilising different digital recording tools was required to capture data for five historic buildings, which were selected in this research as case studies, to identify the most appropriate recording method to capture information about a heritage building (**Chapter 04**).

5- The results confirm that using a smartphone digital camera, digital camera device, and/or laser scanner has the ability to create a realistic 3D model of a heritage building's tangible elements with acceptable accuracy (**Chapter 05**).

6- The integration of the data extracted from these devices can help to create georeferenced and realistic 3D models of heritage buildings' tangible elements (**Chapter 05**).

7- It is not enough to digitally record heritage buildings to create a realistic 3D model of their tangible elements for documentation, it is valuable to improve the recording by creating a holistic digital record system that includes realistic 3D models of heritage buildings integrated with their tangible and intangible information to obtain a comprehensive 3D model of heritage buildings for conservation and future investment (**Chapter 05**).

8- This research explored that to have a holistic digital record that includes tangible and intangible information for the Shafei mosque's minaret, the adoption of the HBIM method can help to create, document, and manage its heritage information, including its geometric and non-geometric attributes and relationships, as well as Historic Geographic Information Systems (HGIS) method adoption for managing building data to understand the relationships between tangible and intangible information for better understanding and appreciation of the heritage buildings (**Chapter 06**).

9- This study has shown that the integration between Building Information Modelling (BIM) and Geographic Information Systems (GIS) of the heritage buildings in Jeddah city was conducted to create a holistic digital recording system that includes their tangible and intangible data in a map containing layers illustrating the heritage buildings in their exact location linked with their numerical data as well as descriptive, including text, tables, and images through the ArcGIS online website for creating, managing, analysing, sharing, and collaborating on any data to improve communication, management, and decision-making. This integration was managed to establish and experiment with process-based methods of integrating tangible and intangible information (**Chapter 06**).

10- The creation of the Hijazi Region Intangible Cultural Heritage Domains website to allow the publication and dissemination of information to be accessed by public users is an important finding in the understanding and discovery of the hidden heritage and to verify the effectiveness of the integration of information. All types of data were saved digitally in the platform storage system for future use, such as sharing the data within organizations, specific groups, or everyone by giving access to the digital record to allow specialists or public users to proceed with the processes of updating the created holistic digital record of historical buildings to remain them up to date for sustainable purposes (**Chapter 06**).

11- In this research, a story map of Jeddah's heritage buildings was also created through ArcGIS StoryMaps, a web-based application. A story was entered for each building on the map. The location of each building, images, and information were added, and the story map was published to make it available to expert users. This allows for a better understanding and appreciation of the heritage aspects because they are presented within a unified digital record that provides access to all tangible and intangible information about Jeddah's heritage buildings. After publishing the story map, a URL link for the Jeddah heritage buildings map was obtained. This link can illustrate the story through smartphone applications on the record's website, which can help digitally visualize building elements and understand their relationship with surrounding buildings, streets, sidewalks…etc (**Chapter 06**).

12- This study created several layers: Sharif Gate, Jadid Gate, Makkah Gate, Ribat Banajah, and the Shafei Mosque on the ArcGIS online website, and their exact locations were identified on the map. Tangible and intangible information was then added as pop-ups, including texts, images, and hyperlinks. This type of comprehensive approach allows for a better understanding of the sites for future management and decision-making for professional users (**Chapter 06**).

13- The resulting works from **Chapters 04 and 05** led to the creation of a framework for a holistic digital record system of heritage buildings. This framework contributes to improving the recording process for the creation of a holistic digital record of heritage buildings of the Kingdom of Saudi Arabia by integrating information about their intangible and tangible heritage to conserve and promote them locally and internationally in a digital format; various systems were employed to achieve this integration. This framework can help achieve the direction of the Kingdom of Saudi Arabia's 2030 vision of the third-level targets assigned to the quality of life program in the area of culture and heritage (**Chapter 06**). The results from that chapter helped improve the understanding and appreciation of the values of heritage buildings by disseminating the information through digital platforms, which can help increase public engagement in future.

7.4. Original Contribution to Knowledge

There are several contributions from this study regarding the original contribution to knowledge. First, there is an original contribution to knowledge in terms of usage and application of the holistic digital record system as follows:

1- Utilizing a range of typical commercial sensors and more precision survey equipment such as smartphone cameras, digital cameras, and laser scanners to collect images and points cloud data of a historic building to derive and fuse data. From my reading of previous literature, this research is the first to use these different techniques to record heritage buildings in the Kingdom of Saudi Arabia.

2- The research is the first to use citizen science to collect data on historical buildings in the Kingdom of Saudi Arabia. Data captured and constructed by citizens and archived in several different locations for the historical buildings studied in this research was used and integrated into parts of the work. This aims to obtain a digital record of historical buildings that includes considerable tangible and intangible data and to avoid, as much as possible, missing data that the researcher cannot collect or build alone due to time limits during the doctoral study stage.

3- "The fundamental concept of data fusion is the extraction of the best-fit geometry data as well as the most suitable semantic data from existing datasets" (Stankutė et al., 2009). Using different types of computer software to combine images, point clouds taken from different devices, and generated 3D models to create a holistic digital record system of the heritage buildings, a method that has not been used before in the Kingdom of Saudi Arabia.

4- This research lies in the use and application of these technologies and software to create a holistic digital record of any built heritage, and it is unlimited to buildings where it could be applied to statuary, archaeological sites, objects, heritage landscapes, heritage ships...etc. Therefore, anybody can repeat, reproduce, and generate this work by following the proposed framework generated in this research to digitally create a holistic digital record of any heritage building. To achieve replicability and reproducibility of the research, there is a need to have access to a heritage building and one of the proposed techniques and software with basic skills in using them to obtain the building's tangible and intangible data.

5- There is an original contribution to knowledge in this study which has been done in Saudi Arabia on particular heritage buildings because those buildings were not previously studied. Sharif Gate, Jadid Gate, Makkah Gate, Ribat Banajah, and Shafei Mosque's minaret have not been digitized before. So, having these buildings in digital form for the first time is the creation of the original resource which others can use for future works, where naturally, over time, those buildings are exposed to further deterioration due to erosion, neglect, or misuse. So, this digitisation process could enable time-based insights when collecting buildings' information for a specific period to observe the possible changes for future conservation and preservation.

6- This research started the record of these historic buildings at a particular point in time for the first time to show the current state of these buildings, and then they were accurately modelled and conserved in digital format, which led to obtaining a reference that can be seen. If the researcher repeats the study again for twenty years, these buildings can be modelled every five years and then can compare each model with the others to show the changes that occurred during this period based on conducting a time-based study of weathering, planning changes, and modification and/or restoration.

7- This research establishes the first holistic digital record of the five heritage buildings in Jeddah city, which other researchers or conservationists can now refer to in their works. So, if there is a need to restore these buildings in the future, there is a need to return to their original reference, and the earliest references are the ones that have been stored in the digital record in this research.

8- Another original contribution to knowledge is the understanding and appreciation of these buildings from various aspects. The appreciation of the building is not limited to bricks and mortar. It is an appreciation of the meaning of the building from a historical, social, economic, religious, architectural, and cultural point of view. In addition to the urban heritage of the Kingdom of Saudi Arabia and what this means for a sense of cultural identity, belonging, and pride in our place. So, in this research, all kinds of elements can be integrated to create a rich picture much richer than just pragmatics, such as the interpretive side, statistic side, spiritual side, and cultural engagement aspects which are also important.

9- My research is the first one that handles creating a digital record system that integrates information about the tangible and intangible aspects of heritage buildings in Saudi Arabia. The project's contribution lies in its findings that deliver a rich source of geometric and non-geometric information about the heritage buildings in Jeddah historical city in a single digital record which leads to contribute to improved understanding and appreciation of the value of heritage buildings in Saudi Arabia. In addition, to assist in developing future integration, a new framework model for integrating heterogeneous datasets for heritage buildings is suggested to help the public reproduce and generate a holistic digital record of any built heritage assets by following the created framework in this research.

10- This research offers a new model system to disseminate the digital records information of heritage buildings in Saudi Arabia via private and/or open source to allow users from planning, architecture, tourism, and/or archaeology fields …etc. Access and interaction with the information wherever, whenever, and however is needed for future investment.

7.5. Limitations of the Study

Various limitations emerged during this study and issues for replication, which are summarized in several points in Table 7.1 and discussed later in this section.

	Topics		
Limits of the study	Time constraints	Tools usage limitations	Site accessibility restrictions
Issues for Replicating	The limitation of the availability of accessible data	The limited time of using data processing software	Displaying data in a single platform

Table 7. 1: *Limitations of the study and issues for replicating.*
(Author, 2022)

As for time limitation, this research was limited to a certain period of time to be completed in three years during the PhD, where it was carried out by one researcher only. The process of collecting secondary data for high buildings with large areas takes a long time and requires several people working in cooperation with each other. In terms of limited resources and access. One of the most important evaluation criteria on which this study was based is the availability of data for the study area. Some historical buildings were initially considered but were later rejected from this study, despite their significant historical value and unique structure due to the unavailability or inaccessibility of data. Some of the secondary resources needed approvals from government agencies to be used in this study, which took a long time to obtain. The lack of secondary data on the selected historical buildings in the study area led the researcher to create the data herself and then disseminate it as it can be used as an open reference in the future by other researchers. As for tool limitations, there was limited access to the equipment required to complete this study to obtain the highest level of accuracy. Where there was a plan to use drones to capture primary data, however, because of their high cost and the restrictions imposed by government agencies in the country for political purposes, they were prevented from using them in the study area because of their high sensitivity. In terms of software limitations, there were other limitations related to the data processing software that was used in this study, as most of them are not free. These programs provide a free trial for a specified period of time for several days, and then there is a need for a monthly or annual subscription so then it can be used to take advantage of their extra features. Integrating 3D models onto currently available web platforms to extract historical, architectural, geographic, and other data is still problematic. There is no progress in systems such as

3Ds Max, SketchFab, and Revit to convert these models into formats that can be exported directly to web platforms such as ArcGIS Online to visualize and interact with them. In addition, these systems do not provide an archive of the 3D models and do not help to input and retrieve the information from the created 3D models.

One of the objectives of this research is to share data, but the researcher faces several obstacles. During the research phase of how to share data with people, there was no single platform that had the ability to display all the heterogeneous data that the researcher created and collected in one place. Therefore, the researcher published the data on several platforms, and each platform is directed to a specific audience of community members. An early template of an online platform is created which can help to view and document all the collected and created heterogeneous data of the heritage buildings. This suggested platform can allow access and interaction with the information from a single place (Figure 7. 1). In terms of site access limitations, there were restrictions on access to some of the study sites. Where there was a plan to obtain data on the interior parts of the buildings, but it was not allowed to access these sites due to their closure for health and security reasons during the Coronavirus pandemic around the world.

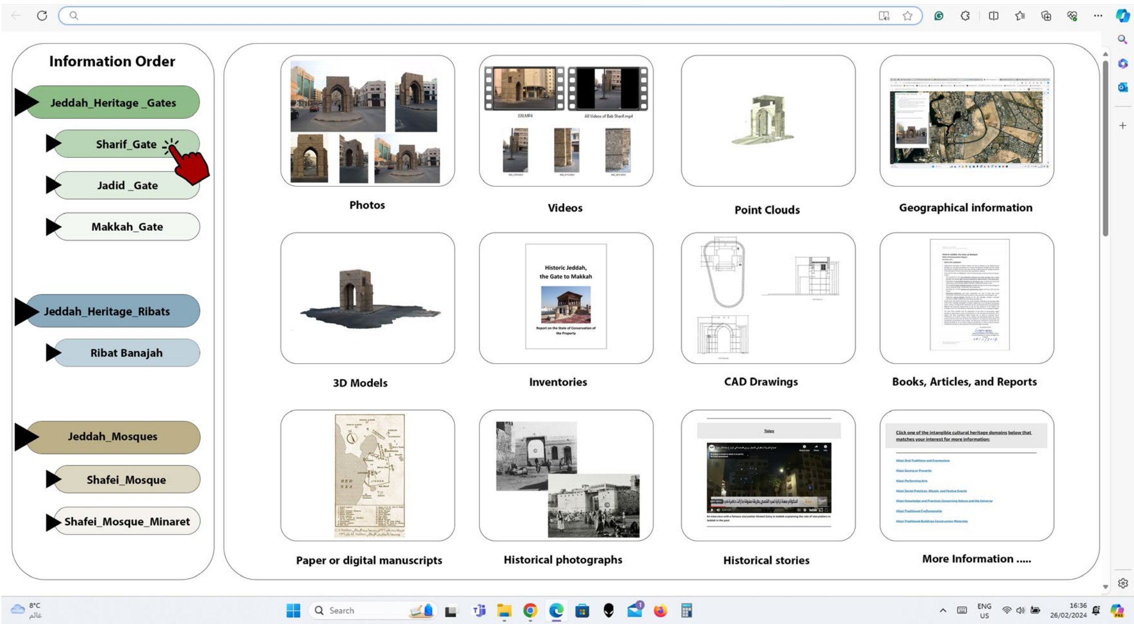


Figure 7. 1: *An early template of an online platform for displaying all the heterogeneous data of heritage buildings.*
(Author, 2024)

7.6. Recommendations for Further Research

This research has aimed to create a holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in the historical city of Jeddah in Saudi Arabia, in order to understand and appreciate the value of heritage buildings, which supports heritage conservation and documentation digitally. Considering the research findings, several recommendations are necessary when conducting replication and reproduction of this research for future studies. These recommendations centre around suggestions for future studies, and technical and usage recommendations explained below.

7.6.1. Future Studies Recommendations

- In light of the promising results of this study, further studies are needed relating to digital documentation of heritage buildings' tangible and intangible information using the recent research in the case of other similar valuable heritage buildings.

-The created system should be applied extensively to digitally document the most tangible and intangible information about heritage buildings in historic Jeddah.

- Current trends in 3D capture are the use of more AI-based applications or platforms and the involvement of citizens. Artificial Intelligence (AI) technologies are the new revolution that helps digitally record, document, model, and conserve heritage buildings. AI applications are important for their ability to develop the conservation system, develop skills, and provide effective and cost-effective restoration methods, guaranteeing the sustainable preservation of heritage sites for future generations (AKYOL et al., 2023, pp. 99-100). For example, Luma, a company specializing in 3D artificial intelligence, created the Luma AI platform to create interactive 3D models that are embeddable and shareable with audiences around the world via the web, iOS, or Android. An interactive scene viewer, meshes, and many other 3D export formats, such as Gaussian Splat PLY files, and Luma Unreal Engine UE files, can be obtained when citizens capture images or videos with their smartphones, digital cameras, or 360 cameras and upload them to the Luma AI platform.

-The neural Radiance Fields (NeRFs) approach is an AI-based technology tool that processes static images into rendered 3D scenes (Müller, 2023). For instance, NVIDIA, a leading company in the field of computing, has developed tools and frameworks and makes them available on its hardware and software platforms for users willing to work with NeRFs-based technologies. NVIDIA launched Instant NeRF software, which is a rendering tool that can transform a group of two-dimensional (2D) images into a realistic 3D scene more detailed and realistic than traditional modelling techniques (Montgomery, 2023; Müller, 2023). Recently, the NeRFs approach has been an emerging tool in the field of cultural heritage (Croce et al., 2023). Based on that, NeRFs can be considered a powerful approach when combined with citizen-science 3D capture in the field of cultural heritage. More scientific research in Saudi Arabia is needed to highlight the potential applications and results of using the NeRFs approach in capturing images and then creating 3D models of historical buildings by the citizens using photogrammetry through either digital cameras or smartphone cameras.

7.6.2. Future Technical Recommendations

- In future research, it can be necessary to cooperate with technical experts skilled in the use of the most recent laser scanning equipment and programs, 3D modelling software, and professional photographers to get better results for the heritage data to be documented.

- As for accurate reconstructions, it is recommended to use artificial targets such as planar targets, spherical targets, and control points, and then attempt to define a coordinate system for acquiring more accurate results.

- Heritage building's digital record data collection, processing, and implementation can be more easily developed if the latest technology is adopted, including drones for data collection in high-altitude buildings, high-speed computers for data processing, and a high-capacity external hard drives and/or digital clouds such as Google Drive to store the data for future dissemination.

-In addition, utilising the latest methods in merging heterogeneous data, such as maps and services, to any application using Feature Manipulation Engine (FME) software to transform data and apply integration capabilities is recommended.

-3D Gaussian Splatting is a cutting-edge computer technique that creates high-accuracy and realistic 3D scenes by using multiple overlapping 2D images of an object from various angles. This technology also has the advantage of being able to quickly provide real-time rendering and the visualization of small details (Chen et al., 2024, p. 1; Basso, 2024, p. 58; Alessio, 2023). 3D Gaussian splatting can be used in generating realistic models of heritage buildings to digitally conserve and visualize for a better understanding of their fine characteristics (Basso, 2024, p. 58; Pixcap, 2024). Therefore, 3D Gaussian Splatting can be considered also an emerging technique in citizen-science 3D capture in the field of cultural heritage. Further scientific research and technical application are required in Saudi Arabia to explore the possible results of using it in comparison to the NeRFs approach for creating 3D models of historical buildings. In addition, the process can be improved by the participation of citizens in collecting and/or analysing the data.

- Lately, Esri, a leading company in GIS software, location intelligence, and mapping, established a new software so-called SURE for ArcGIS (Esri, 2024, Esri 2022). This tool can be used to reconstruct Jeddah city and/or Saudi Arabia aerial mapping by transforming imagery and LIDAR data into point clouds, 3D, meshes, and realistic orthophotos with the participation of citizens either by collecting the data and/or analysing the results.

7.6.3. Future Usage Recommendations

- It is suggested to 3D print the recorded heritage buildings and distribute them as souvenirs for tourists or prizes in local competitions to demonstrate and enhance the region's cultural identity.

- One of the digitally documented elements can also be used as an inspiration source to architects and designers in modern designing, as well as a reference for social, geographical, historical disciplines, etc.

- Heritage building digital records system can enhance community participation in data collection and creation, taking into account the credibility or reliability of this data through adopting the citizen science and the Volunteered Geographic Information method (VGI).

- Regarding the lack of a digital library that documents the Saudi Arabian architectural elements styles, it is recommended that such a digital library of architectural elements be created for the heritage buildings in Jeddah city, which can be developed to build a Jeddah Historic City Information Model (JHCIM) and, eventually, even a Saudi Arabia Countrywide Information Model (SACIM).

- It is also recommended to investigate the digital documentation of the interior spaces and elements of the historical buildings, such as windows, doors, inscriptions, decorations, lighting, furniture…etc.

- Investigating and developing the use of dashboards to fully integrate the heterogeneous information of tangible and intangible data of Jeddah's heritage buildings in a single platform for monitoring the city performance and providing synthetic analysis and visualization of urban data, which can help for future decision-making and enhance information analysis.

- Future work should also focus on creating a virtual environment that can facilitate people's access and interaction with heritage buildings using Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR) methods, and/or Game Engine platforms to raise awareness of cultural heritage in the region.

- Lastly, this research can be taken further by testing the use of integrated methodologies, investigating the benefits, and evaluating the results in practice in educational environments. For instance, at the universities in the departments of architecture, interior design, planning, tourism, and/or archaeology in relation to the digital documentation of heritage buildings and other topics related to the cultural heritage sector.

7.7.Conclusion Remarks

The aim of the present research was to create a holistic digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia. Five historic buildings of Jeddah city were selected to study: Sharif Gate, the Jadid Gate, Makkah Gate, Ribat Banajah, and the Shafei mosque. The study combines findings from secondary resources indicated by documentary research and case study and primary data resources by digital metric survey techniques from fieldwork to contribute to an improved understanding and appreciation of the value of heritage buildings in Saudi Arabia.

People have inhabited the historical area of Jeddah for thousands of years. However, with the urban development, the owners abandoned the buildings within this area. So, these buildings were deteriorated or demolished, either due to lack of attention, erosion factors, or ignorance of their cultural value.

The results of this study demonstrate that several scientific researchers attempted to record some heritage buildings in the Kingdom of Saudi Arabia digitally. A few researchers tried to digitally record architectural elements of heritage buildings in the historic city of Jeddah, such as the Roshan (Wooden window) and discover its details as an essential element in the Hijazi architecture style for digital documentation purposes. Therefore, the findings from this study suggest that due to the increasing interest in recording heritage information internationally and locally, and with technological development, the documentation needs to go further than recording the physical elements in heritage buildings. Recording intangible attributes with tangible elements has become a prerequisite for obtaining a comprehensive recording of heritage buildings to better understand and appreciate their significant values. The experiments in this research confirmed that utilising different digital recording tools was required to capture the tangible elements and intangible attributes of Jeddah's heritage buildings to obtain rich, reliable, and accurate information.

This research explored that to have a holistic digital record that includes tangible and intangible information about heritage buildings, the adoption of the HBIM method was needed to create, document, and manage its heritage information including its geometric and non-geometric attributes and relationships, as well as HGIS method adoption for managing building data to understand the relationships between tangible and intangible information for better understanding and appreciation of the heritage buildings. This study also has shown that the integration between BIM and GIS of the heritage buildings in Jeddah city played an essential role in creating a holistic digital recording system that includes their tangible and intangible data in a map containing layers illustrating the heritage buildings in their exact location linked with their numerical data as well as descriptive, including text, tables, and images through the ArcGIS online website for creating, managing, analysing, sharing, and collaborating on any type of data to improve communication, management, and decision-making.

Creating the Hijazi Region Intangible Cultural Heritage Domains website is an important finding to allow the dissemination of information to be accessed by public users to understand and discover the hidden heritage. Saving the data digitally in the platform storage system is required for future use, such as sharing the data within organizations, specific groups, or everyone by giving access to the digital record to allow specialists or public users to proceed with the processes of updating the created holistic digital record of historical buildings to remain them up to date for sustainable purposes. This research has also shown that the creation of a story map of Jeddah's heritage buildings through ArcGIS StoryMaps, a web-based application, and then publishing it within a unified digital record can provide easy access to expert users to all tangible and intangible information about Jeddah's heritage buildings via a URL link that can illustrate the story using smartphone applications, which can help digitally visualize building elements and understand their relationship with surrounding buildings, streets, sidewalks…etc. This study indicates that the creation of several layers of Jeddah's heritage buildings in the ArcGIS online website, identifying their exact locations on the map, including their tangible and intangible information as pop-ups including texts, images, and hyperlinks, is a comprehensive approach that allows a better understanding of the sites for future management and decision-making for professional users.

These findings led to the creation of a framework for the digital record system of heritage buildings. This framework contributes to improving the recording process for the creation of a holistic digital record of heritage buildings of the Kingdom of Saudi Arabia by integrating information about their intangible and tangible heritage to conserve and promote them locally and internationally in a digital format; various systems were employed to achieve this integration. The results from that research helped improve the understanding and appreciation of the values of heritage buildings by disseminating the information through digital platforms, which can help increase public engagement in future.

The creation of the holistic digital record system and the resulting published information highlights the essential research needed regarding technology practical application and system accuracy between HBIM systems and GIS systems and developing training skills strategies in using technical tools, data accessibility, acquisition, and processing, and stakeholder interactions with platforms for digital documentation and dissemination, and future management and decision-making. It is time to shed light on the ability of including cutting-edge systems and technologies such as City Information Modelling systems (CIMs) and/or Digital Twins in the holistic digital record system and examine the effectiveness of integrating heterogeneous information systems, and technologies for future development.

Appendices

Appendix A: A Plan of the Historical Jeddah-City Map / Jeddah Municipality

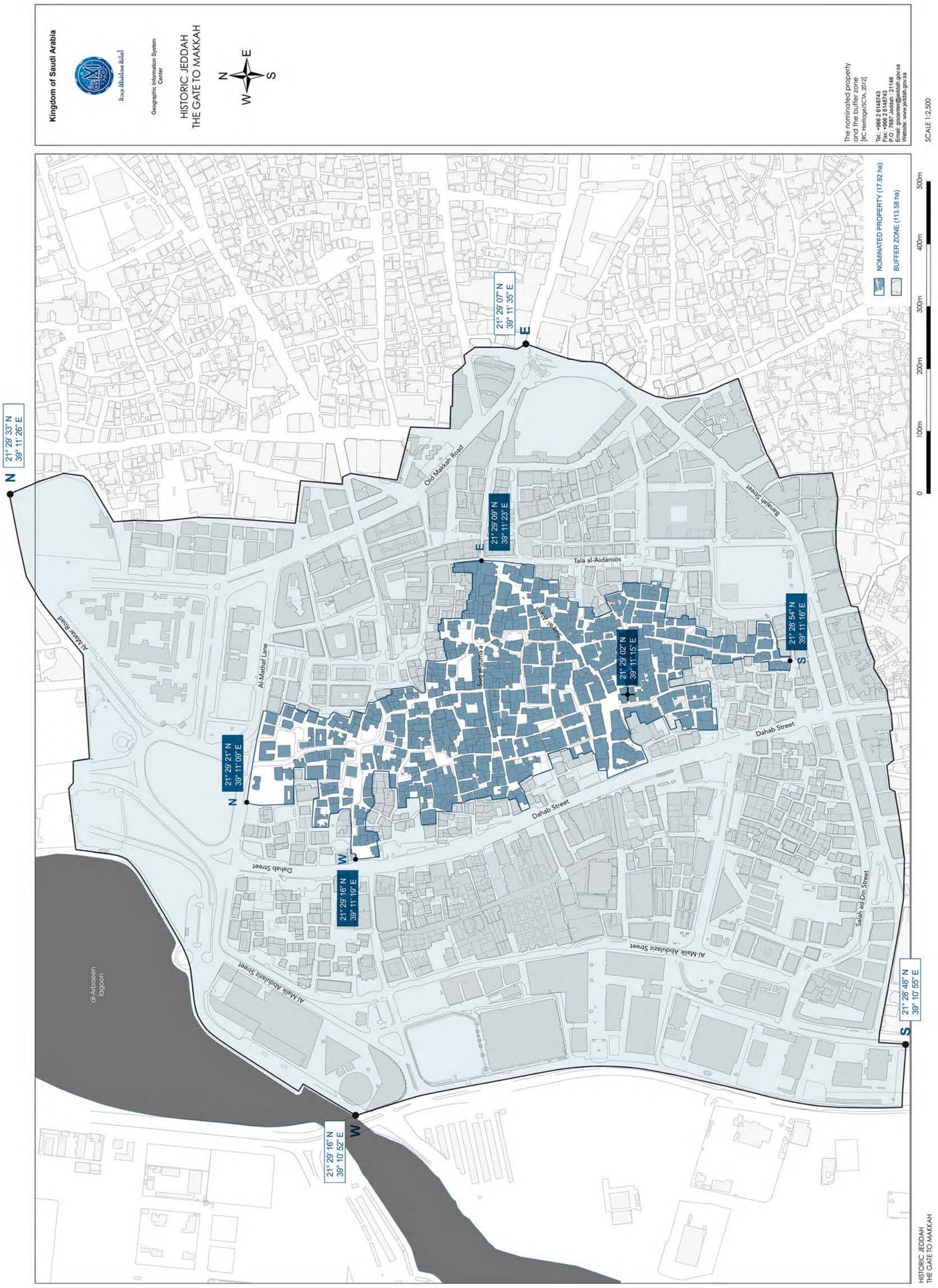


Figure A.1: *A Plan of the Historical Jeddah-City map.*

Appendix B: Approved Balad Map-Model / King Abdulaziz University

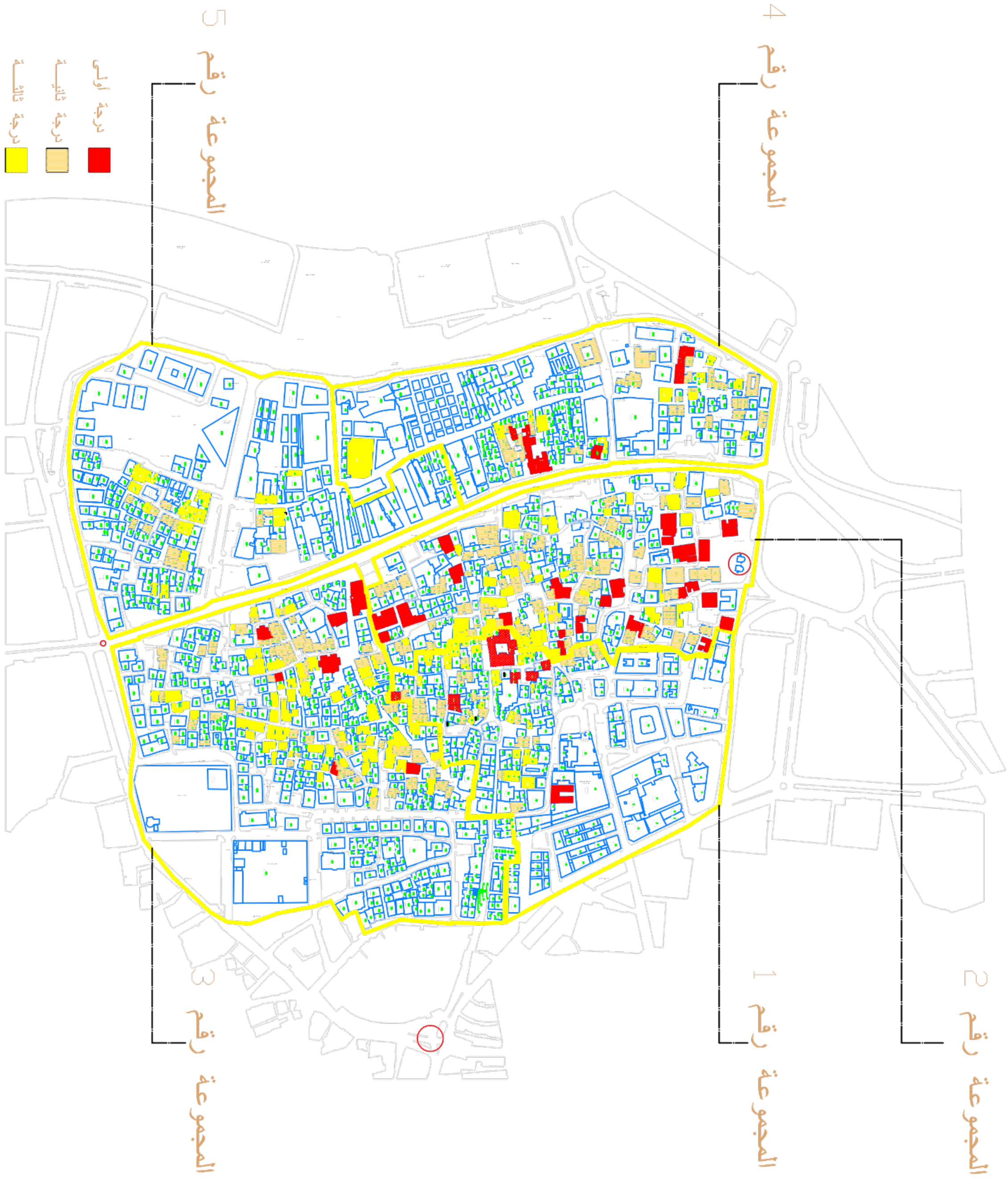


Figure B.1: *Approved Balad map-model.*

Appendix C: The Sharif Gate's 2D AutoCAD Plans, Elevations, and Sections of / King Abdulaziz University

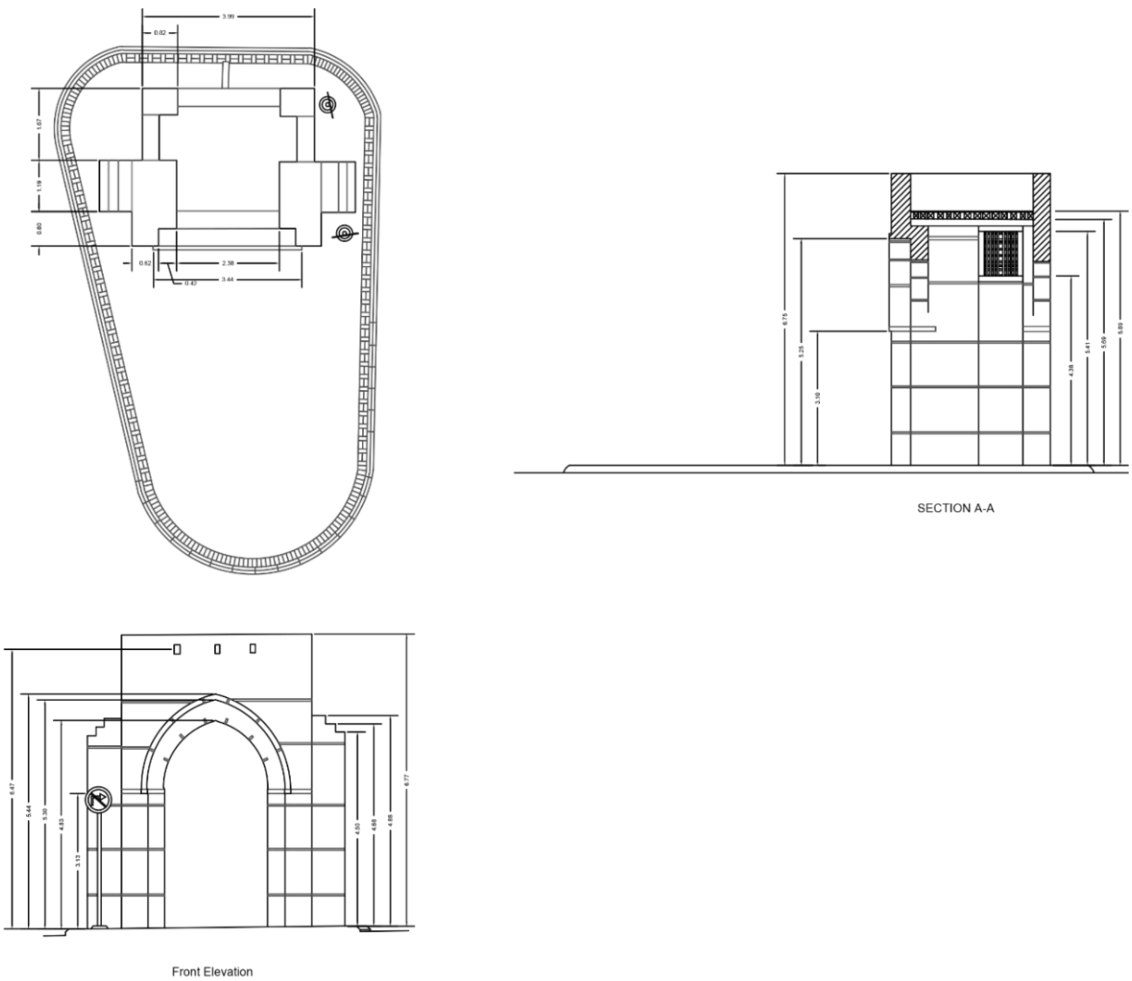
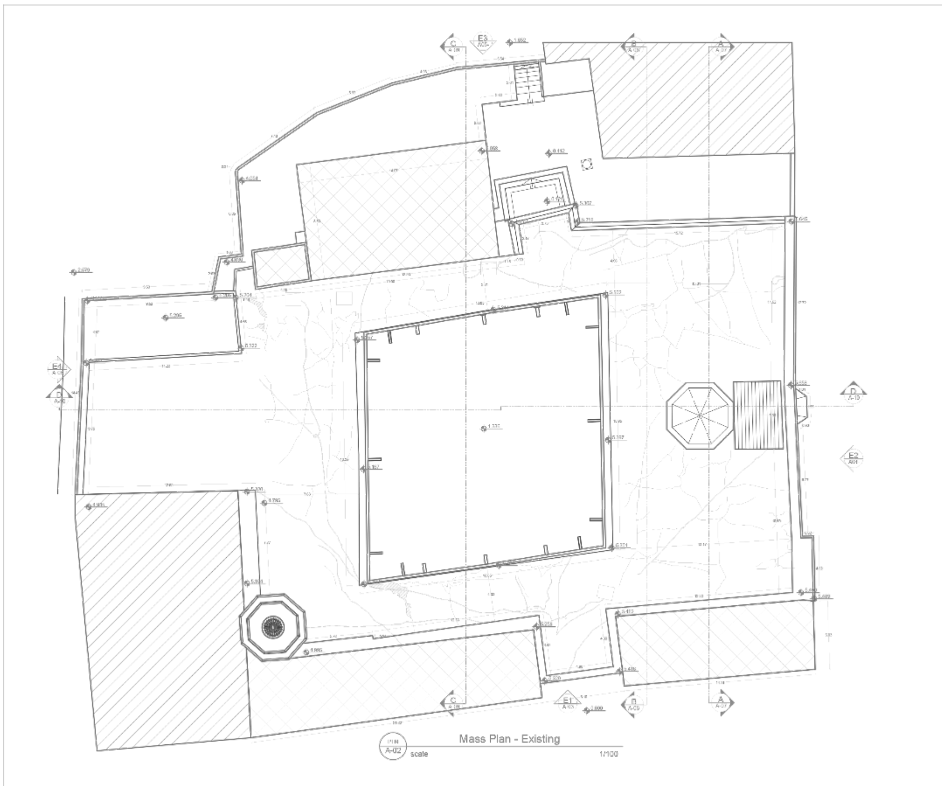


Figure C.1: *The Sharif Gate's 2D AutoCAD plans, elevations, and sections.*

Appendix D: The Shafei Mosque's 2D AutoCAD Plans, Elevations, and Sections / King Abdulaziz University



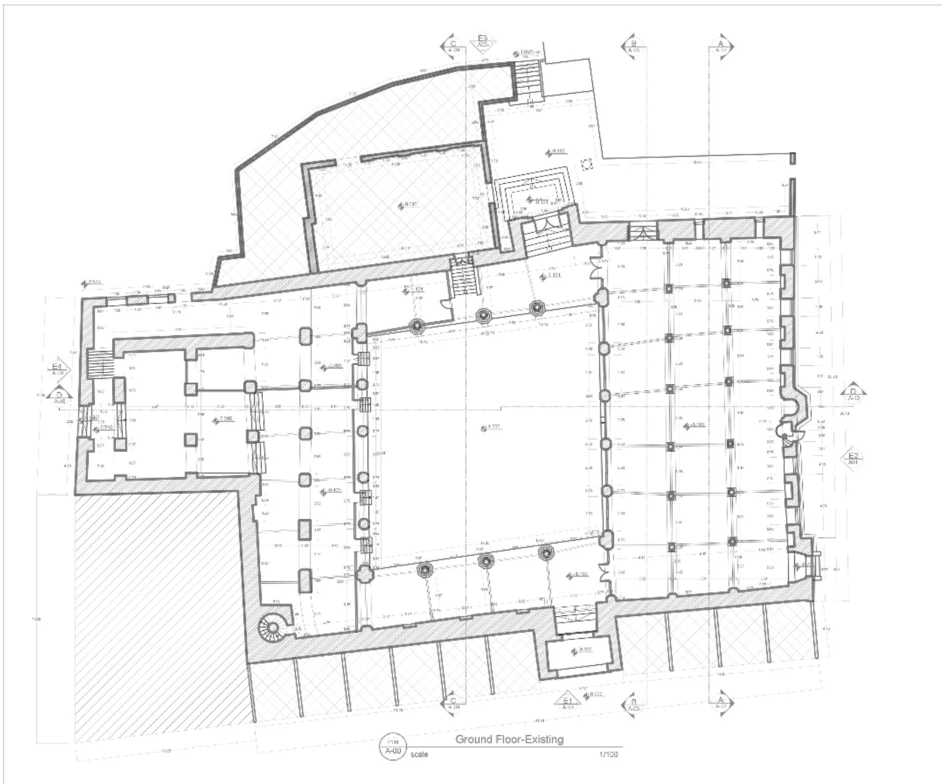


Figure D.1: *The Shafei mosque's 2D AutoCAD plans.*

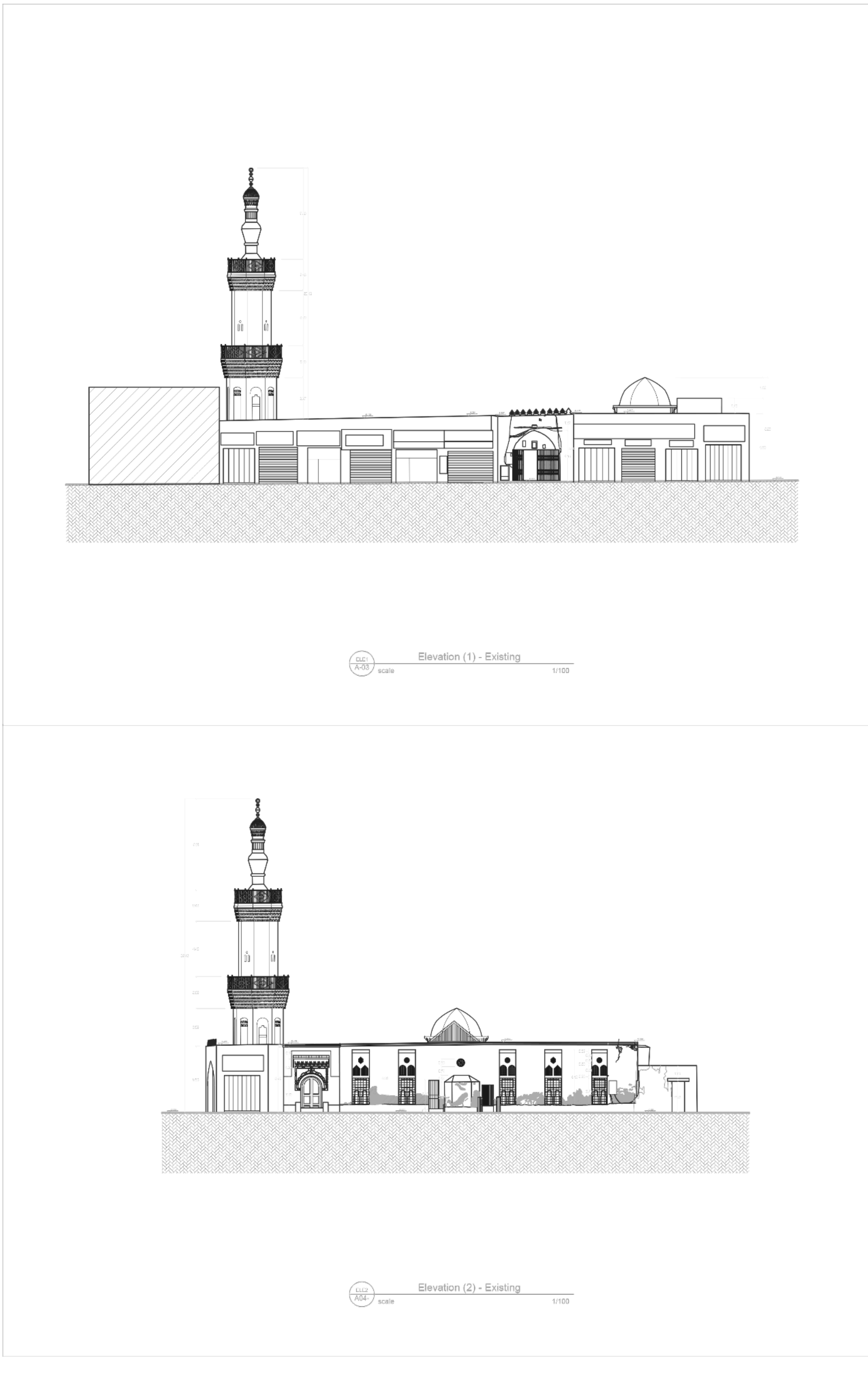


Figure D.2: *The Shafei mosque's 2D AutoCAD elevations.*

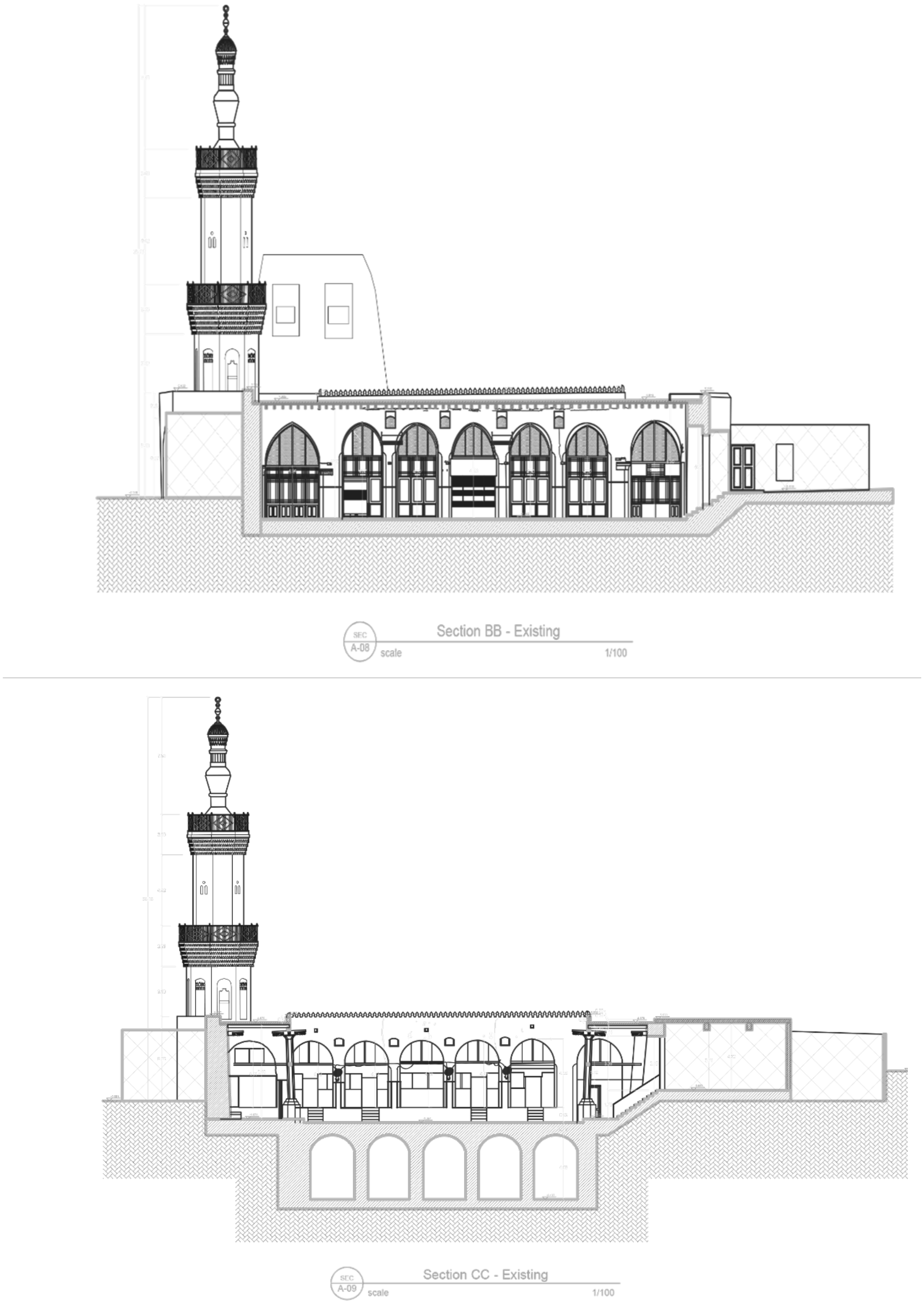


Figure D.3: *The Shafei mosque's 2D AutoCAD sections.*

Appendix E: Historical Jeddah 2D AutoCAD Coordinates with Contour Lines Submitted/ King Abdulaziz University- Sourced from Masaken Engineering Consulting Office.

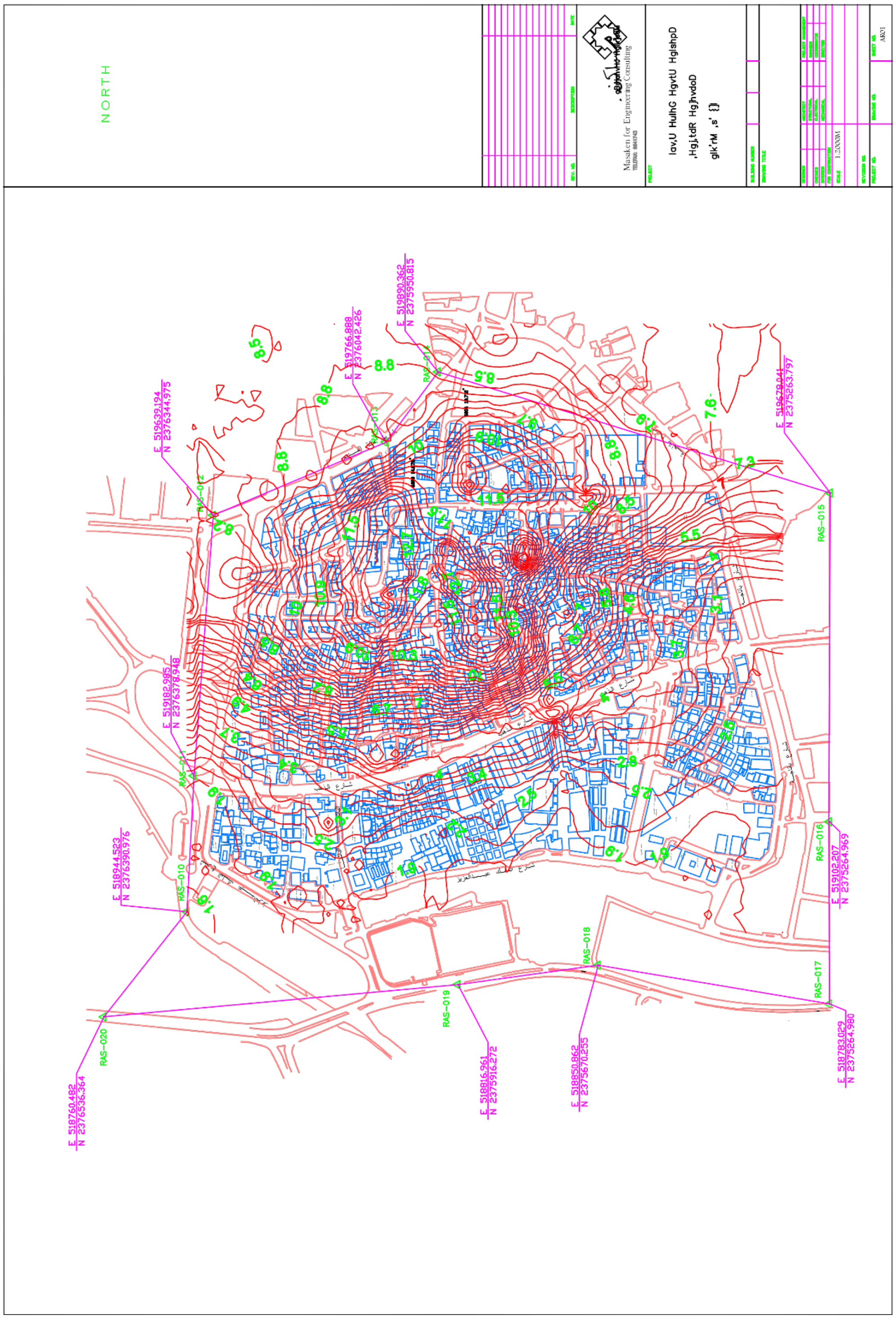


Figure E.1: *Historical Jeddah 2D AutoCAD coordinates with contour lines submitted / King Abdulaziz University- Sourced from Masaken Engineering Consulting Office.*

Appendix F: Georeferenced Points Clouds of Five Heritage Buildings/ King Abdulaziz University

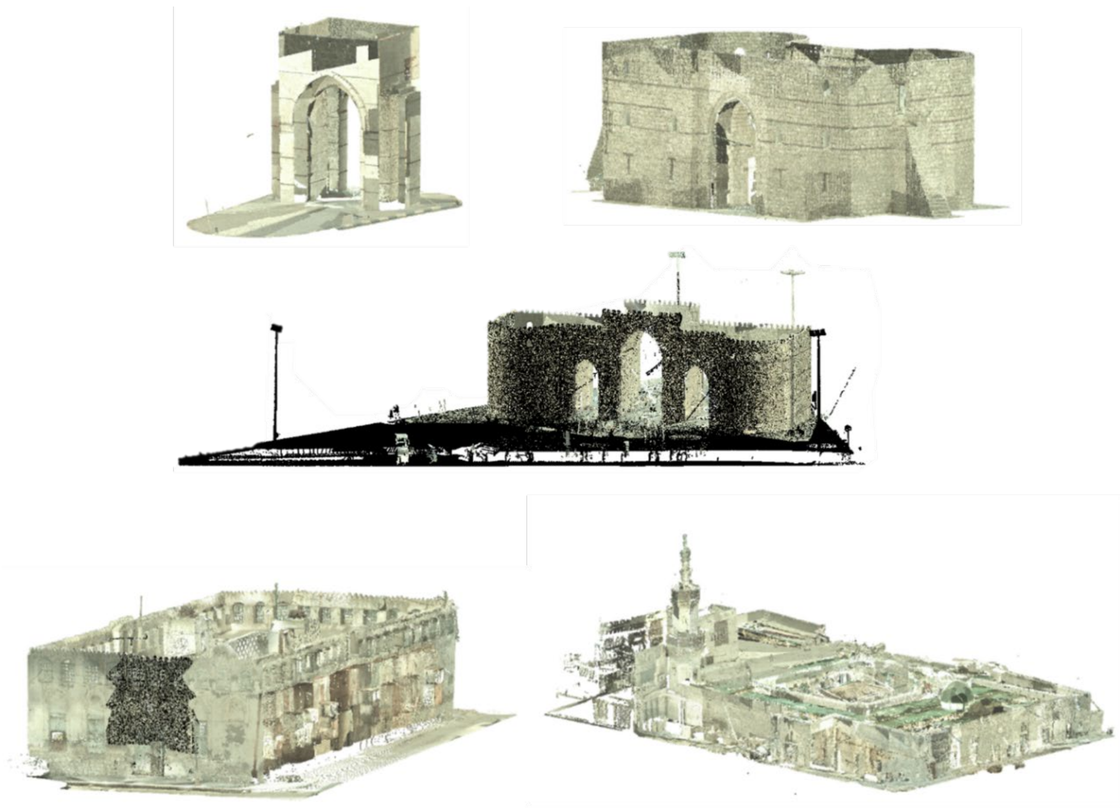


Figure F.1: *Georeferenced points clouds of five heritage buildings.*

Appendix G: Some of the Author Extensive Experiments in Photogrammetry

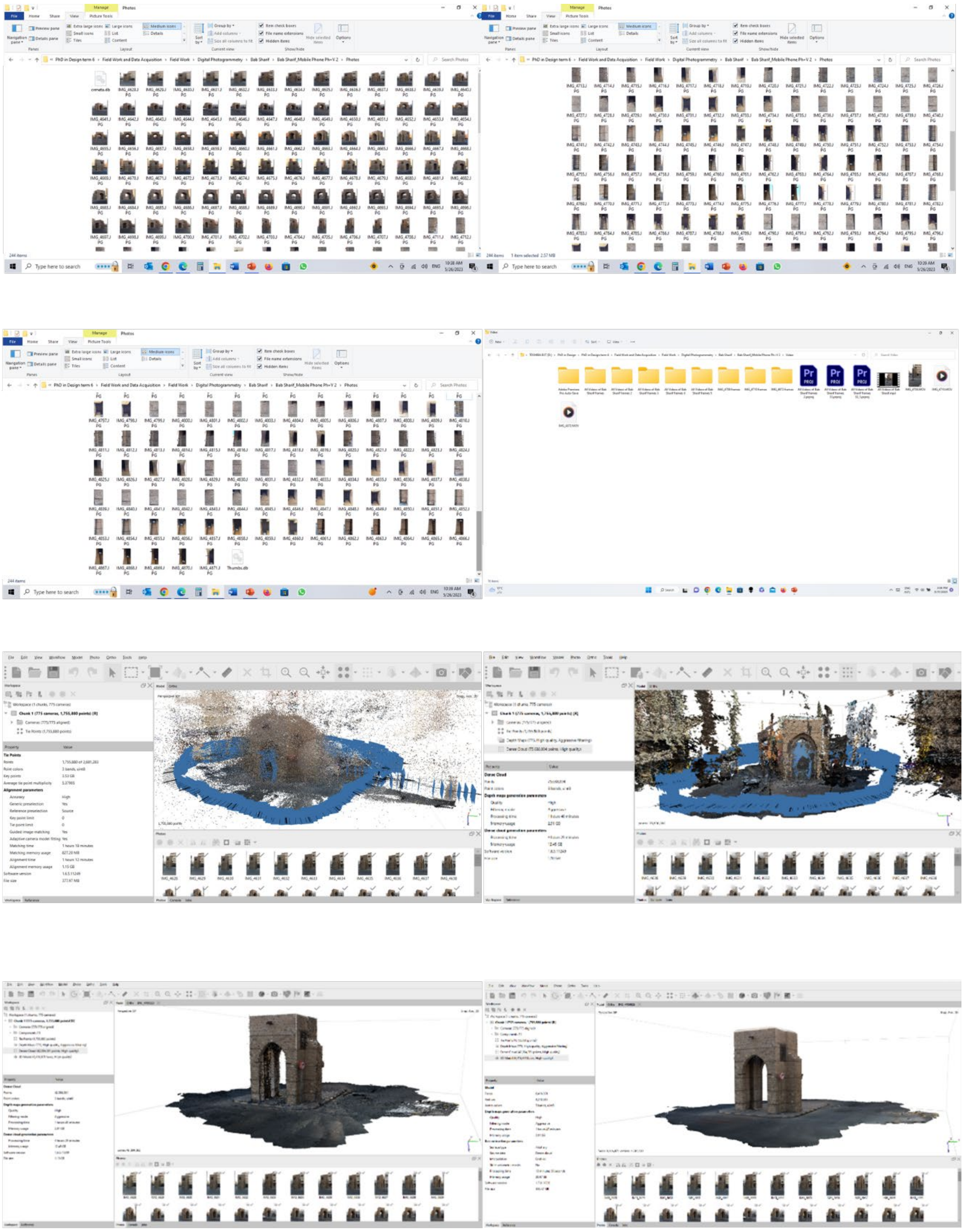


Figure G.1: *Acquired sequential photos and videos and processing examples of Sharif Gate.*

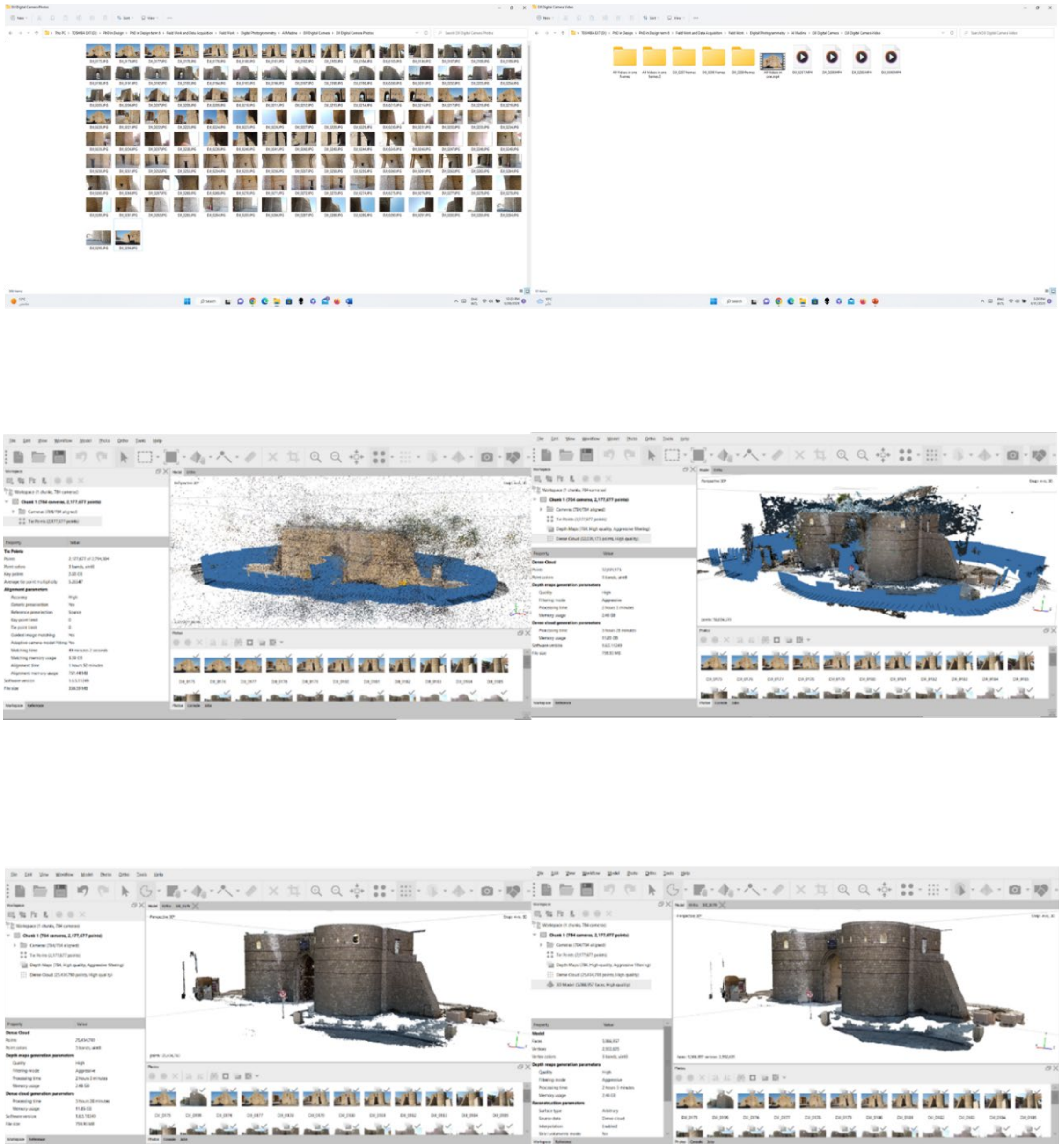


Figure G.2: *Acquired sequential photos and videos and processing examples of the Jadid Gate.*

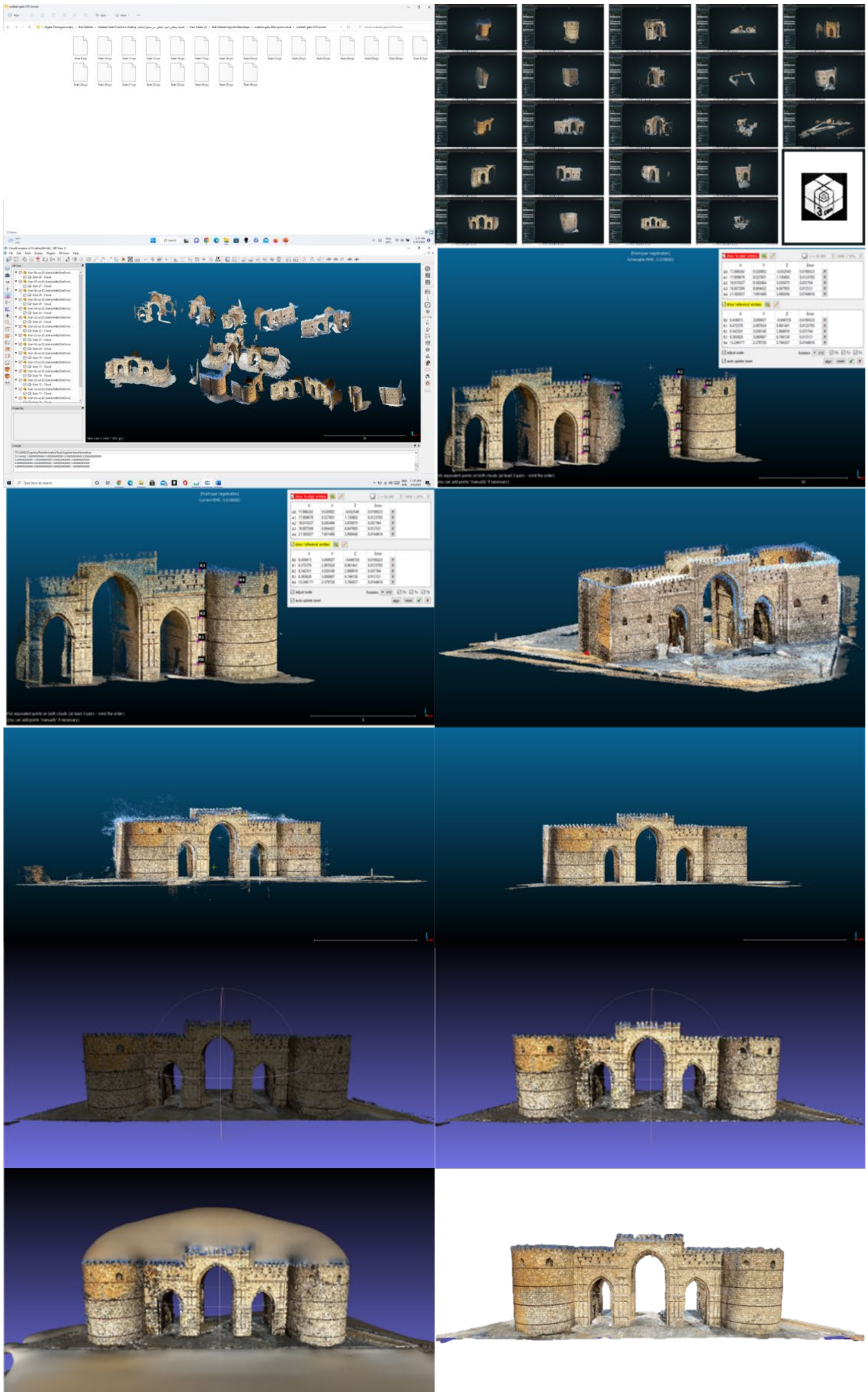


Figure G.3: *Acquired sequential photos and videos and processing examples of Makkah Gate.*

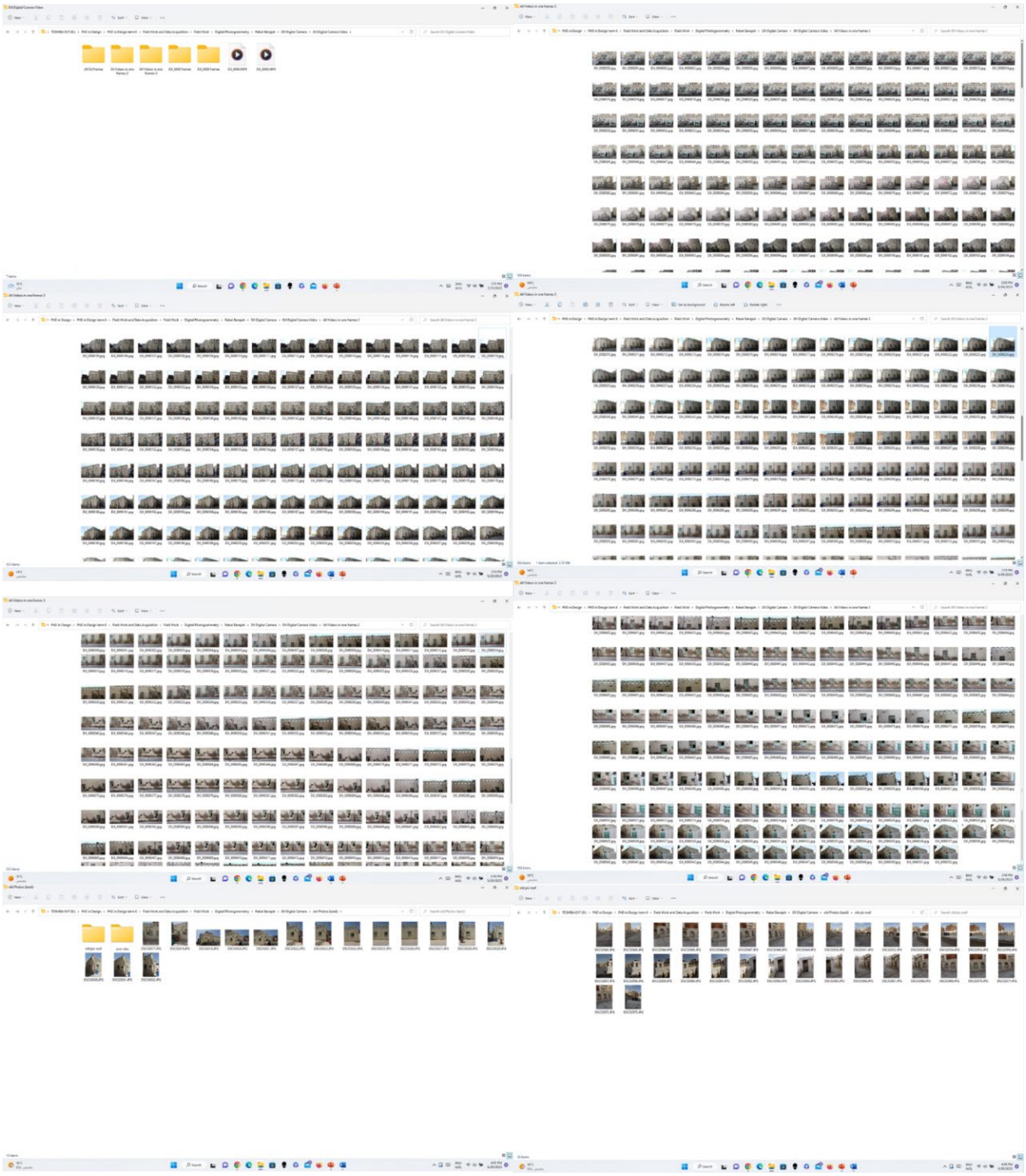


Figure G.4: *Acquired sequential photos and videos of Ribat Banajah.*

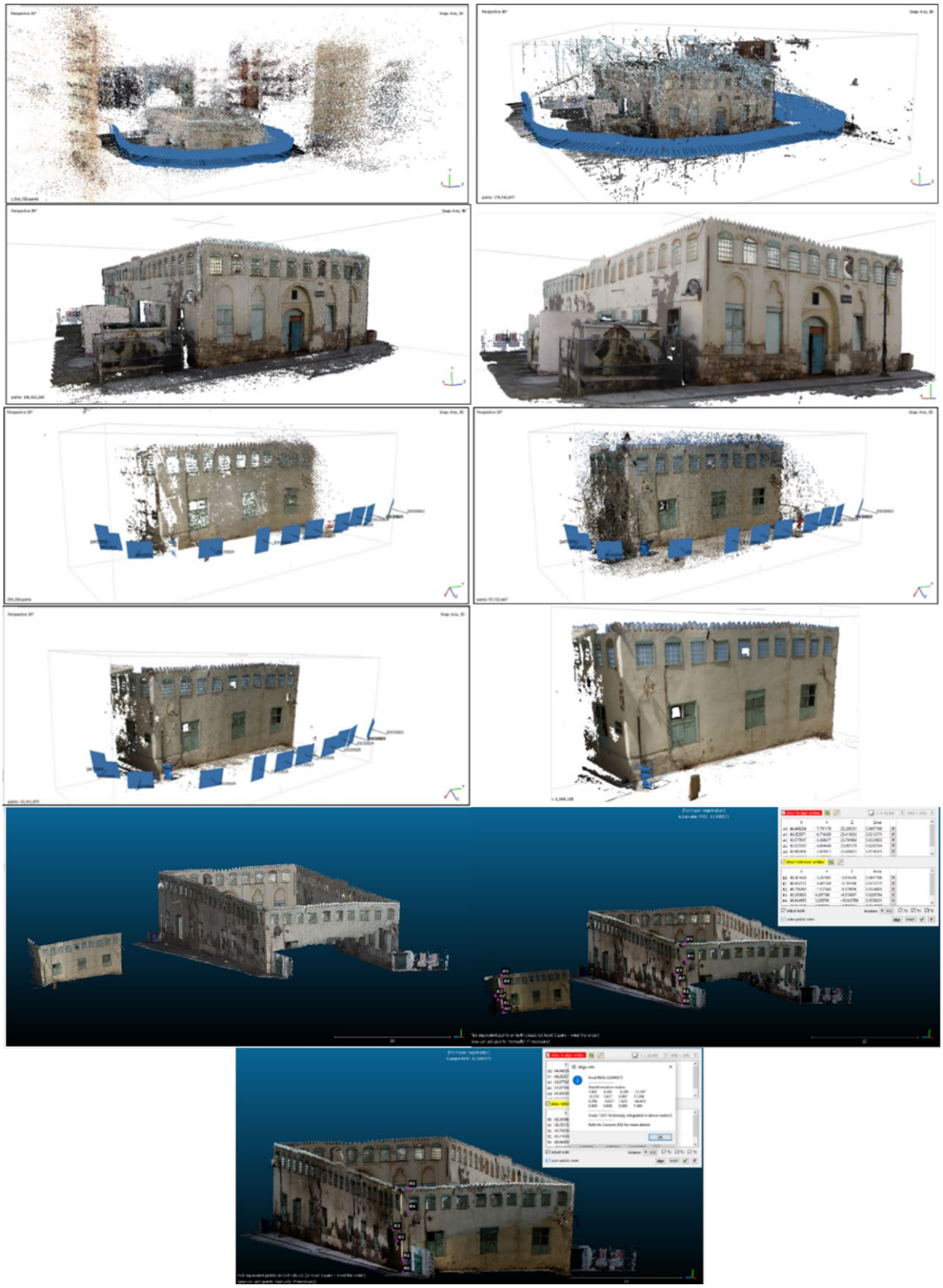


Figure G.5: *The processing examples of Ribat Banajah.*

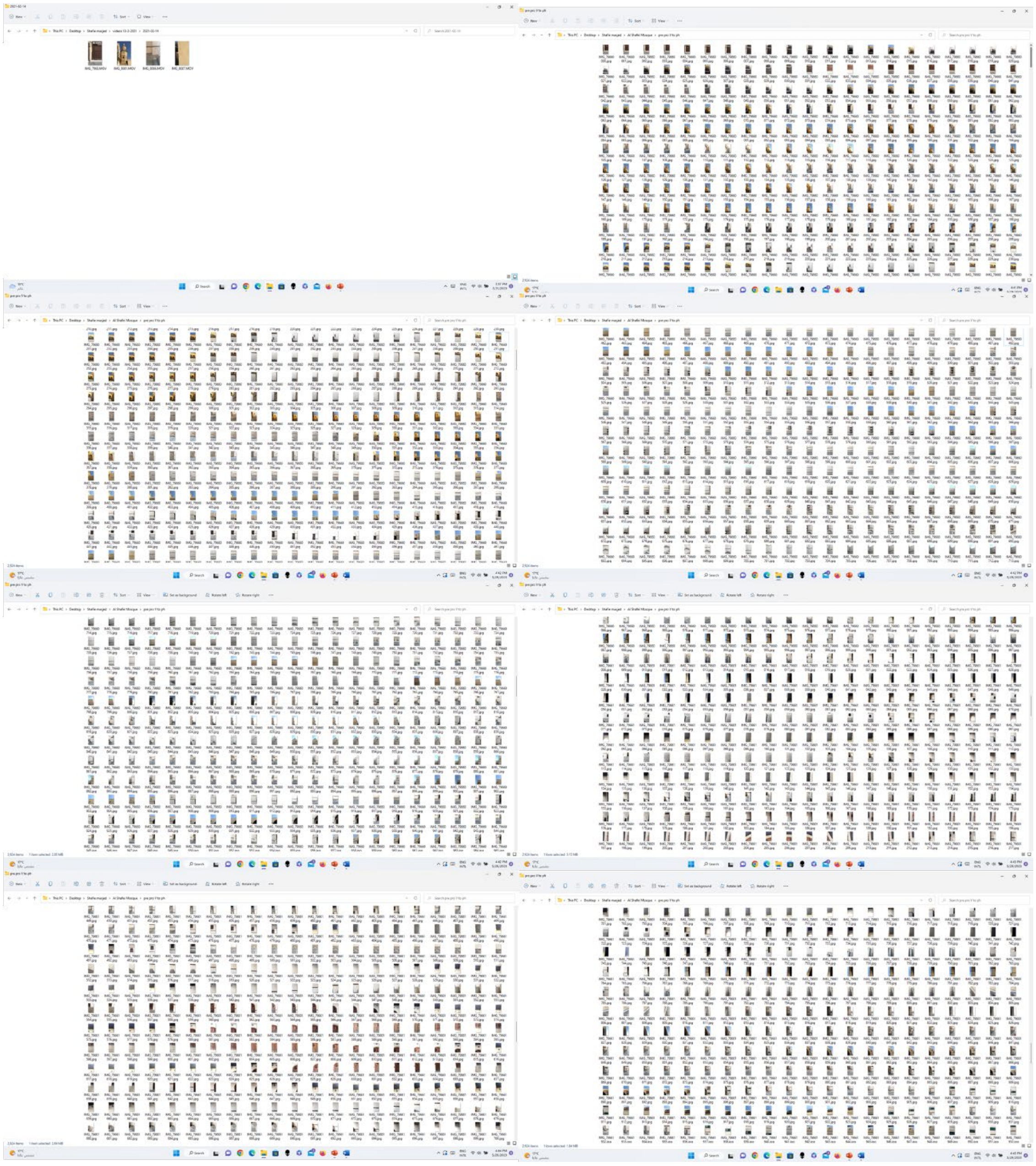


Figure G.6: *Acquired sequential photos and videos of the Shafei mosque.*

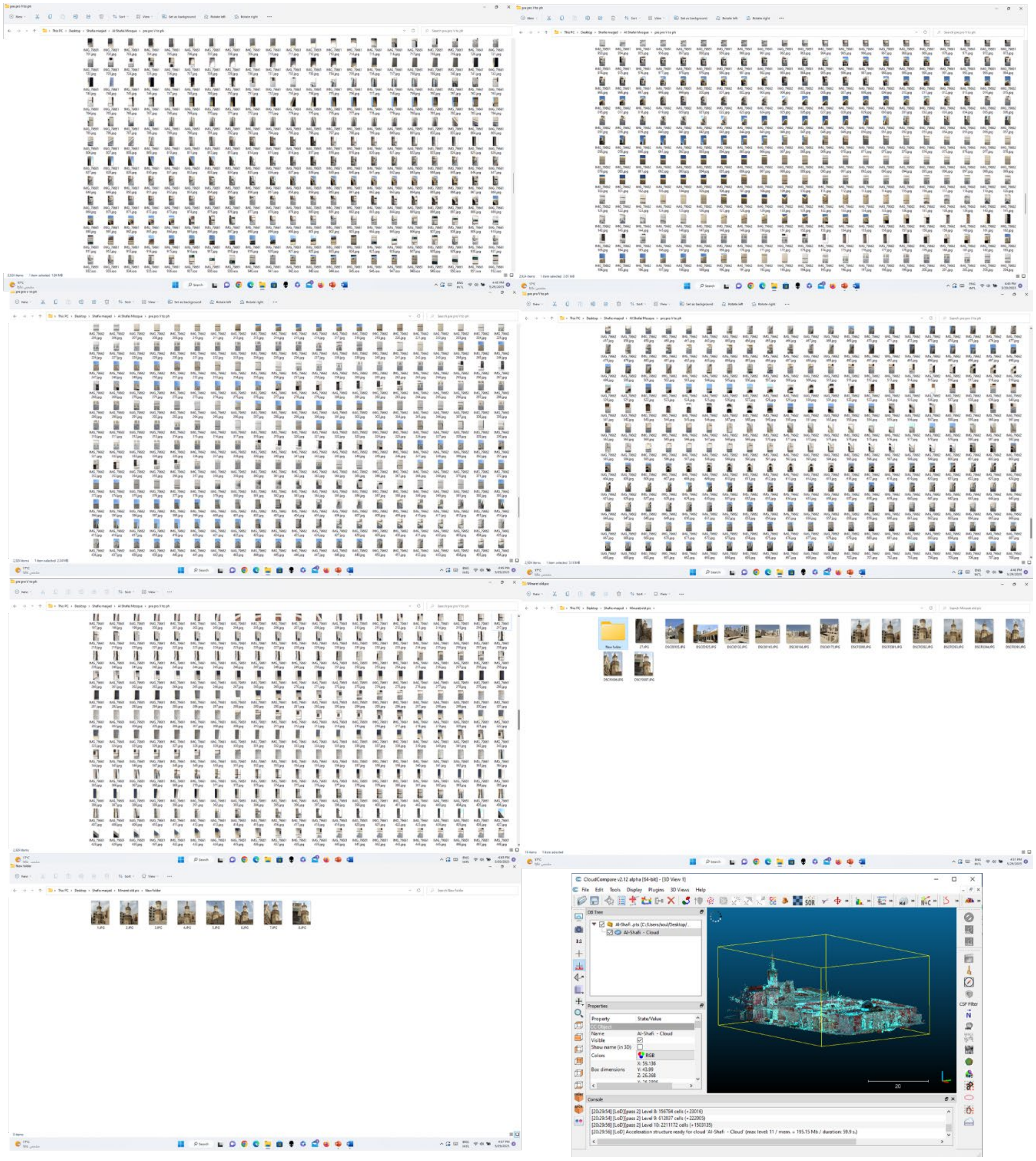


Figure G.7: *Acquired sequential photos, videos, and points cloud of the Shafei mosque.*

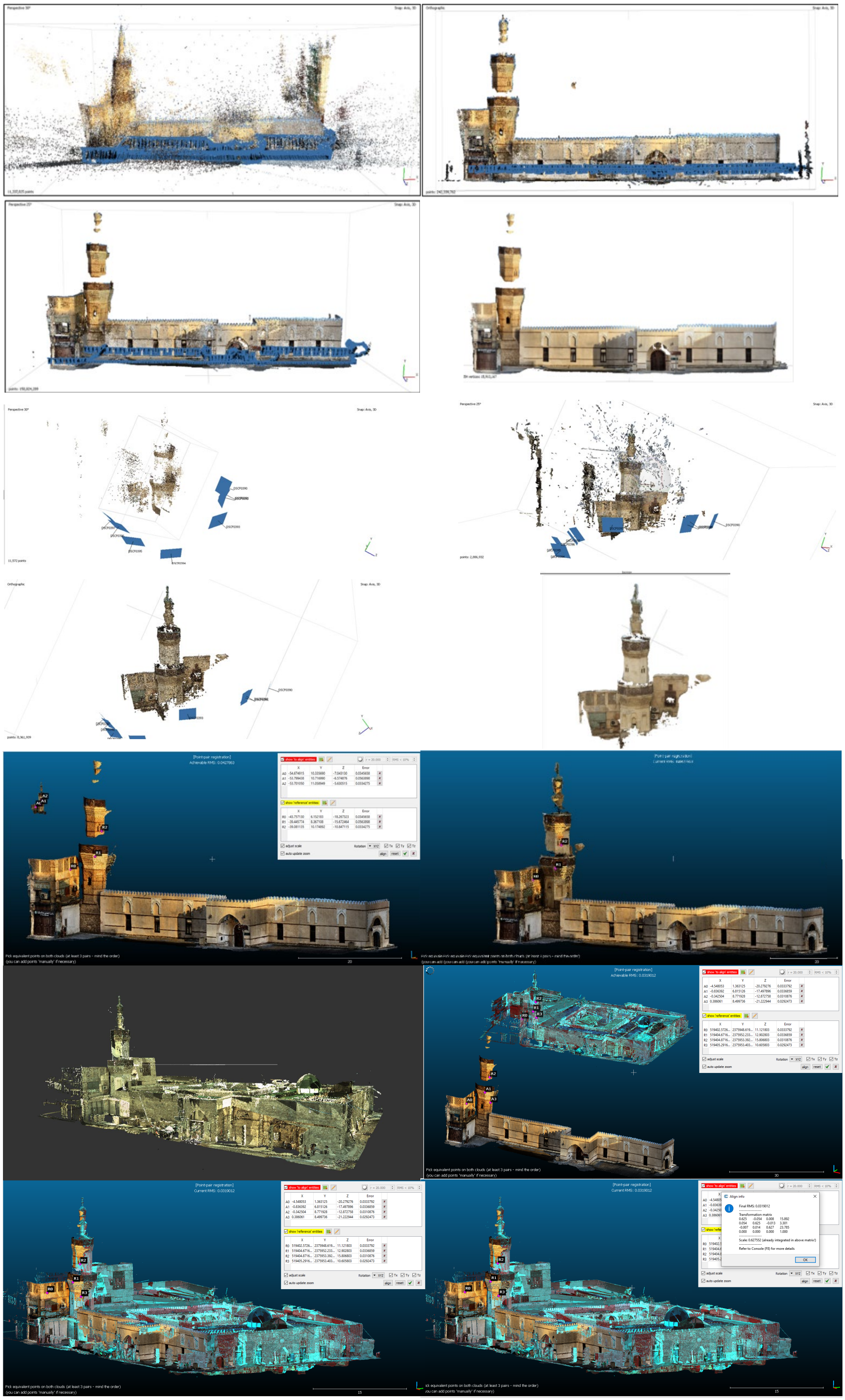


Figure G.8: *The processing examples of the Shafei mosque.*

Appendix H: The Range of Experiments of Heritage Buildings Recordings

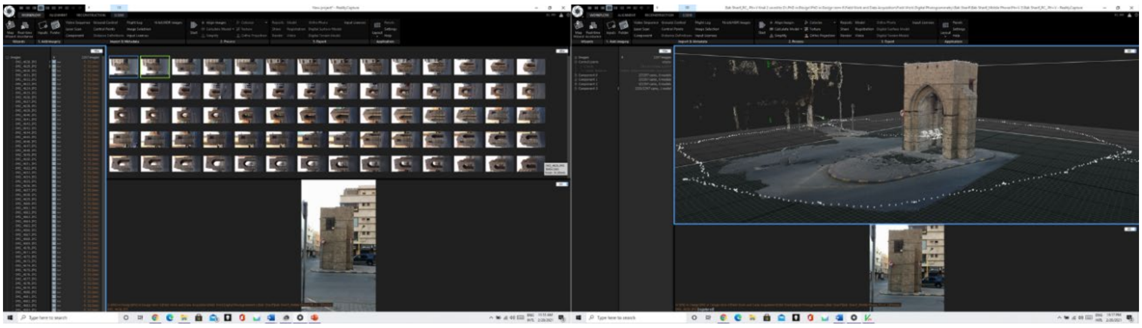


Figure H.1: *Experiment of Jadid Gate at RealityCapture software.*

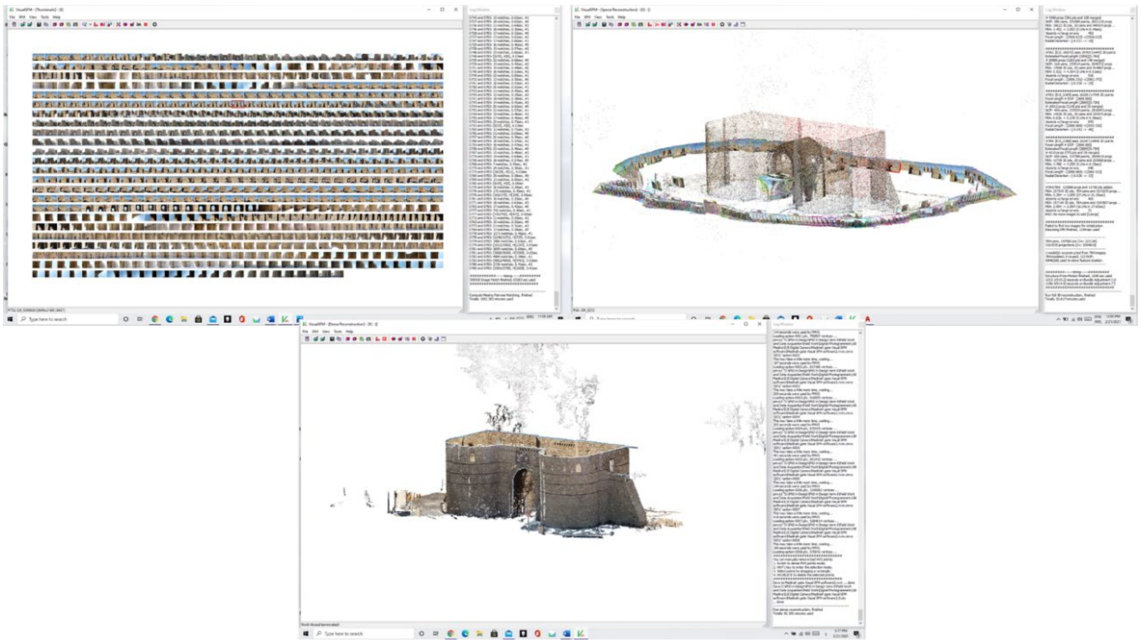


Figure H.2: *Experiment of Jadid Gate at Visual SFM software.*

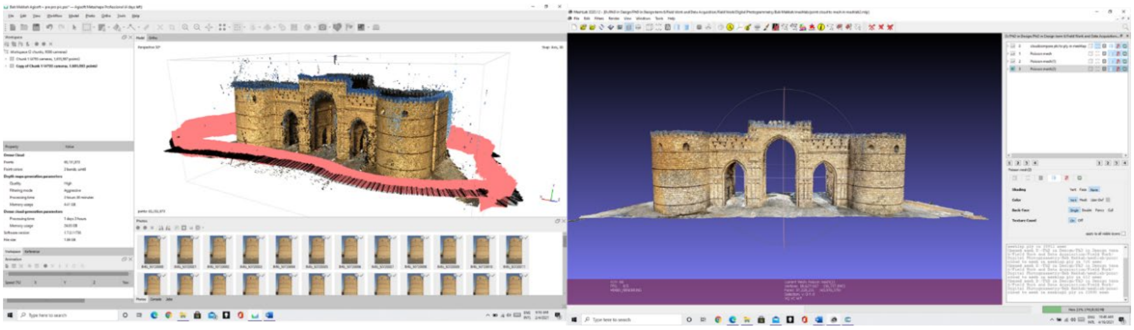


Figure H.3: *Experiment of Makkah Gate at Agisoft Metashape (Left) and MeshLab (Right) software.*

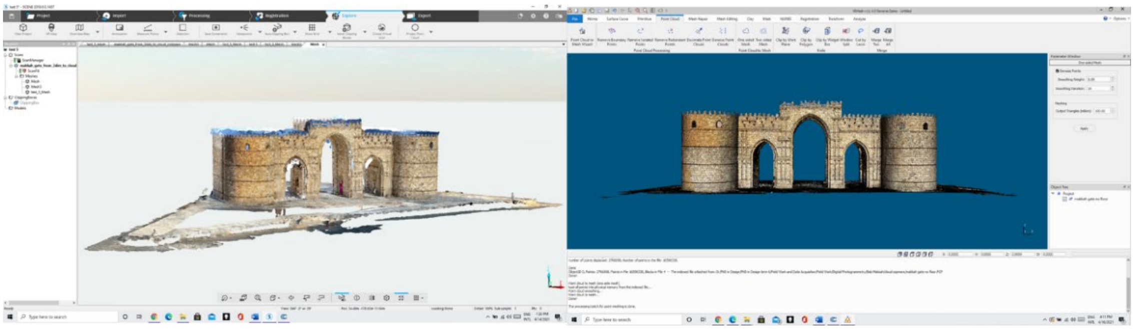


Figure H.4: *Experiment of Makkah Gate at Scene (Left) and VRMesh software (Right).*

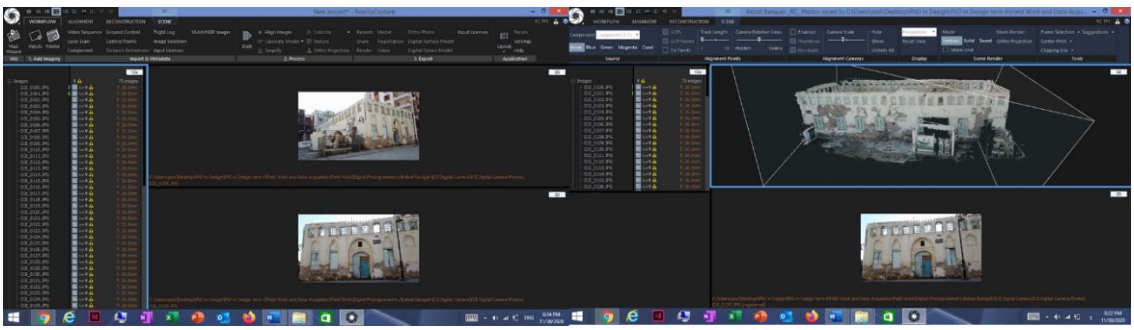


Figure H.5: *Experiment of Ribat Banajah at RealityCapture software.*

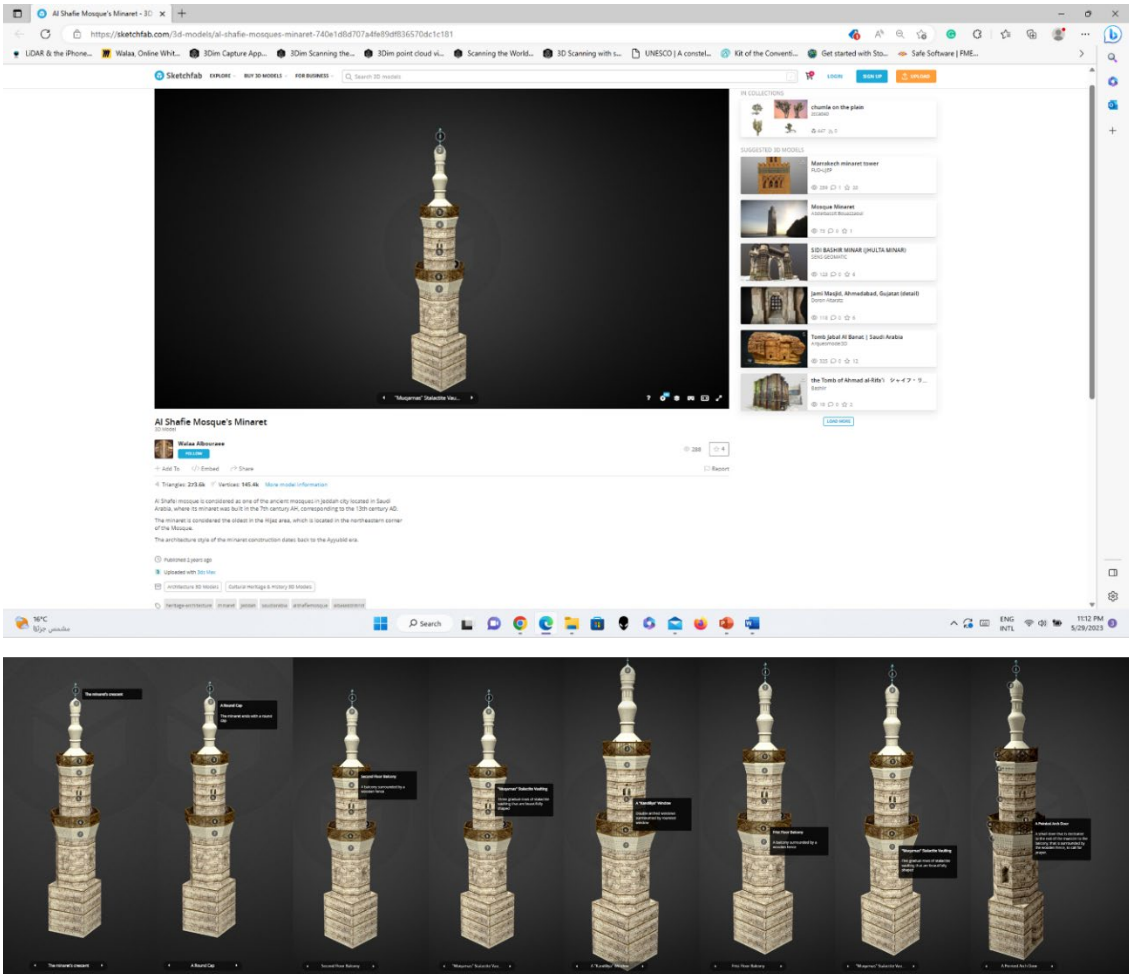


Figure H.6: *Experiment of the Shafei mosque's minaret at Sketchfab software (top) and the pop-up information (bottom).*

Appendix I: Ethics Application Form for Staff and PhD Students

Lancaster University

Faculty of Arts and Social Sciences and Management School Research Ethics Committee (FASS-LUMS REC)

ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

Instructions: Before completing this application form please read the instructions and questions on the ethics webpage under the heading: **'What level of review is required for my project?'**
Please also refer to NOTES in this form for guidance.

SECTION ONE [Must be completed by all applicants]

Project Details	Answer
Name of applicant/researcher	Walaa Taha A Albouraee
Title of Project: Note 1	A Digital Record System to Integrate Tangible and Intangible Information for Heritage Buildings in Saudi Arabia
Department	Lancaster Institute for the Contemporary Arts
Appointment/position held by applicant within FASS or LUMS	PhD Student
ACP ID Number (if applicable)	
Funding source (if applicable)	Royal Embassy of Saudi Arabia Cultural Bureau- Scholarship Holder Sponsored by the Government of the Kingdom of Saudi Arabia
Grant Code (if applicable)	

NOTE
[1] Make your title short and descriptive so that people can easily identify the main topic of the research. The title of your project does not need to be the same as the title you propose to use for your publication (e.g. your thesis).

Type of study

☒ Involves existing documents/data only or the evaluation of an existing project with no direct contact with human participants. **Complete sections one, two and four of this form**

☐ Includes direct involvement by human subjects (including but not limited to interviews, completing questionnaires, social media and other internet based research). **Complete sections one, three and four of this form.**

Contact details

1. Contact information for applicant:
   E-mail: w.albouraee@lancaster.ac.uk
   Telephone: 07366564667 (please give a number on which you can be contacted at short notice)
   Lancaster University Address: LICA Building, Bailrigg, Lancaster, UK, LA1 4YD
2. Names and appointments/position of all members of the research team:

Name of research team	Appointment/position
Walaa Taha A Albouraee	PhD Student

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ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

PhD Students

Complete this section if this is a PhD student project

3. Project supervisor(s) names: Prof. Stuart Walker and Dr. Paul Cureton.

SECTION TWO

Complete this section if your project involves existing data only, or the evaluation of an existing project with no direct contact with human participants

1. Anticipated project dates (month and year) Note 2
   Start date: 01-05-2020 **End date:** 30-09-2021

   NOTE
   [2] These dates should indicate when you wish to begin your project (taking into account the timescale of the ethical approval process) and when funding ends or your thesis will be submitted.

2. Please state the aims and objectives of the project (no more than 150 words, in lay-person's language) Note 3:

   The aim of this research is to support the direction of the Kingdom of Saudi Arabia's vision 2030 in developing recording and scientific research in the field of national heritage. So, an approach for creating a digital record system that integrates information about the tangible (physical: dimensions, materials) and intangible (cultural: methods, skills, history) aspects of heritage buildings in Saudi Arabia will be created in this research.

   The research objectives are:

   1- Determine what type of information will be included in the digital record and why.
   2- Identify the most appropriate recording method to capture information of a heritage building.
   3- Understanding of the relationships between tangible and intangible information.
   4- Establish the most effective method of integrating tangible and intangible information.
   5- Verify the effectiveness of the integration of information, and for whom.

   NOTE
   [3]This summary should concisely but clearly tell the reviewer (in simple terms and in a way which would be understandable to a general audience) what you are broadly planning to do in your study.

3. Please describe briefly the data or records to be studied, or the evaluation to be undertaken.

   The data and records to be studied in this research are a combination of technical and non-technical information including:

   a. ***Point cloud*** digital data of a heritage building which will serve as the fundamental basis and reference to facilitate the creation of a digital geometric 3D model.
   b. ***Images*** of a heritage building which can be used to add photorealistic textures and colours to the digital geometric 3D model.

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c. ***Global Positioning System (GPS)*** data of a heritage building which can be used for identifying and positioning the heritage building coordinates.

d. ***Inventories*** from government institutions which can provide a list of information about architectural elements such as doors, windows, ceilings, floors, walls, stairs etc…

e. ***Previous studies*** of other authors who have written on a similar subject (i.e. secondary data).

f. ***Historical records*** such as papers or digital manuscripts to identify components names and functions, historical photographs to identify the forms and/or historical stories for establishing the cultural, historical and architectural value, style, age and significance of the historical building and/or its elements.

4. How will any data or records be obtained?

The data and records will be obtained using technical and non-technical data acquisition including:

1- Obtaining records by technical means:

a. ***Laser scanner*** to provide point cloud data.

b. ***Digital photogrammetry*** to provide images.

c. ***Total Stations Technique*** (TST) integrated with the ***Global Navigation Satellite System*** (GNSS) to provide coordinates of a heritage building.

2- Obtaining data by non-technical means:

a. ***Inventories*** will be obtained from Government institutions such as King Abdulaziz University, Jeddah Municipality, and/or Saudi Geological Survey through the researcher personal contacts.

b. ***Surveying the literature*** will focus on previous studies and publically available documents, including books, articles, journals, conference studies, government reports etc… through digital or non-digital databases research.

c. ***Historical records*** will be obtained from local studies libraries including papers or digital manuscripts, historical photographs and/or historical stories through digital or non-digital libraries databases research.

5. Confidentiality and Anonymity
If your study involves re-analysis and potential publication of existing data but which was gathered as part of a previous project, conducted by another individual or collective, involving direct contact with human beings, how will you ensure that your re-analysis of this data maintains confidentiality and anonymity as guaranteed in the original study?
Not applicable.

6. What plan is in place for the storage of data (electronic, digital, paper, etc)? Note 4
Data will be stored on encrypted as well as password protected computers and servers that are accessed only by the researcher. In addition, data will be stored securely in Lancaster's University online encrypted system (OneDrive) throughout the research process. If the researcher works away from the university, data will be stored in the LU server (OneDrive) to securely sharing the data between the researcher and supervisors as well as to securely transferring data to the LU campus for longer term storage.

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ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

Please ensure that your plans comply with the General Data Protection Regulation (GDPR) and the UK Data Protection Act 2018 .

NOTE

[4] State clearly where and in what format your data will be stored.

Timescales: The standard guidance we provide to people about length of time for retaining data is for a minimum of 10 years. This is not a requirement but a general recommendation. Your study may have a rationale for retaining data longer, but if so, please explain. Where electronic data is to be stored for longer than the recommended period, we recommend storing data on University storage. If data is collected or stored by own devices they need to be encrypted. For data sharing with external partners we recommend using Box.

Data security: Data stored on all portable devices (eg laptops) should be encrypted as well as password protected; data stored on the University server does not, however, need to be encrypted. If you are based and work predominantly away from the University, give consideration to how you will store the data securely as you undertake your research, and how it will be securely transferred to the LU campus for longer term storage.

7. What are the plans for dissemination of findings from the research? Note 5

Dissemination of the research findings will be done for academic and educational purposes, where they will be disseminated in the PhD thesis, reports, journal articles, conference presentations, and websites which can be accessible by public users to interact with the it.

NOTE

[5] Dissemination covers a wide range of activities including (but not limited to) reports, academic submissions (such as theses and journal articles), newspaper articles, etc.

8a. Is the secondary data you will be using in the public domain?

Yes.

8b. If NO, please indicate the original purpose for which the data was collected, and comment on whether consent was gathered for additional later use of the data.

9. What other ethical considerations (if any), not previously noted on this application, do you think there are in the proposed study? How will these issues be addressed?

None.

10a. Will you be gathering data from discussion forums, on-line 'chat-rooms' and similar online spaces where privacy and anonymity are contention?

No.

10b. If yes, your project requires full ethics review. Please complete Sections 1, 3 and 4.

SECTION THREE

Error! Reference source not found.**Complete this section if your project includes direct involvement by human subjects**

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Lancaster University

Faculty of Arts and Social Sciences and Management School Research Ethics Committee (FASS-LUMS REC)

ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

NOTE:
In addition to completing this section you must submit all supporting materials such as participant information sheet(s), consent form(s), interview questions, questionnaires, etc. See the **checklist** at the end of this form for guidance.

1. Summary of research in lay terms, including aims (maximum length 150 words) Note 6:

NOTE
[6] The summary should concisely, but clearly, tell the reviewers what you are planning to do. It is very important that you describe your study in such a way that it is understandable to a general audience. Your study will be reviewed by colleagues from different disciplines who will not be familiar with your specific field of research and it may also be reviewed by the lay members of the FASS-LUMS Research Ethics Committee; therefore avoid jargon and use simple terms.

2. Anticipated project dates (month and year only) Note 7

Start date: **End date:**

NOTE
[7] These dates should indicate when recruitment will begin, (taking into account the timescale of the ethical approval process) and when funding ends or your thesis will be submitted.

3. Please describe briefly the intended human participants (including number, age, gender, and any other relevant characteristics):

4. Are members of the public involved in a research capacity, for example as data collector (e.g. participatory research) and if so, do you anticipate any ethical issues resulting from this? Note 8

NOTE
[8] This does not refer to members of the public being interviewed, but to forms of participatory research, where you invite members of the public to collect data.

5. How will participants be recruited and from where? Note 9

NOTE
[9] Please include here (if applicable) information about the following: How will participants be able to find out about the study? Will all volunteering participants be included or may you have to turn some away? If you will use different recruitment procedures for different participant groups, clearly indicate this and outline each set of procedures.

6. Briefly describe your data collection methods, drawing particular attention to any potential ethical issues.

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7. Consent

7a. Will you take all necessary steps to obtain the voluntary and informed consent of the prospective participant(s) or, in the case of individual(s) not capable of giving informed consent, the permission of a legally authorised representative in accordance with applicable law?

If yes, please go to question 7b.
If no, please go to question 7c.

7b. Please explain the procedure you will use for obtaining consent? Note 10
Please include sample participant information sheets (PIS) and consent forms in your application. If applicable, please explain the procedures you intend to use to gain permission on behalf of participants who are unable to give informed consent. Please include copies of any relevant documentation.

NOTE
[10] Please include sample participant information sheets (PIS) and consent form(s) or verbal consent protocol (where written consent is not possible) in your application. Written consent is preferable but may not always be possible. If you are using the verbal protocol, please explain why this is appropriate and how you plan to record the consent (for example audio-recording, coded table, etc.). A sample participant information sheet and consent form are available here. A sample verbal protocol is available here.
If non-handwritten forms of consent will be used in the study, explain why and what they will be.
If your research includes anonymous surveys for data collection, no consent form will be used because that would compromise anonymity. However, a cover sheet or opening page/section or some type of introduction should clearly inform participants that by completing the survey they are providing consent for the use of the data for research. The cover sheet or introduction may also remind participants of other aspects of what they are agreeing to (but without requiring them to sign or type identifying information such as a name at the end of the information).
If you are using computer-based forms of data collection, describe carefully how consent processes will be addressed.

7c. If it will be necessary for participants to take part in the study without their knowledge and consent at the time, please explain why.(For example covert observations may be necessary in some settings; some experiments require use of deception or partial deception – not telling participants everything about the experiment).

8. What discomfort (physical and psychological eg distressing, sensitive or embarrassing topics), inconvenience or danger could be caused by participation in the project beyond the risks encountered in normal life?
Please indicate plans to address these potential risks. Note 11
State the timescales within which participants may withdraw from the study, noting your reasons. Note 12

NOTE
[11] Be as thorough as possible in anticipating potential sources of discomfort.
Provide a plan for addressing the discomfort that may arise during the conduct of the research and discomfort that may develop following the conduct of the research, potentially as a consequence of participation in the research. We suggest you include possible sources of support in the Participant Information Sheet. You may also consider providing a debriefing sheet.

[12] **Time limits for withdrawing from the study:** please avoid the phrase "participants may withdraw at any time" because withdrawal for most studies is time limited. For example, once you have published your data, withdrawal is clearly not possible in the true sense. You may want to consider a reasonable time period for withdrawal following data collection, depending on the type of study you are doing, for example:

i. If you are collecting interview data and will be conducting simultaneous data collection and analysis, it may be reasonable to give participants a 2 week period following the interview to withdraw their data. [For other studies, longer periods of time may be appropriate.] An example of wording that may be used is "Participants are welcome to withdraw from the study at any time before or during the interview and up to 2 weeks following their interview (or survey completion)."
ii. If you are collecting your data via focus groups or group interviews, it is impractical to allow participants to withdraw their contribution once the group has started and recording begun. An example of wording that may be used is "Participants are welcome to withdraw from the study at any time before the focus group begins, but will not be able to withdraw their contribution to the discussion once recording has started." You should be explicit in this section about your intention to brief participants about this at the start of the focus group (for example during the setting of ground rules).
iii. If you use anonymous surveys, you need to clearly indicate to participants that they will NOT be able to withdraw their data/contribution once they have submitted it because it will not be possible to identify it as theirs.

9. How will you protect participants' confidentiality and/or anonymity in data collection (e.g. interviews), data storage, data analysis, presentation of findings and publications? Note 13

NOTE

[13] In the context of research confidentiality means that you will only disclose information that participants share with you in the forms agreed by them in the consent form. In most case, this includes offering anonymity, i.e. using pseudonyms and ensuring that individual participants cannot be identified in your dissertation/publications/presentations.

If, as part of your study, you will take photographs of participants or if you will film participants, please explain what you intend to do with these images. You may only use these images to help you with your data analysis. In that case, you will not show these images to other people nor will you use them in publications/your thesis. Or, you may want to use images of participants in your publications and presentations. In that case, you need to ask participants to consent to your use of these images. These images make them identifiable, unless you pixelate/blurr faces. Whatever you intend to do with images of participants, make sure to explain this on the application form and also in the information sheet and consent form.

In some studies, it is possible that in the course of the research information arises that gives the researcher cause for concern and that may require her/him to breach confidentiality. For example, if in an interview a participant discloses information that indicates that they or others may be at risk of harm, the researcher may need to share this information with others. In your PIS, when eliciting consent, explain the limits to confidentiality. This is in particular important when working with vulnerable individuals or groups.

10. Do you anticipate any ethical constraints relating to power imbalances or dependent relationships, either with participants or with or within the research team?
If yes, please explain how you intend to address these? Note 14

Faculty of Arts and Social Sciences and Management School Research Ethics Committee (FASS-LUMS REC)

ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

NOTE
[14] For example, if you are a teacher/former teacher conducting research in the school/language school you used to or are still working in, what are the implications for research participants? Explain clearly that their participation or decision not to take part does not affect their studies or any assessments.

11. What potential risks may exist for the researcher and/or research team?
Please indicate plans to address such risks (for example, noting the support available to you/the researcher; counselling considerations arising from the sensitive or distressing nature of the research/topic; details of the lone worker plan you or any researchers will follow, in particular when working abroad. Note 15

NOTE
[15] The University's guidance on Lone Working can help you with this, see here: http://www.lancaster.ac.uk/depts/safety/files/loneworking.pdf

12. Whilst there may not be any significant direct benefits to participants as a result of this research, please state here any that may result from participation in the study.

13. Please explain the rationale for any incentives/payments (including out-of-pocket expenses) made to participants. Note 16

NOTE
[16] If you are intending to use incentives/payments, keep in mind that they should be modest so as not to suggest coercion of the participants. If you are reimbursing for travel, please indicate the financial limit of the reimbursement.

14. What are your plans for the storage of data (electronic, digital, paper, etc.)? Note 17

Please ensure that your plans comply with the General Data Protection Regulation (GDPR) and the UK Data Protection Act 2018 .

NOTE
[17] Data storage: non-audio and non-video data. State clearly where and what format your data will be stored.
Timescales: The standard guidance we provide to people about length of time for retaining data is 10 years (minimum). This is not a requirement but a general recommendation. Your study may have a rationale for retaining data longer and for various intended purposes, but if so, please explain. For example, some data may be specifically collected with intent to be added to a formal databank (quantitative or qualitative), or there may be plans for secondary data analysis that is anticipated from early in the design of the project. Where electronic data is to be stored for longer than the recommended period, it should only be kept on Lancaster University servers, and not on portable or home devices.
Data Stewardship: Please state who will have guardianship of the stored data (and if you are a student, who will be responsible for storing/deleting your data once you have completed your course). Please also include information on who will see the data (e.g. supervisors; research team members; transcribers)
Location: If your data is stored centrally or will be accessible to others, you should note in your application who will have access to the data.

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Data security: Data stored on all portable devices (eg laptops) should be encrypted as well as password protected; data stored on the University server does not, however, need to be encrypted.
If you are based and work predominantly away from the University, give consideration to how you will store the data securely as you undertake your research, and how it will be securely transferred to the LU campus for long term storage.

15. Please answer the following question only if you have not completed a Data Management Plan for an external funder.

15a. Do you intend to deposit your (anonymised) data in a data archive? Note18 Yes ☐ No ☐

NOTE
[18] Most funders require researchers to preserve and share their data via a data archive. Lancaster University's Research Data Management Policy also suggests that all researchers, PhD students included, should store and archive their data in ways appropriate to the specific study and type of data. Please note that if you store data in a data archive where other researchers, upon request, can have access to this data, this needs to be explained on participant information sheets & consent forms.
There are different ways of storing and sharing data, but you are likely to follow one of these two options:
Example 1: Data will be deposited in Lancaster University's institutional data repository and made freely available with an appropriate data license. Lancaster University uses Pure as the data repository which will hold, manage, preserve and provide access to datasets produced by Lancaster University research.
Example 2: Data will be offered to the UK Data Archive (as per the standard ESRC procedures) or another similar data archive.
For further guidance on data archiving, please see here: Library Deposit your research data

15b. If you have responded '**no**' to question 15a, please explain briefly why you cannot share your data via a data archive or repository. Note 19

NOTE
[19] You may have reasons for not making your data widely available. For example, due to the small sample size, even after full anonymization, there may be a small risk that participants can be identified. It may also be the case that due to the (commercially, politically, ethically) sensitive nature of the research, no participants consented to their data being shared.
You can find more information about ethical constraints on sharing data on this site:
Library data access statements

16. Will audio or video recording take place?
no ☐ audio ☐ video ☐

16a. Will portable devices (laptop, USB drive, audio- and video- recorders, etc) be encrypted (in particular where they are used for identifiable data)?
yes ☐ no ☐

16b If it is not possible to encrypt your portable devices, please comment here on the steps you will take to protect the data. Note 20

NOTE
[20] Transporting audio/video data: you should state that if you store any identifiable data (audio recordings, participant contact details etc) on portable devices such as a memory stick or laptop you will

use encryption. Password protection alone is not sufficient for identifiable data. Information on encryption is available from ISS http://www.lancs.ac.uk/iss/security/encryptionoptions/ and their service desk is also able to assist.
If your portable device cannot be encrypted, you must confirm that any identifiable data (including recordings of participants' voices) will be deleted from the recorder as quickly as possible (eg when they have been transferred to a secure medium, such as a password protected & encrypted PC) and state that the device will be stored securely in the meantime.

16c What arrangements have been made for audio/video data storage?
At what point in the research will tapes/digital recordings/files be destroyed? Note 21

NOTE
[21] **Storage.** Audio and video data is considered more sensitive than most written data because of its capacity to threaten confidentiality more directly. There are, however, no fixed deadlines, and recordings such as oral histories may be kept in perpetuity.
With audio data that does not need to be kept for the long term, it is common to erase/destroy the recording once it has been transcribed and checked. However, we suggest that you retain the recordings until your work has been examined and/or published, in case you need to check the original recordings for any reason.
For video, it may depend on the types of analyses proposed for the study. There may be good reason to keep the data longer, but the key in completing this section of the application form is to be explicit about timescales for storage, and the reasons for your timescale should be clearly indicated and explained.

16d. If your study includes video recordings, what are the implications for participants' anonymity? Can anonymity be guaranteed and if so, how? If participants are identifiable on the recordings, how will you explain to them what you will do with the recordings? How will you seek consent from them?

17. What are the plans for dissemination of findings from the research? If you are a student, include here your thesis. Note 22
Please also include any impact activities and potential ethical issues these may raise.

NOTE
[22] Dissemination covers a wide range of activities including (but not limited to) reports, academic submissions (such as theses and journal articles), study summaries, and publications:
- If you are a student, be sure to include your academic paper (such as dissertation or thesis) as a form of dissemination.
- Phrasing regarding publication should reflect that you may pursue submission for publication, but you cannot guarantee that the dissemination will include publication. For example, you may write "Results of the research may be submitted for publication in an academic/professional journal."

18. What particular ethical considerations, not previously noted on this application, do you think there are in the proposed study? Note 23
Are there any matters about which you wish to seek guidance from the FASS-LUMS REC?

NOTE

Lancaster University

Faculty of Arts and Social Sciences and Management School Research Ethics Committee (FASS-LUMS REC)

ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

[23] It is rare that studies have no ethical considerations at all. Try to be thorough and thoughtful when considering this question. You should not try to invent issues, and at the same time, do not assume that by noting a problem you are hurting your application. This section provides an opportunity for you to demonstrate to the committee that you have a substantial and clear understanding of the potential ethical issues, and that you have given thought to how to address them (even if they may not be able to be addressed perfectly).

SECTION FOUR [Must be completed by all applicants]

Statement and Signatures

By submitting and signing this form, I confirm that

- I understand that as Principal Investigator/researcher/PhD candidate I have overall responsibility for the ethical management of the project and confirm the following:
- I have read the Code of Practice, Research Ethics at Lancaster: a code of practice and I am willing to abide by it in relation to the current proposal.
- I will manage the project in an ethically appropriate manner according to: (a) the subject matter involved and (b) the Code of Practice and Procedures of the university.
- On behalf of the institution I accept responsibility for the project in relation to promoting good research practice and the prevention of misconduct (including plagiarism and fabrication or misrepresentation of results).
- On behalf of the institution I accept responsibility for the project in relation to the observance of the rules for the exploitation of intellectual property.

- If applicable, I will give all staff and students involved in the project guidance on the good practice and ethical standards expected in the project in accordance with the university Code of Practice. (Online Research Integrity training is available for staff and students)
- If applicable, I will take steps to ensure that no students or staff involved in the project will be exposed to inappropriate situations.

- **I confirm that I have completed all risk assessments and other Health and Safety requirements as advised by my departmental Safety Officer: please tick this box to confirm** ☒

Please note: If you are not able to confirm the statements above please contact the FASS-LUMS research ethics committee and provide an explanation.

Applicant electronic signature: Note 24 Walaa Albouraee Date: 09-04-2020

NOTE [24] If you are a student, make sure that you have discussed the project and the application with your supervisor. Build in enough time in your preparation schedule for your supervisor to properly review your application and give their comments before submitting it for ethical review.

Student applicants:

Please tick to confirm that you have discussed this application with your supervisor, and that they agree to the application being submitted for ethical review ☒

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Faculty of Arts and Social Sciences and Management School Research Ethics Committee (FASS-LUMS REC)

ETHICS APPLICATION FORM FOR STAFF and PhD STUDENTS

Project Supervisor name: STUART WALKER, LICA **Date application discussed** 9 April 2020

Students must submit this application from their Lancaster University email address, and copy their supervisor in to the email with this application attached

All applicants (Staff and Students) must complete this declaration:

I confirm that I have sent a copy of this application to my Head of Department (or their delegated representative).

Tick here to confirm ☒

Name of Head of Department *(or their delegated representative)* Prof. Judith Mottram

In addition to completing this form you must submit all supporting materials. For examples of supporting documents see the checklist below. Note25

Checklist

☐ Advertising materials (posters, emails)
☐ Letters/emails of invitation to participate
☐ Participant information sheets
☐ Consent forms
☐ Questionnaires, surveys, demographic sheets
☐ Interview question guides/interview schedules
☐ Focus group scripts
☐ Confidentiality agreement (if using an external transcriber)
☐ Debriefing sheets, resource lists

NOTE [25]

If you experience formatting issues in your supporting documents after you have copied and pasted them here, at the end of this application form you may find the following guidance useful:

1. On your keyboard select F1 (**or** click on the Microsoft Word help button at the top right of this document)
2. Enter this text in the search field: 'keep source formatting' then select 'Control the formatting when you paste text' and follow the guidance in the 'help window'.

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Figure I.1: *The ethical application form of the research.*

Ethics approval (reference FL19133) please quote this reference in all correspondence about this project

FASS and LUMS Research Ethics <fass.lumsethics@lancaster.ac.uk>

Tue 21/04/2020 9:08 AM

To: Albouraee, Walaa (Postgraduate Researcher) <w.albouraee@lancaster.ac.uk>

Cc: Walker, Stuart <s.walker@lancaster.ac.uk>;Cureton, Paul <paul.cureton@lancaster.ac.uk>

Dear Walaa

Thank you for submitting your application and additional information for *A Digital Record System to Integrate Tangible and Intangible Information for Heritage Buildings in Saudi Arabia*. The information you provided has been reviewed by members of the Faculty of Arts and Social Sciences and Lancaster Management School Research Ethics Committee and I can confirm that approval has been granted for this project.

As principal investigator your responsibilities include:

- ensuring that (where applicable) all the necessary legal and regulatory requirements in order to conduct the research are met, and the necessary licenses and approvals have been obtained;
- reporting any ethics-related issues that occur during the course of the research or arising from the research (e.g. unforeseen ethical issues, complaints about the conduct of the research, adverse reactions such as extreme distress) to the Research Ethics Officer;
- submitting details of proposed substantive amendments to the protocol to the Research Ethics Officer for approval.

Please do not hesitate to contact me if you require further information about this.

Kind regards,

Debbie

Covid-19 (Corona Virus): The University's guidance for researchers is accessible here

Debbie Knight | Research Ethics Officer

Secretary FASS & LUMS Research Ethics Committee & UREC | Research and Enterprise Services Lancaster University | Room A04, Bailrigg | +44 (0)1524 592605, https://www.lancaster.ac.uk/ethics

Lancaster University

Figure I.2: *The ethical approval copy of the research.*

Abbreviations

2D: Two-Dimensional

3D: Three-Dimensional

AI: Artificiel Intelligence

AR: Augmented Reality

BIM: Building Information Modelling

CAD: Computer-Aided Design

CIM: City Information Modelling

CityGML: City Geography Markup Language

FM: Facility Management

GCPs: Ground Control Points

GeoBIM: Geographical Information and Building Information Model

GIS: Geographic Information Systems

GLONASS: Global Navigation Satellite System

GNSS: Global Navigation Satellite System

GPS: Global Positioning System

GSA: European Global Navigation Satellite Systems Agency

HBIM: Historic Building Information Model

HGIS: Historic Geographic Information System

IFC: Industry Foundation Classes

LoDs: Levels of Details

MR: Mixed Reality

NeRFs: Neural Radiance Fields

SfM: Structure from Motion

TLS: Terrestrial Laser Scanning

TST: Total Stations Technique

VGI: Volunteered Geographic Information

VR: Virtual Reality

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