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# FRAMEWORK FOR MAINTAINABILITY MEASURES OF HERITAGE BUILDINGS USING 3D LASER SCANNING AND GIS MAPPING

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## ABSTRACT

Conservation and rehabilitation of cultural Heritage is gaining international concern due to many reasons the most important of which is retaining the cultural identity of countries. The Cultural heritage buildings in Egypt are considered a national treasure as they are a living proof of Egyptian ancient civilization, with unlimited potential for national income through tourism by exhibiting iconic cultural landmarks equipped with modern services. This paper aims at developing a framework for identification of maintainability measures for cultural heritage buildings in Egypt. Using the latest technologies in archiving and documenting of buildings features, three-dimensional laser scanning, the influencing deterioration factors on buildings will be identified and recorded. The resulting pool of factors is analyzed to identify the best representing group which will finally be benchmarked against maintenance fundamentals to produce a grading scale. Later, through the integration of the 3D model into a 3D GIS, a map will be produced for buildings in Cairo showing their grading according to the performed study.

**Keywords:** Heritage Building, Engineering Management, 3D-GIS, Laser Scanning, Building Information Modeling.

## INTRODUCTION

Egypt's heritage is considered one of the most valuable and diverse heritage in the world, with a vast number of architectural monuments and structures belonging to different historical era alongside the river Nile and adjacent to both the Mediterranean and Red Seas. The 500-feddan site in BeniSuef governorate on the outskirts of El Fayoum has substantial monuments and burials dating from the ancient Egyptian to the Coptic era. The ancient Egyptian necropolis of Dahshour 40km south of Cairo was chosen by the Pharaohs of the old and middle Kingdoms as a resting zone for eternity. In Khedival Cairo, buildings of historical and architectural value witnessed distinctive urban renaissance events during the second half of the 19th and the early 20th century. Additionally, within historical Cairo there is Al-Muizz Street, and Darb Al-Ahmar area, Villas of Casdagli, Ispenian in Cairo and Villa Aghion in Alexandria all represent the magnificent Islamic and Coptic buildings heritage. These Heritage buildings provide character and tangible connection to the past; they reach back and have greater links to identity and history, which cannot be easily replaced. Heritage buildings require maintenance approaches specific to their context as they were constructed from different materials compared to modern buildings, consequently they perform differently.

Haagenrud [1] stated that different agents cause deterioration, generating direct and indirect consequences in terms of building maintenance and repair costs. The service life of buildings is an important element in the socioeconomic stability of contemporary societies. The gradual degradation of architectural heritage buildings overtime concerns users and influences their needs and expectations, prompting a significant increase in research into buildings service life. Despite the

great value of the rich and diverse Egyptian built heritage, it is subject to numerous difficulties and threats. Many buildings are subject to partial or full destruction. Beside intentional demolition of buildings, some suffer from partial collapse due to their deteriorated condition. The deterioration of built heritage in the Egypt is a result of many reasons. Low maintenance, weak management, lack of finance and failure of enforcing laws are some of the reasons. The influence of time and weather conditions along with insignificant maintenance can make the problem worse. Maintenance and preservation of a building is crucial to ensure its continuity. To wrap up, most heritage buildings and sites are treated with ignorance from the local population, and unless safeguarding is in place by the government, areas surrounding monuments are converted into markets in the morning and coffee shops at night. Promoting maintenance has become a necessity rather than an option in building conservation. Maintenance is the key to longevity and sustainability for any heritage structure. Regular inspections and maintenance play a key role in prolonging the life of any structure, whether new, old or heritage. Often very important aspects are neglected, causing more damage than usually anticipated.

The ASCE Committee on America's Infrastructure [2], assigned grades to rate performance using criteria for infrastructure as follows:

- ***Capacity*:** Does the structure's capacity meet current and future demands?
- ***Condition*:** What is the structure's existing physical condition?
- ***Funding*:** What is the current level of funding from the government for the structure compared to the estimated funding need?
- ***Future Need*:** What is the cost to improve the structure? Will future funding prospects address the need?
- ***Operation and Maintenance*:** What is the ability to operate and maintain the structure properly?
- ***Public Safety*:** To what extent is the public's safety jeopardized by the condition of the building and what could be the consequences of failure?
- ***Resilience*:** What is the building's persistence against multi-hazard threats and incidents?
- ***Innovation*:** What new and innovative techniques, materials, technologies, and delivery methods can be implemented to improve the structure while preserving its identity?
- A grading Scale was adopted to assign according to the building condition:
- **Exceptional, Fit for the Future:** The building is generally in excellent condition, recently rehabilitated, and meets capacity needs for the future. A few elements show signs of general deterioration that require attention. Facilities meet modern standards for functionality and are resilient to withstand most disasters and severe weather events.
- **Good, Adequate for Now:** The building is in good to excellent condition; some elements show signs of general deterioration that require attention. A few elements exhibit significant deficiencies. Safe and reliable, with minimal capacity issues and minimal risk.
- **Mediocre, Requires Attention:** The building is in fair to good condition; it shows general signs of deterioration and requires attention. Some elements exhibit significant deficiencies in conditions and functionality, with increasing vulnerability to risk.
- **Poor, at Risk:** The structure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion exhibits significant deterioration. Condition and capacity are of serious concern with strong risk of failure.
- **Failing/Critical, Unfit for Purpose:** The structure is in unacceptable condition with widespread advanced signs of deterioration. Many of the components exhibit signs of imminent failure.

The generation of 3D cultural heritage models has become a topic of great interest in recent years. One reason for this is the more widespread use of laser scanning and Photogrammetry for recording cultural heritage sites. These technologies have made it possible to efficiently and accurately record complex structures remotely that would not have been possible with previous survey methods. In addition to these developments, digital information systems are evolving for the presentation, analysis and archival of heritage documentation.These new digital information systems allow for the production of multi-purpose models that can be used for more than just visualization. Historic Building information modelling (HBIM) consists of surveys of existing structures using remote sensing followed by the mapping of parametric and information rich objects onto a geometric framework based on the remote survey data. The parametric objects which represent the

architectural elements are graphically constructed or coded and are based on historic architectural documents. The resultant HBIM can then be used for automatically producing conservation documentation and analysis of historic structures in addition to visualization. Virtual models have great potential for sharing and disseminating knowledge and documenting historic buildings. They give the opportunity to understand the historic building and its architectural and structural elements, to conduct analysis to identify damaged parts and follow up during their life cycle. Comprehensive three-dimensional models also give a comprehensive overview for decision-makers to help make the right decision concerning these buildings. Zlatanova and Isikdag [3] stated that BIM does not apply abstractions or simplifications; all components are represented with their true 3D shape. To capture the true 3D shape, both accurate and precise geospatial measurement techniques are required.

The main objective of this research is to develop a framework for identification of maintainability measures for cultural heritage buildings in Egypt. Using the latest technologies in archiving and documenting of buildings features three-dimensional laser scanning, while additional properties are recorded through traditional field visits and office reports investigations. The influencing deterioration factors on buildings are identified and recorded. The resulting pool of factors is analyzed to identify the best representing group, which will finally be benchmarked against development fundamentals to produce a grading scale. Later, through the integration of the 3D model into a 3D GIS, a map will be produced for buildings in Cairo showing their grading.

## HERITAGE ASSESSMENT

International standards for recording and documentation for tangible and intangible cultural heritage have been established by the London Charter [4], which relates to both the digital and paper-based documentation of cultural heritage [5]. The creation of digital 3D cultural heritage models includes the use of remote sensing based on terrestrial laser scanning and photogrammetry in addition to the use of BIM, 3D CAD, GIS and other computing simulation techniques for modelling and adding intelligence to the objects. Models based entirely on remote sensing are limited to a record encompassing data relating to geometry, texture and appearance. Cultural heritage researchers have begun applying Building Information Modelling (BIM) to historic buildings for several years. The intelligent data or information contained in the model can range from geometric and spatial to material, structural, environmental, cultural and economic. The model is comprised of intelligent objects, which represent the elements of a building structure and are organized within a 3D virtual environment, its structure, materials, and environment, providing the associated information related to its design, construction and future lifecycle. The idea of creating extensions of BIM more adapted to existing and historic buildings originated with the case studies of the researchers [6,7] that developed the concept of positioning parametric 3DCAD objects, comprising of architectural primitives, in the point cloud data. The benefit of using parametric objects was their ability to change geometry according to the altered dimensions of the parameters and to fit the historic structures as closely as possible.

While the term HBIM was coined in Dublin Institute of Technology and Trinity College Dublin, many academic researchers became interested in the field and HBIM is now a broad area of research. Most of the research carried out in the past few years was case study-based and was initiated by educational institution in different countries [8, 9, 10]. The development of the Batawa Model in 2011 acknowledged the call for hybrid documentation. It brought together heterogeneous data sets and data types into a single digital object that allow access to and ongoing verification of the individual assets that comprise the whole. This included data related to building type, construction, and performance, as well as material. The Batawa Model allowed for multiple narratives based on currently verifiable historical and projective information. So that if the "facts" change, the model can integrate this new material without having to be completely rebuilt. It pointed out the potential of parametric relationships between all data types for heritage documentation. The most significant contribution to the field of heritage documentation is the ability to reveal time-based parametric relationships between tangible and intangible heritage assets.

The methodology used by these researchers to develop HBIM involved data collection using laser scanning and modelling historic architectural elements graphically using BIM software platforms followed by mapping 3D objects in the point cloud data. The automatic generation of structured

building information models from point clouds is a primary focus for a lot of research in this area. Xiong [11] and Zhang [12] have shown promising results for automatic object recognition and feature extraction from point cloud data. Although progress has been made in this area, results are currently limited to automatic extraction of basic elements such as planes and openings. Automatic extraction of complex architectural elements that occur in existing and historical buildings is still in its infancy. The results from existing automatic approaches include surface models, planes, 3D vectors or a subset of the original point cloud. All of these results still need to be converted into structured information enhanced and parametric building components which at present needs to be carried out manually [13].

Moreover, the 3D laser scanning advances have been presented in the field of surveying and can obtain 3D data about physical objects of different shapes and sizes in a cost and time effective way. Laser scanners enable a large number of points to be recorded in a few minutes. As a result of their common sense and flexibility, these sorts of instruments can possibly be broadly utilized as a part of the field in architectural, archeological and environmental surveying [14]. It can give faster, better quality and investigation that is more exact and highlight location for building study [15]. The attempt of laser scanning use in identifying influencing factors for heritage buildings is considered a pioneering effort. Dore [16] has used Geographic Information Systems (GIS) for storing, visualizing and analyzing geographic data. Spatial features were stored as geometry and referenced with map Projections and coordinates. On the other hand, GIS has traditionally been used with 2D mapping to analyze data over large areas. However, as a result of technological advancements, the principles of 2D GIS are now being applied to 3D spatial data to enable more complex analyses, visualization and documentation. This enables complex analysis to be carried out for many applications such as planning, disaster management, noise mapping and cultural heritage.

## FRAMEWORK FOR HERITAGE BUILDINGS

The proposed framework consists of mainly four phases, initiated by accurate recording of existing conditions of the monument using laser scanning, photogrammetry, and existing non-graphical information, then constructing the three-dimension model. The goal of this phase is to present well-structured evaluation criteria of the building by collecting data and information, analysis of conditions and elements of the building's components. In addition to examination of the structure, external walls and roof, thermal performance, water usage, day lighting are evaluated to decide on the strategies to be applied to the building according to the existing situation of the building. The second phase includes furnishing the historical Building Information Model with different physical and non-physical parameters influencing heritage buildings protection, conservation, maintenance and management and further visualization options. The third phase involves generating a pool of factors and performing analysis to identify the most influencing factors thus producing a grading scale. Factor selection criteria will be developed and a selection algorithm will be used to identify most influencing groups. The last phase is to create a map of heritage buildings in Cairo according to proposed grading scale. Figure 1 presents the detailed activities schematics with reference to the identified four main phases of the research.

## CASE STUDY

Tosson Palace is considered as a case study which is located in Shubra - Road El-Farag - Cairo as depicted in Figure 2 [17]. Based on the available information from the laser scanner and architectural survey, the model was divided into "work sets" with building elements such as walls, doors, floors, stairs, and pipes. Collected information was used to construct a three-dimensional digital model as a copy of the original. The developed Heritage Building Information Modeling for the Mansion adds a historical/Heritage layer to the 3D physical modeled through collected non-geometric data. It utilizes processed point clouds to give a different purpose of the 3d model with different levels of development to suit different identified factors. The process of applying the proposed scanning activity framework is divided into three sub-tasks; planning; 3D laser scanning of the site; processing of the High Density Point Cloud (HDPC). Evaluation of the structural and architectural situation of the building (Thermal Performance, Water Usage, Day lighting, Satisfaction, Security and Safety Issues) are also studied to issue a pool of parameters. Part of the identified factors is tabulated in Table 1 while the final pool of factors are on the process of generation and work for including additional factors is undergoing.

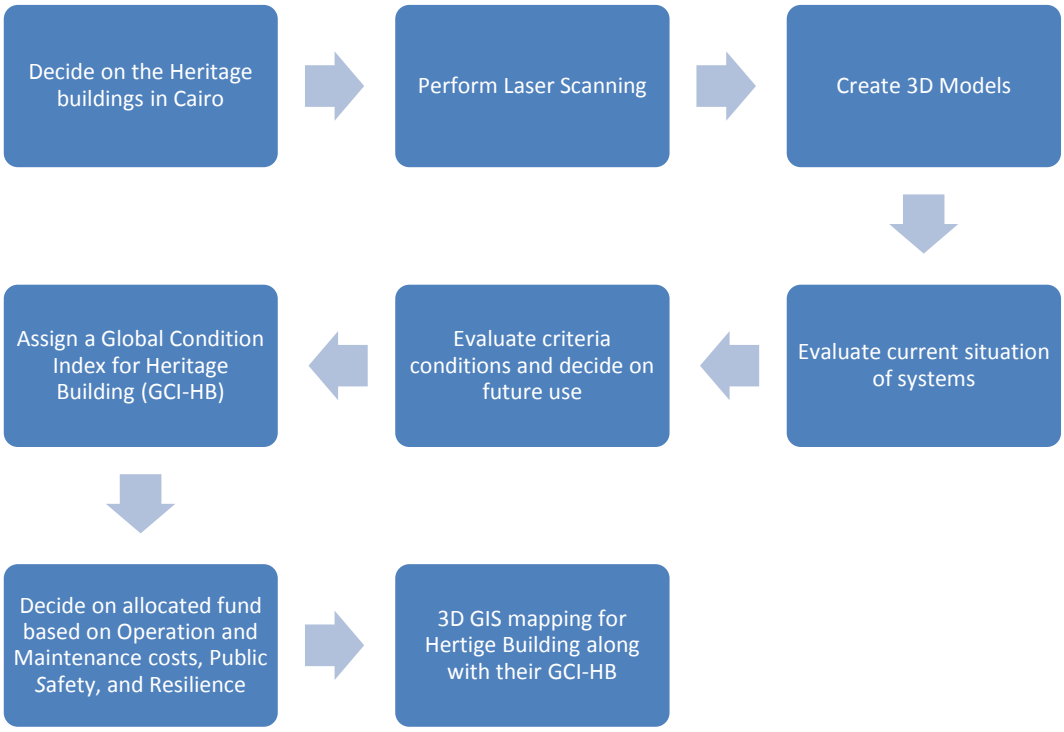


**Fig. 1: Workflow of the Proposed HBIM framework**


**Fig. 2: Ariel view of Tosson palace [17]**

**Table 1. Identified Factors for criteria condition evaluation**

| Group | Selected Indicator |
|---|---|

| | |
|---|---|
| Environmental | Pollution |
| | Temperatures |
| | water table |
| Economic: | Availability of funding |
| | Periods between each maintenance and the other for the area of the cultural heritage site |
| | Government interest in conservation of cultural heritage |
| Social | Employment rate |
| | Poverty of surrounding area |
| | Population growth |
| | Integration of the local community |
| | The quick very high profit from stealing and selling of artifacts |
| Natural | Location |
| Political | Unrest |
| | Terrorism |
| Cultural | Religious beliefs (monuments are to be destroyed) |
| | Pride of heritage |

## CONCLUSIONS

Laser scanning is a new trending technology that supports introduction of pioneer concepts for archiving and evaluation of heritage buildings. This paper presents a framework for evaluation and identification of most influencing factors on maintainability of cultural heritage buildings in Egypt. It implements Heritage Building Information Modeling (HBIM) concepts. Additionally, enhanced Heritage Asset Component Management is investigated by creating a new grading and classification System specifically for Heritage Components with hierarchical relationships. Full information descriptors including historical, social and technological context were discussed. The framework proposes plotting those findings on GIS maps for decision makers to take the decision concerning priority maintenance works.

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