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SMART FACILITIES MANAGEMENT IN POST-CONFLICT CITIES: THE CASE OF THE OLD CITY OF SANAA

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ABSTRACT

This research examines the strategies of Smart Facility Management and their impact on managing historical cities affected by conflict, focusing on creating an integrated database for the management, protection, restoration, maintenance, and monitoring of cultural heritage, specifically in the case study of the Old City of Sanaa, Yemen. It suggests implementing the strategies of Smart Facilities Management in historical cities post-conflict period, Facilities Management involves integrating systems, processes, technologies, and personnel to optimize the urban scale for historical sites. The Facilities Management Implementation Committee (FMIC) has introduced the Guide to Smart Facilities Management which outlines a five-step processes are the Set of Objectives and Outcomes, Mapping Out Solutions framework , Adopting a Suitable Implementation Model, Reviewing, and Tracking Outcomes for Continuous Improvement. In addition, applying advanced technologies integrating Heritage Building Information Modeling (HBIM) and Geographic Information Systems (GIS) to provide for an integral transfer of BIM data to the GIS platform. The work led to integration between the two informative systems, by relating them and allowing for an easy switch from one system database to the other. This integrated framework is intended to enable facility managers to easily visualize in the GIS platform, through queryable 2D maps with 3D modeling relevant to information from BIM to efficiently manage. The research employs a mixed-method approach that combines theoretical review and field studies, in addition to interviews with employees of the General Authority for the Preservation of Cities and Historic Monuments in the Old City of Sana'a, which contributes to understanding the status of the current management system of the city.

KEYWORDS: Smart Facilities Management (SFM), Post-Conflict, HBIM, GIS , Old City of Sanaa.

الإدارة الذكية للمرافق في مدن ما بعد الصراعات (حالة مدينة صنعاء القديمة)

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الملخص

يتناول هذا البحث استراتيجيات إدارة المرافق الذكية وأثرها على إدارة المدن التاريخية المتضررة من الصراع، مع التركيز على إنشاء قاعدة بيانات متكاملة لإدارة وحماية وترميم وصيانة ومراقبة التراث الثقافي لدراسة حالة مدينة صنعاء القديمة، اليمن. يقترح تنفيذ استراتيجية إدارة المرافق الذكية في المدن التاريخية بعد فترة الصراع، وتتضمن إدارة المرافق دمج الأنظمة والعمليات والتقنيات والموظفين لتحسين النطاق الحضري للمواقع التاريخية. طرحت لجنة تنفيذ إدارة المرافق (FMIC) دليل الإدارة المرافق الذكية، والتي تتضمن خمس عمليات هي تحديد الأهداف والنتائج، ورسم إطار الحلول، وتبني نموذج تنفيذ مناسب، ومراجعة وتتبع النتائج للتحسين المستمر. بالإضافة إلى ذلك، تطبيق التقنيات المتقدمة التي تدمج نمذجة معلومات المباني التراثية (HBIM)ونظم المعلومات الجغرافية (GIS) لتوفير نقل متكامل لبيانات (HBIM)إلى منصة (GIS) . وقد أدى العمل إلى التكامل بين النظامين المعلوماتيين، من خلال ربطهما والسماح بالتبديل بسهولة من قاعدة بيانات نظام إلى آخر. ويهدف هذا الإطار المتكامل إلى تمكين مديري المرافق من التصور بسهولة في منصة نظم المعلومات الجغرافية، من خلال خرائط ثنائية الأبعاد قابلة للاستعلام مع نمذجة ثلاثية الأبعاد ذات صلة بالمعلومات من (BIM)لإدارة فعالة. وقد تضمن البحث أسلوبًا مختلطًا يجمع بين المراجعة النظرية والدراسات الميدانية، بالإضافة إلى المقابلات مع موظفي الهيئة العامة للحفاظ على المدن والمعالم التاريخية في مدينة صنعاء القديمة، مما يساهم في فهم وضعية منظومة الإدارة الحاليه للمدينة.

الكلمات المفتاحية : إدارة المرافق الذكية (SFM)، ما بعد الصراع، HBIM، GIS، مدينة القديمة في صنعاء.

1. INTRODUCTION

Cities with a heritage that has been affected by conflict face unique challenges when it comes to reconstruction and maintaining their infrastructure. The protracted conflict, encompassing both natural disasters like rain and earthquakes, as well as man-made disasters such as war, has inflicted substantial harm upon the Old City of Sanaa which is the capital of Yemen, leading to the degradation of infrastructure and the disruption of essential services. Insufficient planning, ineffective coordination strategies, and inadequate stakeholder engagement often lead to failures in endeavors. According to an official from the Governmental Organization for the Preservation of Cities, the historic site GAPHCM, most efforts focus on restoring famous buildings without a clear purpose or framework, and are hindered by inadequate planning and financial resources.

The Old City of Sanaa was designated as a UNESCO World Heritage Site in 1986 and officially included in the World Heritage List as a World Cultural Heritage site, garnering substantial international acclaim. The city's urban fabric is a notable feature that has effectively preserved its medieval elements, resulting in a unique and authentic urban expansion [1]. However, the Old City of Sana'a was added to the list of World Heritage in Danger by UNESCO in 2015 [2].

Urban-scale World Heritage Site (WHS) management requires balancing preservation with urban development to meet contemporary living standards and urban facility management services. This can be challenging due to conflicts between preservationists and developers, over tourism, inappropriate visitor behavior, and damage to heritage sites. Many WH sites are located in developing nations or areas with limited resources, which presents additional challenges in terms of conservation funding and management resources. Climate change and natural disasters can pose significant threats to WH sites [3].

Facilities Management Approach

Traditional facilities management is helping to address the intricate requirements of historic cities. The function of Facilities Management in the revitalization of heritage buildings and historic cities incorporates four tiers of project requirements: knowledge, key performance indicators, construction process, and management information system. The knowledge system evaluates the effects of restoring heritage buildings, determines the needs of the project, and oversees tasks such as upkeep, service quality, contract administration, marketing strategies, and fostering and sustaining public involvement [4].

This study aims to explore the feasibility of utilizing smart facilities management to revitalize the Old City of Sanaa. The study specifically concentrates on operational aspects. The five strategies of Smart Facility Management involve the incorporation of Heritage Building Information Modeling (HBIM) and Geographic Information Systems (GIS) to aid in facility management processes. Smart facilities management is an all-encompassing approach that incorporates systems, processes, technologies, and personnel to improve facilities management [5]. This study examines the role of smart facilities management in supporting complex projects, specifically in the preservation of historic cities after conflicts, focusing on the Old City of Sanaa. It also explores how facilities management addresses the needs of different stakeholders.

2. LITERATURE REVIEW

2.1. Post-Conflict in Historical Cities

Since the First World War, societies across the globe have demonstrated the capacity to recover from calamities by reinstating significant architectural heritage and urban landscapes. Conservation practices such as preservation, rehabilitation, restoration, and reconstruction have contributed to the development of resilient cities. A comprehensive and collaborative approach has resulted in long-lasting revitalization, strengthening the process of societal restoration. Reconstructions are now more widely accepted, even by conservation bodies that were initially skeptical [6].

A specialist in conflict recovery defines a disaster as an event caused by either an environmental occurrence or an armed conflict, that leads to substantial stress, personal harm, physical destruction, and economic disruption [7]. The reconstruction endeavors in cities that have experienced conflict are frequently hindered by scarce resources, a lack of coordination, and the need to strike a balance between immediate humanitarian requirements and long-term development objectives. Prior research has emphasized the importance of implementing a holistic strategy for reconstruction, encompassing both physical and social aspects [8].

Efficient conflict preparedness and prevention measures necessitate the exchange of knowledge within an organization. An all-encompassing disaster recovery plan requires input from essential departments. The facilities manager oversees all aspects of facilities management and ensures the restoration of support services to facilitate the efficient operation of the organization [8].

The reconstruction and management of historical cities post-conflict present significant challenges due to the extensive damage to heritage structures and the need for sustainable restoration frameworks. The integration of advanced technologies, such as Heritage Building Information Modeling (HBIM) and Geographic Information Systems (GIS), has emerged as a transformative approach to addressing these challenges. This integration enhances the management, preservation, and operational efficiency of historical structures throughout their lifecycle by creating a unified database for informed decision-making and facilitating collaboration between stakeholders [9].

The Old Bridge of Mostar, destroyed during the Bosnian War in 1993, exemplifies successful post-conflict heritage restoration using advanced frameworks. Recognized as a UNESCO World Heritage Site, its reconstruction adhered to international standards to preserve its historical significance. Heritage Building Information Modeling (HBIM) played a pivotal role in documenting the bridge's original design and structural details through 3D modeling, integrating historical records with modern engineering techniques [10].

The author explains Heritage Building Information Modeling (HBIM) framework aids in accurate reconstruction by providing a central platform for managing the complex data associated with the bridge [10] . This approach enabled seamless communication among stakeholders, including local communities and international organizations, ensuring transparency and collective ownership of the project. Beyond technical restoration, the Mostar example demonstrates how Heritage Building Information Modeling (HBIM) can support cultural reconciliation in post-conflict settings by fostering stakeholder engagement and preserving shared heritage [11].

Technological Integration for Post-Conflict Heritage Management

Research indicates that integrating HBIM with GIS significantly improves maintenance strategies and facilitates predictive maintenance by enabling real-time monitoring of historical structures. The interoperability achieved through this integration supports seamless data exchange across platforms, enhancing decision-making processes in facility management. Standards such as Industry Foundation Classes (IFC) ensure compatibility and adaptability across different systems, making this approach replicable for various cultural heritage sites globally [9,11].

By adopting these advanced technologies, can address immediate restoration needs while laying the foundation for long-term preservation efforts. This methodology not only ensures efficient management of heritage sites but also promotes transparency, accountability, and collaboration among stakeholders [11].

2.2. Smart Facilities Management (SFM)

Smart facilities management (SFM) involves the harmonious integration of systems, processes, technologies, and personnel to optimize the management of a building's facilities [5]. Facilities management is crucial for ensuring business continuity as it oversees the second-largest and most critical business asset, after information technology (IT) [12] .The Guide to Smart FM, an initiative by the Facilities Management Implementation Committee (FMIC), provides a five-step process for stakeholders and FM managers to guide their journey. The method includes set objectives and outcomes, mapping Smart FM solutions as enablers, adopting a suitable implementation model, reviewing, and tracking outcomes for continuous improvement.

In **Fig. 1.**, the proposed framework follows a structured five-step process designed to integrate GIS and HBIM technologies into Smart Facility Management for post-conflict heritage sites:

Step 1: Set Objectives and Outcomes
The initial step is to analyze the current administrative system of the Old City of Sana'a and propose a new system through smart facility management. Secondly, analyze the current conditions of the Al-Qasimi neighborhood before and after the conflict.

Step 2: Map Out Solutions
Suggestions for the most efficient methods to implement smart facility management solutions, such as integration GIS and HBIM. Assess the feasibility and potential impact of these technologies.

Step 3: Implementation Models for Solutions
Build a comprehensive database using GIS and HBIM. This central repository will facilitate better management and decision-making.

Step 4: Review of Implementation Models
The proposal simplifies workflow between smart facility managers and GOPHCY management system, streamlining incident reporting, and promoting transparency and accountability.

Step 5: Track Outcomes and Review for Continuous Improvement

Regularly revisit Steps 1 through 4 to identify areas for improvement. Assess new technological solutions, analyze different implementation models, and examine outcome-based metrics to enhance facility management services. By applying these five strategic principles, the unique challenges of the Old City of Sanaa can be effectively addressed. This approach suggests that advanced technologies will help protect and revitalize the Old City of Sanaa, preserving its cultural significance for future generations.

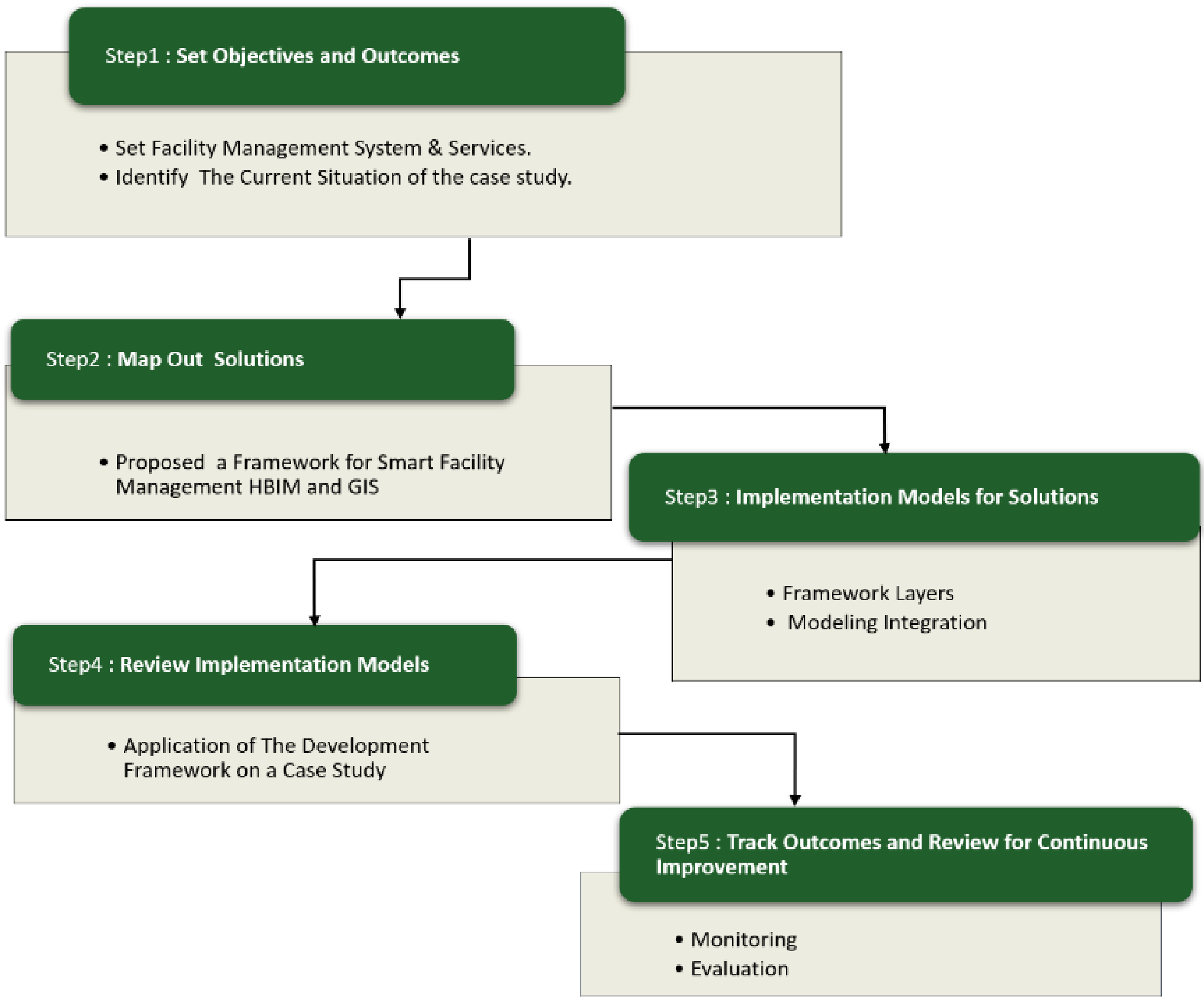


Fig. 1: Step smart process of the proposed framework.

2.3. BIM-GIS Support of Facility Management

The BIM-GIS Support of Facility Management has been discussed by many studies, The integration of Historical Building Information Modelling (HBIM) and Geographic Information Systems (GIS) has emerged as a transformative approach in facility management, particularly for historical buildings. This integration enhances the management, preservation, and operational efficiency of these structures throughout their lifecycle. The integration of Historical Building Information Modelling (HBIM) and Geographic Information Systems (GIS) has become increasingly vital in the management and conservation of historical buildings. This approach not only enhances the operational efficiency of facility management but also plays a crucial role in preserving the architectural heritage.

The integration of HBIM and GIS provides a robust framework for managing the complex data associated with historical structures. By combining the detailed parametric modelling capabilities of HBIM with the spatial analysis strengths of GIS, facility managers can create a comprehensive database that supports various maintenance and restoration activities. This interoperability allows for the seamless exchange of information across different platforms, facilitating informed decision-making in facility management [13] Research indicates that the HBIM-GIS integration significantly improves maintenance strategies for historical buildings. This platform is designed to meet the specific needs of restoration and management bodies, enhancing the planning and execution of maintenance activities [2]. It allows for the creation of a multidisciplinary strategy for the requalification and functionalization of historical architecture.

The integration of HBIM and GIS methodologies allows for the structuring of a wide range of digital data, providing insights into the building's current status and historical significance [14].

The integration process is supported by established standards such as Industry Foundation Classes (IFC) for both HBIM and GIS. These standards provide a framework for representing of multi-scale 3D information, enabling effective data exchange and interoperability between different systems. The adoption of these standards is crucial to ensure that the integrated systems can be reused and adapted for various cultural heritage case studies [13,15]

2.4. Old City of Sanaa

The Old City of Sanaa, a significant example of Arab urban civilization, has been the subject of numerous studies since the 1970s. Despite its outstanding heritage values, it faces threats from rapid modernization. In the 1980s, UNESCO proposed a campaign and action plan to preserve the Old City, which was launched after its inscription on the World Heritage List in 1986 [16,17]. Historians studied Sanaa using inscriptions, archaeological findings, and historical records. They also analysed primary historical sources, such as Christine Niner Senh's chart and Ottoman schemes. The origins of the city can be attributed to two hypotheses: it either started as a modest settlement that evolved into a prominent commercial hub, or it emerged directly as a commercial hub at the intersection of early human settlements during ancient Yemeni civilization [18].

2.4.1. Environments and Urban Components for Old City of Sanaa

The Old City of Sana'a covers an area of approximately 5.87 square kilometers [19]. Ancient Sanaa is a renowned historic city with rich architectural cohesion, characterized by 6,500 edifices and 48 mosques. The city is enclosed by a fortified wall with 9 gates. The commercial market contains 2,000 stores, 48 specialized markets, 26 hotels, and 12 steam baths. The city's architecture features narrow corridors interconnected with expansive urban spaces, offering a diverse range of open areas, including squares of varying dimensions and vegetation-adorned expanses. The city also boasts 43 green areas, showcasing its rich cultural heritage [1].

3. METHODOLOGY

This study adopts a mixed-methods research design to propose a Smart Facility Management (SFM) framework for the Old City of Sana'a. The research focuses on the Al-Qasimi neighborhood, where three in-depth interviews were conducted with expert managers from the General Organization for the Preservation of Historic Cities of Yemen (GOPHCY). These interviews provided valuable data on the challenges faced during and after the 2015 conflict, as well as insights into current strategies for heritage management and preservation. A key point highlighted by one of the expert managers during the interviews was the significance of Yemeni Law No. 16 of 2013, which mandates the preservation of cities, regions, historical monuments, and their urban cultural heritage. However, it was noted that this law has not been effectively implemented, underscoring the urgent need for actionable measures.

The study integrates five-step Smart Facility Management strategies, detailed in Section 2.2, with advanced technologies such as Heritage Building Information Modeling (HBIM) and Geographic Information Systems (GIS). Preservation of architectural heritage and conservation of the historic urban fabric, improved administrative operational efficiency, streamlined management processes, and enhanced governance through better oversight and management of historic sites.

However, several challenges were identified administrative system (GOPHCY) components operate independently, leading to inefficiencies. Limited historical data accessing comprehensive data remains challenging due to its scarcity and complexity. Technical barriers implementation faces significant technical difficulties.

In light, there is a pressing need for a unified database to centralize historical and geospatial data. Such a database would facilitate better decision-making, improve coordination among stakeholders, and ensure compliance with preservation laws. The proposed methodology integrating HBIM and GIS to address these challenges effectively, ensuring sustainable management and preservation of heritage sites in post-conflict contexts.

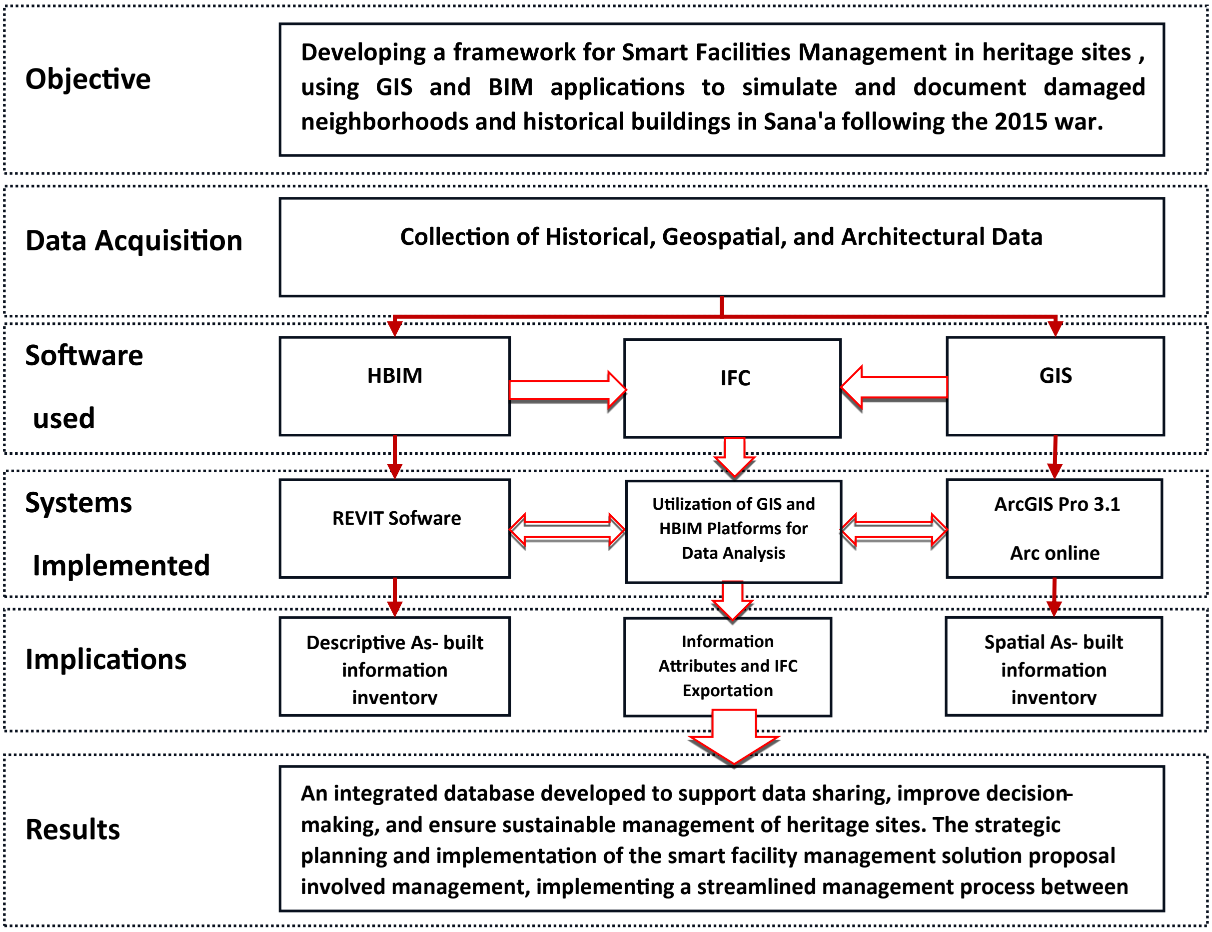


Fig. 2. A flowchart illustrating the study methodology, including the objectives, data acquisition process, software tools utilized for analysis, systems implemented, implications of the findings, and resulting outcomes.

4. RESULTS AND EXPERIMENTAL PHASES

This section aims to validate the methodology introduced by implementing the 5-step SMART process to achieve this objective. Two systems are used: GIS to map the geographical context, including surrounding infrastructure, utilities, and environmental factors, and BIM (Building Information Modeling) to simulate and document the buildings in Old Sana'a City, including its damaged historic neighborhoods and structures, following disasters. These applications are specifically designed for smart facility management services. Emphasis was placed on the application used in the Al-Qasimi neighborhood, which suffered significant damage in 2015 as a result of the war, leading to the destruction of six historic residential buildings. This suggestion that Smart FM is vital for rebuilding and maintaining damaged historic cities after disasters. It relies on integrating systems, processes, technology, and people to improve facility management and ensure sustainability. The 5-step smart process can be effectively applied to achieve this goal [5].

4.1. Step 1: Set Objectives and Outcomes

4.1.1. Facility Management System and Services

The process begins with defining the objectives and desired outcomes of smart facility management. For the Old City of Sana'a, these objectives include documenting and preserving the damaged historic city, improving the quality of life for residents, and ensuring the sustainability of the historic area. The main processes and performance stages of smart facility management include operation, planning, implementation, monitoring, and arbitration. These processes are particularly applicable to the management of damaged historic cities post- conflicts. The scope includes documentation, restoration, cleaning, security, and energy management. Real-time data is collected from various subsystems - architectural, civil, mechanical, and electrical - to detect and rectify deficiencies. The data and information documented by facilities management using HBIM and ArcGIS Pro program.

Through the analysis of interviews with GOPHCY staff, it becomes evident that the administrative system of the General Organization for the Preservation of the Historic Cities of Yemen (GOPHCY) consists of several components: the Office of the General Organization for the Preservation of the Historic Cities of Yemen, responsible for the preservation of cities and historical landmarks; the branches of the authority responsible for monitoring and preservation work; the Center of Architectural Training and Studies; and partners such as UNESCO and the International Community Organization. The analysis reveals that each component of the administrative system operates independently and lacks coordination with the others. Additionally, when administrators are asked about the strategies used for maintaining and monitoring buildings, they report a lack of organized and coherent plans. Administrators attribute this issue to the absence of a unified database. According to the presidency of the republic, the National Information Center, and Yemeni Law No. 16 of 2013 - which pertains to the preservation of cities, regions, historical monuments, and their urban cultural heritage - there is a significant need for a unified database [20].

The prior discussion delineates a definitive goal of creating a consolidated database that amalgamates essential data and information pertaining to the old city of Sanaa through the use of ArcGIS Pro and HBIM. Facilities management can catalog its assets, infrastructure, and public areas, facilitating maintenance, repair, and urban planning. This database will integrate geographic information system functionalities with Historical Building Information Modelling HBIM's comprehensive building modeling attributes, consequently improving decision-making processes.

4.1.2. Identify the current situation of the case study

According to reports from the rapid Intervention project for the rescue and restoration of Damaged and Destroyed Historic Buildings in the Al-Qasimi neighborhood, affiliated with the General Organization for the Preservation of the Historic Cities of Yemen (GOPHCMY) and UNESCO, the Al-Qasimi neighborhood is a residential area located southwest of the historic Old City of Sanaa. In 2015, UNESCO's reports and maps illustrated the extent of the damage to the old buildings caused by the airstrikes on June 12, 2015, as shown in as shown in **Fig. 3.**, the air raid on June 12, 2015, caused extensive damage to historic buildings in the Al-Qasimi neighborhood, demonstrating the vulnerability of shared load-bearing structures. These historic buildings are situated in a straight line between two orchards: Broom to the north and Al-Qasimi to the south.

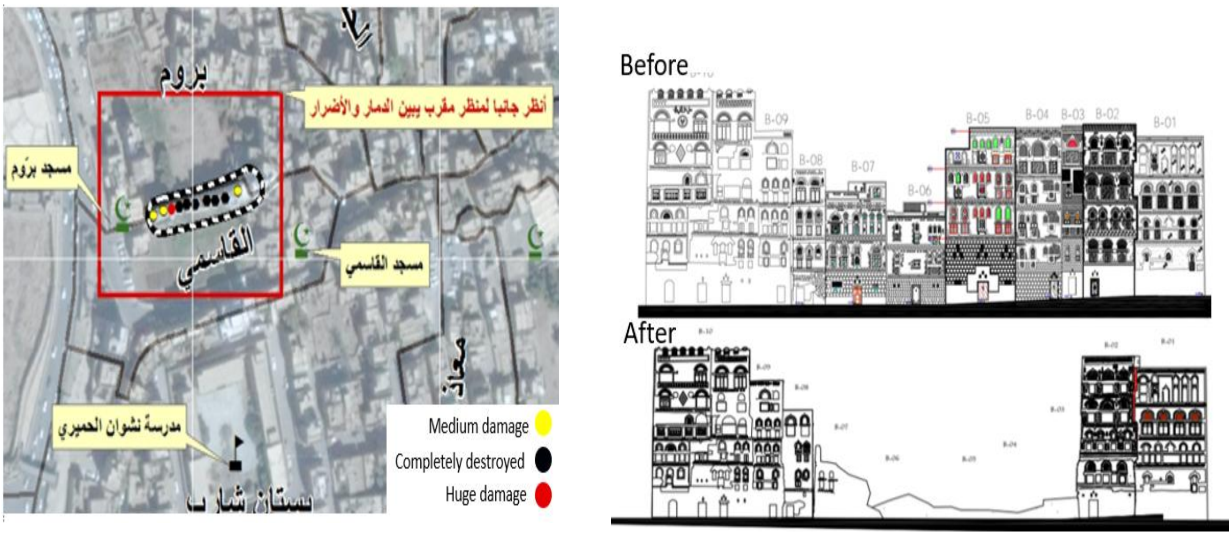


Fig. 3. The image on the left illustrates the extent of damage to historic buildings in the Al-Qasimi neighborhood caused by the air raid on June 12, 2015. The image on the right displays a geographical map highlighting the destruction, with data sourced from GOPHCY. The domino effect of structural collapse due to shared load-bearing walls is evident, particularly in buildings B1 and B2.

The Old City of Sanaa is characterized by its tall buildings adorned with white plaster. These historical structures were constructed using bricks and mud, featuring a simple design with a wide base that gradually tapers to form a pyramid shape. The buildings were designed so that adjacent towers share load-bearing walls on both the eastern and western facades. Consequently, the demolition of one building could trigger the collapse of adjacent structures, creating a domino effect. This phenomenon is illustrated by the ten buildings located in the Al Qasimi neighborhood Due to the disastrous incident of 2015.

The damage to building B1 occurred due to the separation of its load-bearing wall from building B2. It was noted that restoration standards were not as a result, the demolition of one building could trigger the collapse of the adjacent structures, creating a domino effect, as building B2 was dismantled by the responsible party, adversely affecting building B1. Additionally, bricks were used as the primary material for restoration, and the fifth floor of B1 was damaged. The restoration works also caused deformation of the load-bearing wall of the building [21].

Building B7 completely collapsed and was than rebuilt. The entire structure appears to have been removed between September 2017 and November 2017. Building B7 was reconstructed using the same type of bricks as the original and closely resembles the old facade, according to the proposed facade design in the Rapid Intervention Project for the Rescue and Rehabilitation of Damaged and Destroyed Historic Buildings in the Al-Qasimi Neighborhood of the Old City of Sanaa. This project is affiliated with the General Organization for the Preservation of Historic Cities of Yemen. However, other historic residential buildings that were destroyed, including B2, B3, B4, B5, and B6, have not been addressed, leaving the land vacant as if no buildings had previously existed, despite their historical significance. This situation calls for an independent study of its future.

4.2. Step 2: Map Out Solution

The proposal was designed with these challenges and business objectives in mind. To select two HBIM/GIS systems tailored to meet the needs of historic cities under normal, conflict, and post-conflict conditions. To identify smart solutions for each FM service that can meet the business objectives and desired FM outcomes , through three Phases:

Phase 1: Digital Modeling (HBIM/GIS)

Creating BIM digital modelling of architectural, structural, electrical, and mechanical systems by collecting information from reports submitted by GOPHCY, photographs, AutoCAD files, books, and historical records.

Phase 2: Optimization Within System

Convert BIM data to GIS-compatible formats, process the information, and integrate it into a unified platform for seamless collaboration.

Phase 3: Integration of BIM and GIS for Smart Facility Management

This ensures seamless communication and coordination across various systems within an accessible framework that aims to facilitate exploration and on construction work volume estimation projects. It achieves this by integrating data from different systems within a geospatial framework. Smart facility management personnel and other stakeholders interested or involved in the facilities are automatically notified, allowing the facility management manager to intervene if necessary. The objective is to collect data to implement smart facility management solutions for control and monitoring, as illustrated in **Fig. 4.**

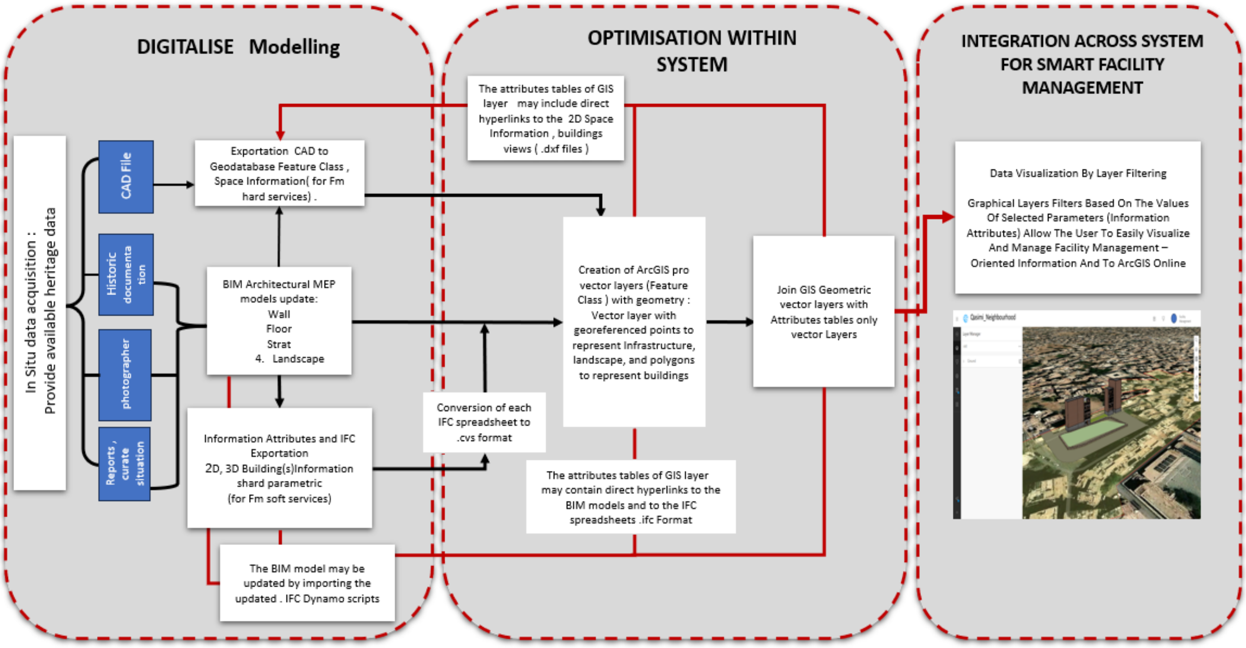


Fig. 4. A three-phase framework for implementing proposed smart facility management solutions in the historic cities of the Old City of Sanaa.

4.3. Step 3: Implementation Models for Solutions

4.3.1 GIS: Framework Layers

Geographic analysis is essential for creating detailed spatial representations of heritage sites, enabling better decision-making. It allows for the integration of different types of data, providing a comprehensive view of historic areas. GIS tools for assessing the impact of proposed interventions on heritage sites. They enable detailed spatial analysis, visualization, impact assessment, monitoring and management, risk assessment, and stakeholder engagement. GIS helps to understand the geographical context of heritage sites, evaluate changes in land use, infrastructure development, and environmental conditions, and predict risks such as natural disasters and climate change impacts. Additionally, GIS facilitates better communication and collaboration among stakeholders [22, 23].

Regular updates to GIS data enable facility managers to track changes, identify areas requiring maintenance, and plan interventions. GIS also fosters collaboration among stakeholders, allowing for better management and conservation of heritage sites. Overall, GIS significantly contributes to the conservation of historic and cultural sites.

The elements and components of the Old City of Sanaa were identified in the feature class file within ArcGIS Pro using various layers to create a comprehensive spatial representation. Vector layers are essential for creating detailed and structured spatial representations of geographic data. These layers can be categorized into three main types: polygon layers, point layers, and line layers [24].

Polygon Layers: polygon layers represent areas and are used to define boundaries and regions. In the context of the Old City of Sanaa, the polygon layers include:

- City Boundary: Defines the outer limits of the city.
- Neighborhood Boundaries: Defines different neighborhoods within the city.
- Buildings: Represents individual buildings.
- Orchard (Al Muqashma): Defines specific orchard areas.

Point Layers: Point layers represent specific locations and are used for features that can be defined by a single point. For the Old City of Sanaa, the point layers include:

- Electricity Locations: Marks the locations of electrical infrastructure.
- Lighting Poles: Indicates the positions of street lighting poles.

Line Layers: Line layers represent linear features and are used for elements that follow a path. In the Old City of Sanaa, the line layers include:

- Roads: Represents the road network throughout the city.
- Sailah Road: Represents a specific road within the city.

As shown in **Fig. 5.**, the vector layers provide a comprehensive visualization of the Old City of Sanaa. these vector layers provide a comprehensive and detailed visualization of the Old City of Sanaa, facilitating better management and analysis of its components. By integrating these layers into a GIS system, stakeholders can perform spatial analysis, visualize data, assess impacts, and make informed decisions regarding the preservation and management of historic sites [24,25].

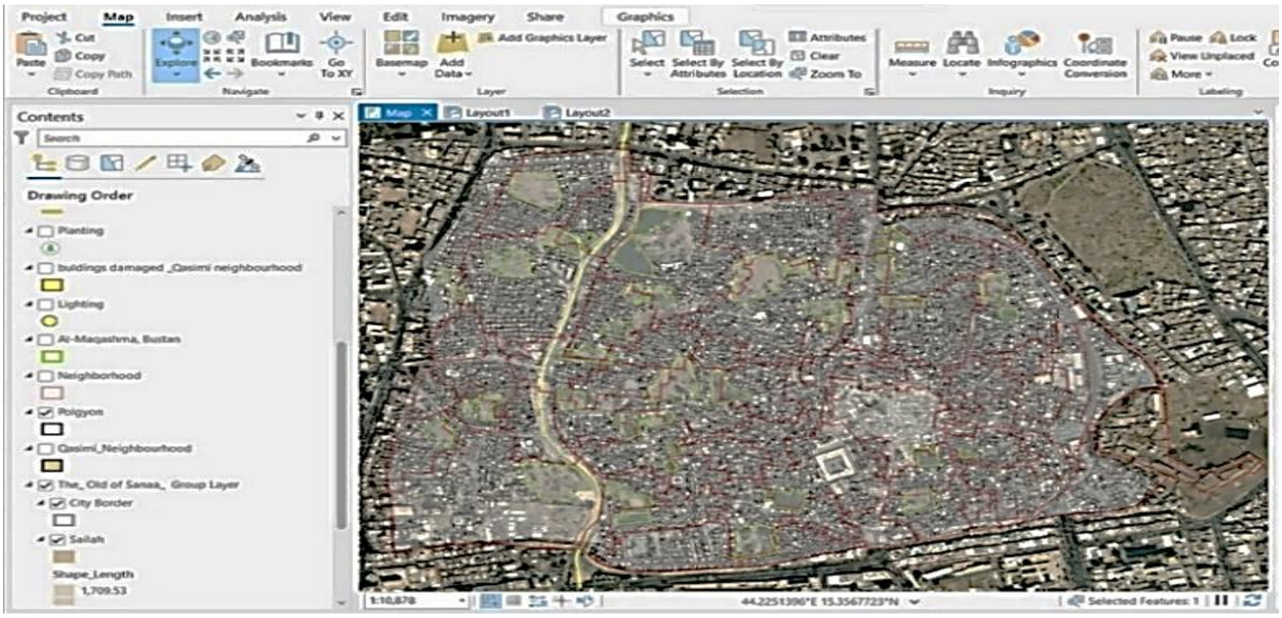


Fig. 5. These layers provide a detailed and structured visualization of the Old City of Sanaa, facilitating better management and analysis of its components.

In the case of the Al-Qasimi neighborhood, the use of GIS for geographic analysis has enabled the creation of a detailed and accurate digital representation of the area. The elements and components of the Al-Qasimi neighborhood were identified within ArcGIS Pro using vector layers to create a comprehensive spatial representation. These layers include:

Polygon Layer:

- Neighborhood Boundaries
- Buildings in the Neighborhood
- Destroyed Buildings in Qasimi
- Orchard (Al Muqashma)

Point Layer:

- Electricity Locations
- Lighting Poles

Lines Layer:

- Roads

- Pedestrian Roads

As shown in **Fig. 6.**, these layers offer a comprehensive and organized visualization of the neighborhood, which enhances the management and analysis of its components .

By utilizing geographic analysis, the management of the Al-Qasimi neighborhood in the Old City of Sana'a can be optimized to ensure the preservation of its heritage while addressing the practical needs of its residents. The detailed spatial data provided by GIS supports informed decision-making and effective collaboration among stakeholders, ultimately contributing to the sustainable management of this historic area.

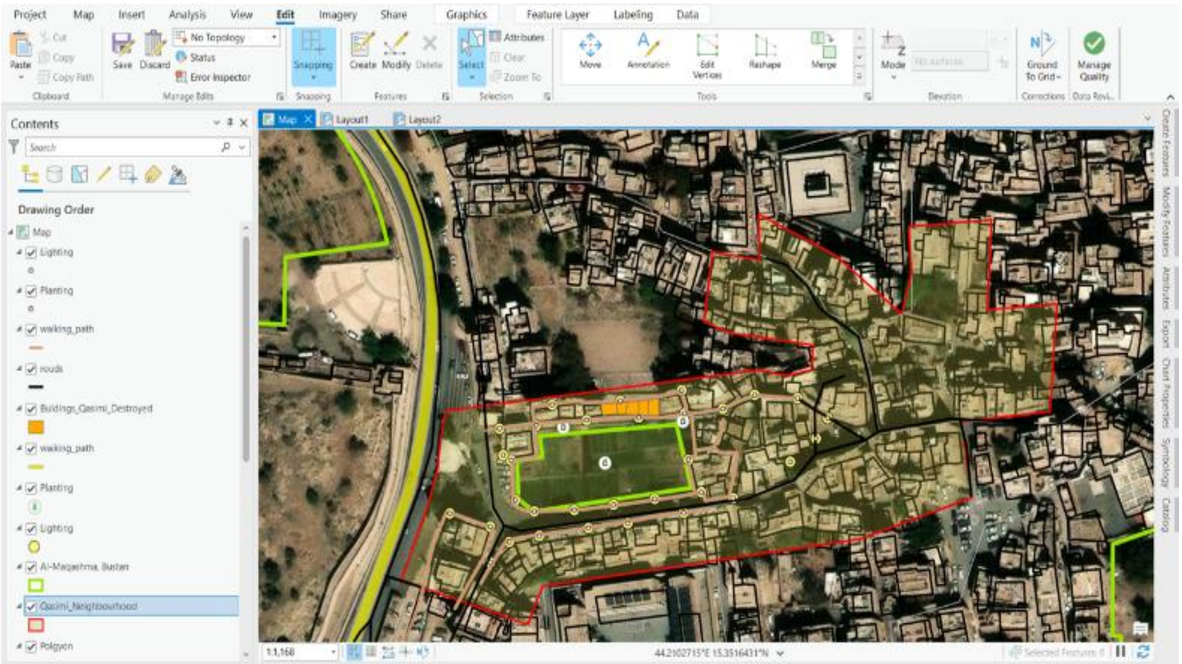
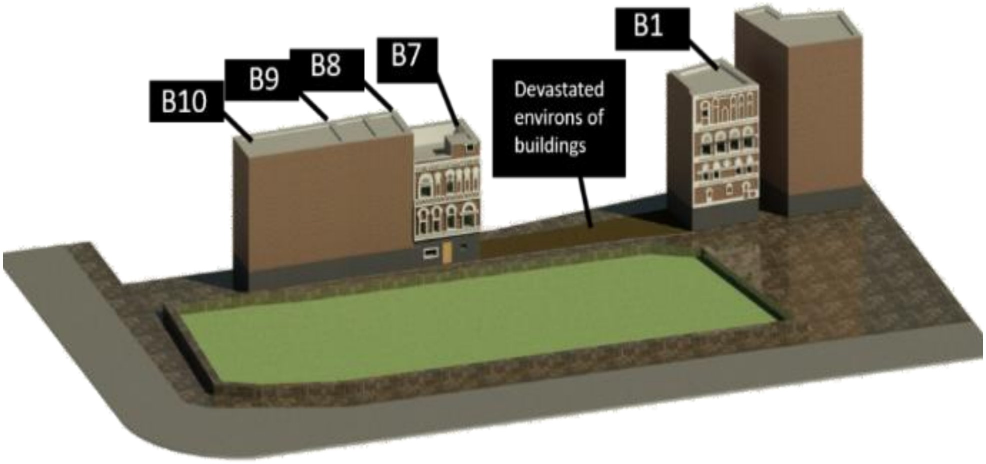


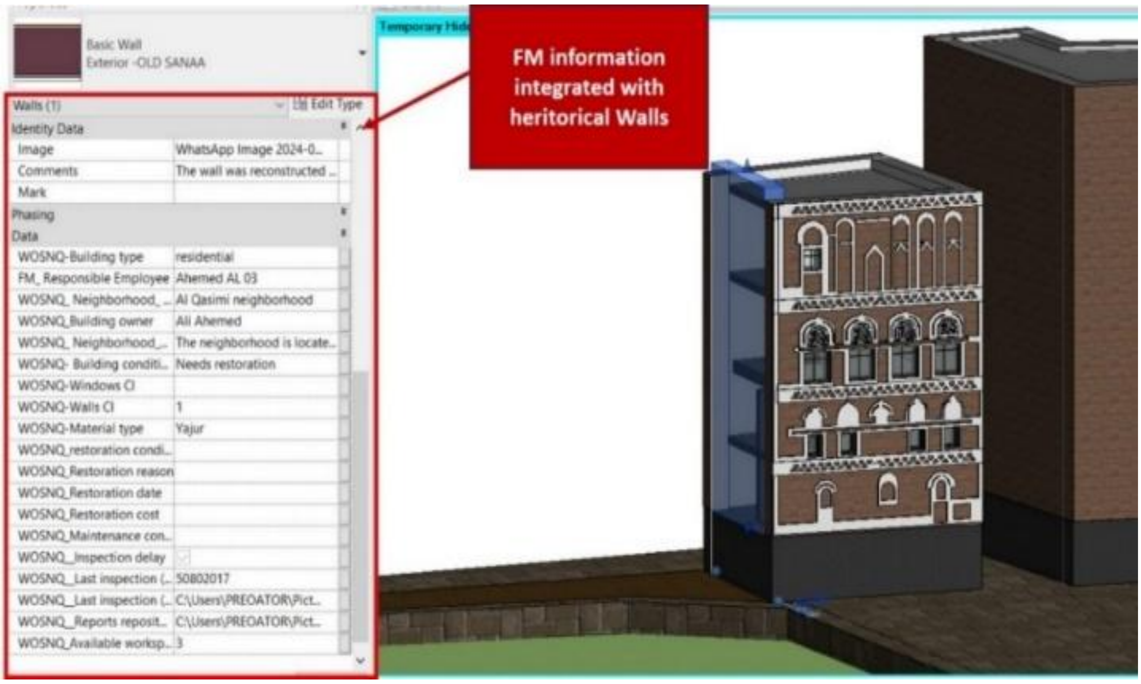
Fig. 6. layers provide a detailed and structured visualization of in the case of the Al-Qasimi neighborhood, facilitating better management and analysis of its components.

4.3.2. HBIM: Framework

The historical buildings in the Al-Qasimi neighborhood were meticulously documented using a PDF map board obtained from the General Organization for the Preservation of the Historic Cities of Yemen (GOPHCMY) as a reference. Autodesk Revit was employed to visualize the architectural structures and site boundaries, establishing it as the primary tool for creating a Heritage Building Information Modeling (HBIM) model. A comprehensive set of parameter families was developed in Revit, drawing on reports, references, and historical books.



3D BIM model of a historic building in the Al-Qasimi neighborhood, showcasing architectural and structural details documented using Autodesk Revit.



(B) Integration of facility management (FM) information into the heritage BIM model, including maintenance schedules, condition assessments, and restoration planning parameters tailored for smart facility management.

Fig. 7: (A) 3D BIM model of the case study, (B) facility management (FM) information integrated with the heritage BIM.

The heritage components—such as the layers of walls, floors, and the intricate architectural decorations of the facades—capture the architectural authenticity of the Old City of Sanaa. These components were enriched with semantic information using Parametric Share, specifically tailored to enhance facility management processes. This integration not only preserves the historical and cultural significance of these elements but also optimizes their functionality to support a variety of critical tasks, including maintenance scheduling, condition assessments, and restoration planning. As illustrated in **Fig.7**, part (A) showcases a detailed 3D BIM model that captures the architectural and structural intricacies of the case study, while part (B) demonstrates the integration of facility management (FM) information into the HBIM model. This integration enables a centralized approach to managing heritage assets, ensuring efficient planning and execution of maintenance and restoration activities.

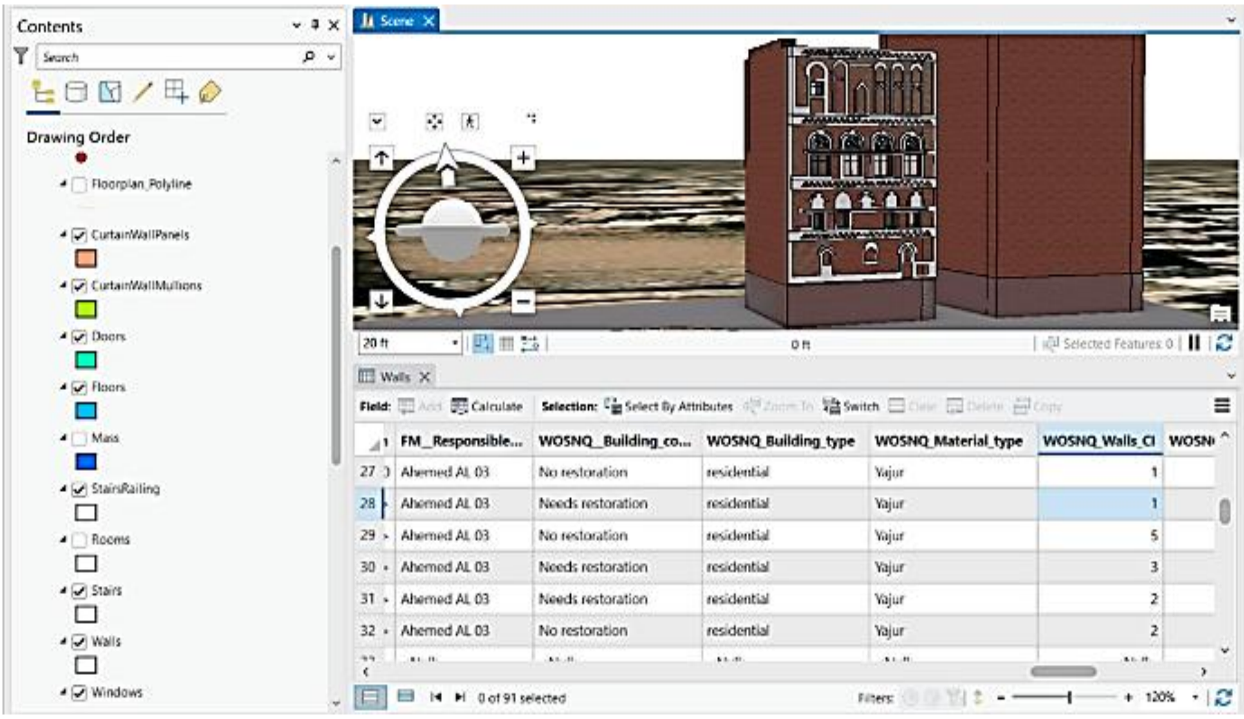
4.3.3 Integration of HBIM/GIS modeling: Al-Qasimi neighborhood

The integration of Historic Building Information Modeling (HBIM) with Geographic Information Systems (GIS) in the Al-Qasimi neighborhood represents a transformative approach to heritage management. This process involves multiple stages to ensure the accurate documentation, analysis, and visualization of architectural and spatial data. The initial phase entails the collection and export of comprehensive data, including architectural and structural details, sourced from reports, historical records, photographs, and AutoCAD files. This data is digitized into HBIM models using tools like Autodesk Revit and exported in Industry Foundation Classes (IFC) format to ensure compatibility with GIS platforms.

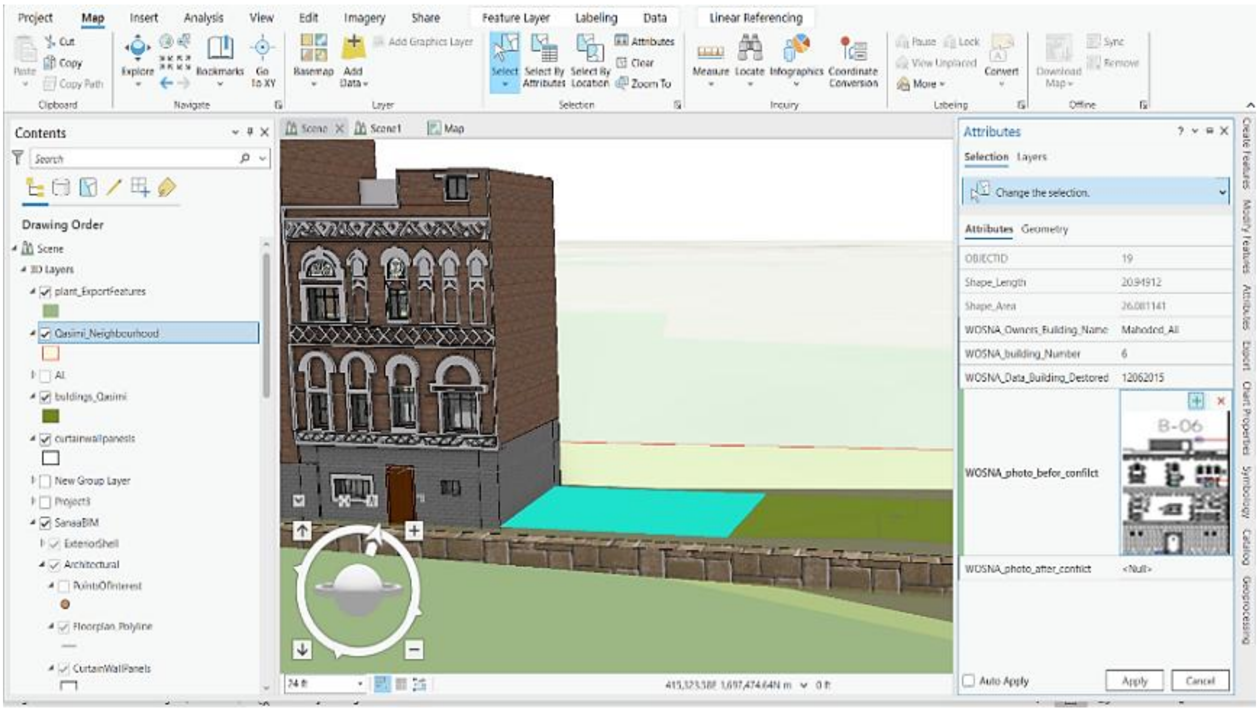
In the subsequent phase, the data is processed and integrated into ArcGIS Pro, a GIS platform that supports spatial data and 3D modeling. This integration facilitates the creation of shared parameters tailored to heritage components, such as architectural specifications, structural conditions, restoration history, and maintenance schedules. These parameters are encoded using standardized naming conventions (WOSNA-<Parameter Semantic Name>) to ensure easy identification and interoperability within the database.**Table 1** provides a detailed mapping of these attributes, which are critical for effective facilities management.

The metadata database plays a pivotal role in organizing textual information, numerical data, and images. For instance, Figure 8 illustrates two cases: Figure 8A demonstrates the transfer of parametric data from Building 1 in Revit to ArcGIS Pro's metadata table, encompassing architectural specifications, structural details, and restoration records. Conversely, Figure 8B highlights how pre-destruction metadata for Building 6 was preserved despite its complete destruction during the 2015 conflict. This meticulous documentation ensures that even lost heritage structures retain their historical significance for future analysis.

Shared parameters related to workspace management are encoded using a standardized naming convention (e.g., WOSNA-<Parameter Semantic Name>). This system ensures easy identification and organization of parameters specific to heritage facilities in Sanaa. This encoding scheme is specifically designed for the Old City of Sanaa and general information, with the prefix WOSNA-. The encoded prefix "WOSNQ-" is used to easily recognize these parameters, this has been designed for use in the Al Qasimi neighborhood.



(A)



(B)

Fig. 8. Demonstrates Metadata Transfer from Revit to ArcGIS Pro for Two Buildings: Building 1, Where Parametric Data Such as Architectural Specifications Were Successfully Integrated Into GIS, and Building 6, Where Pre-Destruction Metadata Was Preserved for Historical Documentation.

Table 1. Detailed mapping of heritage component information into IFC data for efficient facility management.

Parameter name	Parameter description	Type	Exported to GIS
Shared parameter group: Basic Information			
WOSNA - Neighborhood name	District name followed by code (WOSNA/ NUMBER)	Text	Yes
WOSNA - Building owner	District name followed by code (WOSNA/ NUMBER)	Text	Yes
WOSNA - Building type	District Type followed by code (WOSNA/ NUMBER)	Text	Yes
WOSNA - Available workspaces	available workspaces	Integer	Yes
FM Employee Name	Employee Name	Text	Yes

Shared parameter group: Architectural Information			
WOSNQ - Material type	Materials and Finishes	Text	Yes
WOSNQ - Building condition	Structural	Text	Yes
WOSNQ - Walls CI	Walls Condition Index (CI) between 0 and 5	Integer	Yes
WOSNQ - Ceiling CI	Ceiling Condition Index (CI) between 0 and 5	Integer	Yes
WOSNQ - Windows CI	Windows Condition Index (CI) between 0 and 5	Integer	Yes
WOSNQ - Floor CI	Floor Condition Index (CI) between 0 and 5	Integer	Yes
Shared parameter group: restoration Information			
WOSNQ - Restoration condition	Date of item restoration condition	Good/Bad	Yes
WOSNQ -Restoration date	Date of item restoration date	Text	Yes
WOSNQ - Restoration cost	Date of item restoration cost	Integer	Yes
WOSNQ-_Restoration reason	Date of item restoration reason	Text	Yes
WOSNQ - Last inspection (date)	Date and time of the latest inspection	Integer	Yes
WOSNQ - Inspection delay	Alert for delay in scheduled inspections	Yes/No	Yes
WOSNQ - Last inspection (pictures)	Link to pictures about the latest inspection	URL	Yes
WOSNQ - Reports repository	Link to the repository of inspection	URL	NO

Once integrated, the HBIM-GIS system enables seamless visualization through tools like Esri Web Dashboard. This platform allows stakeholders to interact with both 2D maps and 3D models of the Al-Qasimi neighborhood, supporting tasks such as incident reporting, restoration planning, and maintenance scheduling. By combining HBIM's parametric modeling capabilities with GIS's spatial analysis strengths, this integration provides a robust framework for managing historical structures. It streamlines workflows, enhances decision-making processes, and ensures transparency and accountability in heritage management.

The interoperability achieved through this system significantly improves maintenance strategies for historical buildings by providing a unified platform for collaboration among stakeholders. The adoption of open standards like IFC ensures that the integrated database can be reused and adapted for other cultural heritage sites. This methodology not only addresses the challenges faced by the Al-Qasimi neighborhood but also serves as a model for managing historic cities affected by conflicts or natural disasters.

Fig. 9. Visualization of the Al-Qasimi Neighborhood: Integration of HBIM Models into ArcGIS Online for Enhanced Heritage Management and Spatial Analysis.

4.4. Step 4: Review of Implementation Models

Application of the development framework on the case study in **Fig.10.** illustrates the proposed streamlined workflow for Smart Facility Management (FM) in collaboration with the General Organization for the Preservation of Historic Cities of Yemen (GOPHCY) and Stakeholders. This workflow integrates the HBIM-GIS model to enhance communication, accountability, and efficiency in managing facilities within the Old City of Sanaa. The process ensures that feedback and updates are systematically tracked and addressed through a centralized platform, with the facilities manager playing a pivotal role in overseeing and updating data within the HBIM-GIS model.

The workflow commences when a responsible employee identifies an issue or provides feedback. Instead of sending this feedback via email, issues via a ArcGIS Online platform's user interface, which integrates HBIM-GIS data derived from IFC files. The facilities manager, responsible for updating and maintaining data in the HBIM-GIS model, reviews the feedback and assigns it to a point operator. The point operator then forwards the feedback to the respective responsible employee tasked with addressing the issue.

Once assigned, the responsible employee works on resolving the feedback and updates its status daily. The facilities manager actively monitors the progress of this feedback within the HBIM-GIS model, ensuring that updates are accurately reflected and that tasks are being addressed in a timely manner. If any delays or issues arise, the facilities manager coordinates with both the point operator and the responsible employee to ensure resolution.

After the feedback has been fully addressed, the point operator updates its status in the HBIM-GIS system as "closed." The facilities manager then ensures that all data associated with this feedback is accurately documented in Building (B1) within the HBIM-GIS model. Finally, users are notified that their feedback has been resolved, completing the cycle.

This streamlined process not only enhances workflow efficiency but also ensures transparency and accountability at every stage. By centralizing data updates within the HBIM-GIS model under the supervision of the facilities manager, this system provides a robust framework for managing facility-related issues while maintaining an accurate and up-to-date record of all actions taken.

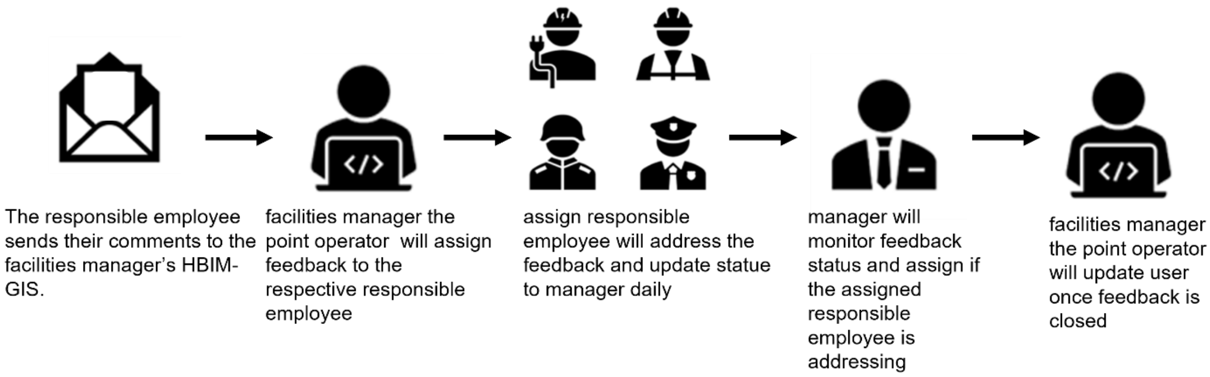


Fig. 10. Proposed Workflow for Streamlined Facilities Management (FM) Integrated with GOPHCY and Stakeholders: Demonstrating the Role of HBIM-GIS in Coordinating Feedback, Assignments, and Status Updates to Enhance Efficiency and Accountability.

4.5. Step 5: Track Outcomes and Review for Continuous Improvement

The final step in the proposed framework focuses on consolidating monitoring processes and reviewing outcomes to ensure continuous improvement in facility management operations. By integrating the multiple offices of GOPHCY (General Organization for the Preservation of Historic Cities of Yemen) with its Smart Facility Management (SFM) team, workflow processes are streamlined and optimized. This integration is achieved through the use of open and organized communication protocols, along with standardized naming conventions for historic urban data points. These measures reduce confusion, improve coordination, and facilitate the overall monitoring of building performance.

The HBIM-GIS model integration plays a pivotal role in this step by providing a comprehensive and easily accessible database. This database enables data analysis across different areas, offering valuable insights for improving facility management operations. The automated workflow system significantly enhances process efficiency by shortening response times and accelerating rectification efforts.

The integration of HBIM and GIS also supports predictive maintenance by enabling facility managers to monitor historical structures in real-time. This capability allows for proactive interventions, ensuring that issues are resolved before they escalate into larger problems. Furthermore, the system's ability to consolidate data from various subsystems—such as architectural, structural, mechanical, and electrical components—ensures that decision-making is informed by accurate and up-to-date information.

By adopting this approach, GOPHCY can establish a unified platform for effectively managing heritage assets. The use of standardized protocols ensures that data is consistently documented and easily retrievable, fostering collaboration among stakeholders. The HBIM-GIS model also enhances transparency by systematically recording all actions taken within the management process. This transparency builds trust among stakeholders while promoting accountability.

This step emphasizes the importance of continuous improvement through regular reviews of outcomes and processes. By leveraging advanced technologies such as HBIM-GIS integration, GOPHCY can ensure the sustainable management of heritage sites like the Old City of Sanaa. This iterative approach not only addresses immediate challenges but also lays the foundation for long-term preservation efforts.

CONCLUSIONS

This research emphasizes the importance of a multi-scale approach to Smart Facility Management (SFM) in the Al-Qasimi neighborhood of Sana'a, Yemen, particularly in the post-conflict context. The study highlights five key strategies: setting objectives and outcomes, mapping solutions, adopting a suitable implementation model, reviewing progress, and tracking outcomes for continuous improvement. It identifies critical challenges faced by the Preservation and Heritage Authority in Sana'a, especially in light of the destruction caused by the 2015 airstrikes.

Utilizing HBIM and GIS, a comprehensive database was created to document and manage the impacts of both natural and man-made disasters on the Old City, with a focus on the Al-Qasimi neighborhood. The proposed framework employs open-source tools and non-proprietary data exchange formats to enhance interoperability, customization, and cost-effectiveness. Key technologies such as Autodesk Revit, IFC, and ArcGIS Pro serve as intermediaries between Building Information Modeling (BIM) and Geographic Information System (GIS) databases, facilitating seamless data integration.

The case study of the General Authority for the Preservation of Historic Cities of Yemen (GOPHCY) reveals significant operational discrepancies among administrative systems and underscores the need for a unified database. The integration of smart facility management technologies, including digital modeling and the combined use of HBIM and GIS, is proposed to address these challenges, ensuring better management of historic buildings both during and after conflicts.

The developed system enables efficient tracking and utilization of facility management information, with scheduled maintenance prompts guiding managers in assessing the condition of heritage elements. The metadata database plays a crucial role in organizing and identifying relevant data, including images and historical records. The integration of HBIM with GIS creates a powerful unified database that enhances incident reporting and tracking, improving collaboration and monitoring capabilities by streamlining workflow between smart facility managers and the GOPHCY management system, and promoting transparency and accountability. The use of the Esri Web Dashboard for visualizations further supports informed decision-making through 2D and 3D representations of the Al-Qasimi neighborhood.

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