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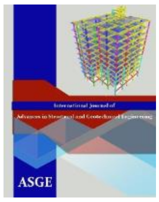

Prioritization of Heritage Buildings in Historic Cairo for Restoration Funding

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Abstract

Egypt is one of the richest countries in its historic and tourism attractions which are among the main contributors to the country's gross domestic product (GDP). Historic Cairo which has hundreds of mesmerizing historic Coptic and Islamic structures (mosques, churches, mausoleums, etc.) has been identified by UNESCO as a world heritage site since 1979. However, it has been noticed that its share in the tourism revenues is quite low compared to its value. One of the reasons is that many of the historic structures are closed because they are severely deteriorated due to urban expansion, pollution, environmental hazards, and aging. To revive the tourism in Historic Cairo, the government has been directing its efforts towards the conservation of those structures and reopening them to the public, and thus increase tourism-based revenues. However, the funding needed to restore all structures is very limited. There are hundreds of historic structures in need for restoration with a budget of more than one billion EGP. Accordingly, this research proposes a decision support system inspired by infrastructure asset management system (IAMS) to guide the fund allocation process. It follows the sequential steps of IAMS from asset inventory, condition assessment, up to prioritization and fund-allocation, yet considering the unique value of each heritage building and the expected socioeconomic benefits of restoring the structures and upgrading their surrounding areas. Therefore, this new structured decision support system will help policy makers develop the best rational restoration plan that will help rejuvenate Historic Cairo, and subsequently Egypt's tourism revenues.

1. Introduction

Egypt is well known for being the land of the world's greatest and earliest civilizations. It is one of the richest countries in terms of heritage ranking the 6th world-wide [1]. According to recent statistics, revenues from the tourism sector averaged 8.17 USD Billion from 2010 until 2021, reaching the highest with 13 USD Billion in 2021 [2]. The contribution of the Travel and Tourism sector to Egypt's GDP reached 22 billion U.S. dollars after recovery from the drop in travel due to COVID-19 epidemic lock down [3]. Accordingly, the tourism sector represents one of the main economy drivers that Egypt relies on. However, most of the tourism revenues are generated from the red sea resorts and the historic sites in Luxor and Aswan in Upper Egypt with Historic Cairo having the least share in those revenues, despite the hundreds of historic and heritage structures (mosques, churches, mausoleums, etc.) that have been declared in

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1979 as a UNESCO World Heritage Site. This is due to the fact that many of those unique structures are either fully or partially deteriorated leading to their closure. Most of them are suffering from severe cracks, distresses, settlement of ground, and underground water submerging problems. Moreover, many of those structures have severely deteriorated due to the exposure to several earthquakes during their lifetime, which have significantly shortened their lifespan, since they are designed mainly for gravity loads rather than lateral loads. Some historic structures have survived severe earthquakes because they were designed with a high safety factor for gravity loads. For example, the spire of Barcelona Cathedral (13th century) was built with a safety factor of 10 against gravity loads [4]. Therefore, historic structures need to be seismically evaluated to determine if they need to be strengthened against the threat of earthquakes to ensure their long-term survival. Moreover, they have been suffering from negligence and human disturbances from the surrounding neighborhood.

However, the conservation and strengthening of those structures is quite challenging due to the size and the complexity of the restoration work that would cost several billions EGP, and the fact that there are limited funds available. Moreover, there is no decision-making system to help policymakers prioritize the restoration of the hundreds of structures that require intervention. Nevertheless, there are multiple dimensions to consider when making decisions, including the physical condition; the value in terms of architecture, age, era [5]; potential for increasing tourism-based revenues and socioeconomic benefits [6]; etc. Accordingly, to accommodate those aspects along with the large number of structures in need for restoration, an optimization model is needed to arrive at the optimum restoration funding decisions under the limited budget available [7].

Few research efforts addressed the prioritization of heritage buildings. Among those efforts, Turskis et al. [8] developed a multi-criteria model using analytical hierarchy process (AHP) for ranking cultural heritage structures for renovation projects, considering economic critieria in terms of project's cost and time, Historical-cultural criteria in terms of the valuable features of the structure, and social criteria in terms of social standard of the district where the structure is located. Saradj et al. [9] discussed a prioritization ranking method for heritage buildings in Iran for conservation considering value of each historic structure, vulnerability and condition assessment, and the cost of restoration. Naziris et al. [10] developed a model for optimum allocation of limited resources available to 20 heritage building to renew the fire safety system, considering the population and value of each heritage building, and the value of the building's contents. Kututa et al. [11] developed a prioritization model for restoration of buildings for considering social, archeological, and economic criteria. Similarly, Perng et al. [12] developed an optimization model to determine best restoration work packages, considering social, political, and economic criteria along with the historic value of the building. Despite those efforts, there is a lack of research on the optimization of fund-allocation decisions for large number of heritage buildings, as in the case of Historic Cairo, where there are several dimensions that need to be considered.

However, several research efforts have addressed optimization of fund-allocation decisions yet in the infrastructure rehabilitation decision making problem, as part of the well-established infrastructure asset management system (IAMS) that starts by asset inventory and ends up by prioritization and fund-allocation [13]. For example, [14-15] developed optimization models to prioritize competing road assets for rehabilitation funding. Barone and Frangopol [16] developed optimization model for rehabilitation of Bridges. Similarly, Rashedi and Hegazy [17] developed fund-allocation model for buildings.

There is quite a resemblance between the decision making problems of infrastructure rehabilitation and heritage buildings restoration. In both problems, policy makers need to make funding decisions for hundreds of competing structures for intervention under limited budget availability. Infrastructure and heritage buildings, are both public structures that deteriorate over time and require costly interventions over their life time. Thus, both mandate proper life cycle benefit cost analysis. Moreover, both are public structures that are one of the economy pillars. Accordingly, this research proposes a comprehensive decision support system (DSS) that follows the steps of the well-established infrastructure asset management system (IAMS) to help policy makers find the optimum fund-allocation decisions that maximize the structural performance and the socioeconomic benefits under the available limited funds, considering the value of the structure.

2. Proposed decision support system

The proposed decision support system consists of sequential steps following the well-established steps of IAMS, yet after adapting them into the conservation problem of historic structures, as shown in Figure 1. As opposed to rehabilitation of infrastructure assets, it is quite necessary to capture, when making restoration decisions, the value of heritage buildings and the vast socioeconomic benefits that will be gained once the structure will be restored and opened to the public. Accordingly, those main differences were embedded in the proposed IAMS-based decision support system.

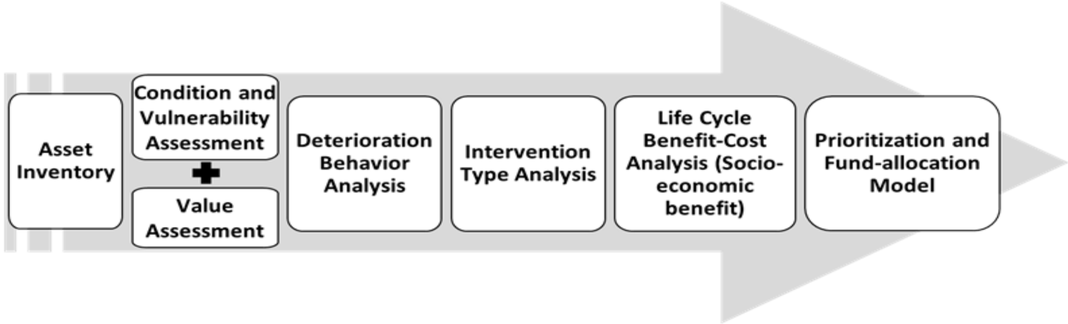

Fig.1: IAMS-based decision support system for conservation of historic structures

Table 1: Attributes of the historic structures stored in the GIS model

Name	ID	Location (X, Y)	Construction Year	Age	Dynasty
El-Refaai Dome	108	30.047, 31.276	1517	504	Mamluk Burji
Qebab El-Sabaa Benat	110	30.048 , 31.276	1517	504	Mamluk Burji
Quba Asfour	132	30.049 , 31.276	1404	617	Mamluk Burji
Abdel Wahab El-Shaarani Mosque	59	30.054 , 31.257	1567	454	Ottman
Zawya Nour El-Din Gulaq	173	30.052 , 31.261	1465	556	Mamluk Burji
Sabil Ibrahim El-Shourbagy	363	30.040 , 31.255	1746	275	Ottman
El-Bardini Mosque	201	30.040 , 31.255	1616	405	Ottman
Maqid Radwan Bey	208	30.041 , 31.257	1650	371	Ottman
Tekya El-Sulaymaniyah	325	30.036 , 31.255	1543	478	Ottman
Prince Almas Mosque	130	30.035 , 31.254	1329	692	Mamluk Bahri
Al-Sitt Miska Mosque	252	30.040 , 31.246	1339	682	Mamluk Bahri

In this research paper, the first three steps that include asset inventory, condition and vulnerability assessment, and value assessment, will be described along with their application to 11 historic structures located in different areas in Historic Cairo (El-Darb El Ahmar, El-Mamalik Desert, and Bab El-Shaarya) to demonstrate its practicality. The remaining steps are still work in progress as discussed in the future works.

Data Inventory and Visual Inspection

This step aimed to construct an inventory of data for the structures in terms of geographical location, historical records about its structural condition, historical background, dynasty, age, year of construction, and date of last intervention. To visualize this data and help with further analysis, a GIS model has been developed to map the collected data. To collect the needed data, a review of the existing archives at the Ministry of Tourism and Antiquities has been conducted. The literature was investigated as well to collect historical data about the structures in terms of the dynasty, year of construction, age. In addition, site visits were conducted to collect basic data about the structure, including its exact geographical coordinates using forms based on forms developed by the Urban Regeneration for Historic Cairo [18]. The form consists of three main sections [7]: 1) the first section collects the structure name, location, and ID as registered in the records of the Ministry of Tourism and Antiquities, dynasty of the structure; 2) the second section collects information about the structure's typology in terms of type and purpose of structure when it was first constructed, and 3) the third section collects information about the current use of the structure, and date of last intervention. Table 1 below summarizes the preliminary attributes collected for each structure.

For the visual Inspection, site visits to the historic structures in collaboration with antiquities' inspectors were held. During those site visits, the structures were visually inspected by structural engineers and photos were taken to collect structural condition relevant data and to help with further computerized analysis related to the condition and value assessment as will be discussed later. To map the historic structures under study and store all the related information (extracted from the data inventory) in form of attributes (e.g., current condition, dynasty, age, etc.), a GIS model was developed. It helps in conducting geospatial analysis to analyze the space around the historic structures under study and how the structures are related to each other in terms of proximity, neighborhood, and accessibility.

Scale	1	2	3	4	5
Architectural Value القيمة المعمارية للأثر	No clear architectural form or architectrual elements are distinguished as Large part is collapsed.	Architectural form can be recognized but architectural elements are partially collapsed or badly deteriorated.	Common architectural form and common architectural elements.	Unique architectural form OR unique architectural elements.	Unique architectural form AND unique architectural elements.
Historic Value القيمة التاريخية للأثر	Related to little known (or unknown) persons, no significant historical era or event	Related to famous public persons, or merchants	Related to army leaders or ministers or famous Imams, related to philanthropic functions or community activities (eg sabil - kuttab)	Related to a historic event or belongs to first degree relatives to Egyptian rulers or sybmolic figures	Related to a significant historical event, belongs to one of the previous rulers of Egypt
Age Value عمر الأثر	400 or less Ottoman	400-700 Mamluk	700-1000 Fattimad	1000-1200 Ekhshidiun-Abbasid-Toloniun	>1200 Early Islam-Ummayed-Abbasid
Neighbourhood Value/ Urban Value القيمة العمرانية (المنطقة التي يتواجد بها الأثر)	The structure is located in a remote and deserted place, away from Historic Cairo.	The structure is related historically or structurally to a neighbouring structure (e.g., the remains of El-Turba El-sultanya)	The structures belongs to a historic complex with unique features in a well-planned neighbourhood (e.g., Qaitbay Complex)	Close to well-established famous area (located in side streets)	Located in Well-established famous neighboourhood (Moez st.)
Geographical Location Attractiveness Value جاذبية الموقع الجغرافي	Side Lane or inside Cemetry	Narrow Lane	Side Street	Main Street	Famous Square
Religious Value القيمة الدينية للأثر	The structure doesn't have any religious value	The structure belongs to a well-known religious figure for the surrounding community only	The structure belongs to a famous religious figure in Egypt	The structure belongs to a famous religious figure in the region (Imams)	The structure belongs to first degree relatives of the prophet or to very well known figure world-wide
Political Value القيمة السياسية للأثر	The stucture doesn't have any political impact	The structure can attract people's attention greatly, and therefore any negligence may affect the image of the concerned departments	Any negligence can attract the attention of NGOs	The structure has great value with respect to the national and / or religious identites, any negligence can stir the public opinion and the image of the authorities	Any negligence can attract the attention of international organizations (UNESCO)
Accessibility Value إمكانية و سهولة الوصول لهذا الأثر و دخوله	Very Hard to reach, unpaved roads	Reachable through 1 route, fairly paved roads, can be reached by asking neighbor residents	Relatively accessible through one or two routes,Good paved roads	Accessible through two or more routes, Very Good paved roads, not on the main road, side roads	Highly accessible through multiple routes, On main road, Very good paved roads, Located in the heart of Historic Cairo

Fig.2: Value Rating Survey Sheet

The GIS model will be integrated later with the fund-allocation model to help with the decision making among the competing structures for fund, taking into consideration the stored geospatial information.

Multi-criteria Value Assessment

The objective of this task was to conduct value assessment for the structures under study to be considered when prioritizing the structures for fund-allocation. The assessment considers the following values: the structure's architecture, neighborhood, accessibility, history, age, political value, cultural value, and religious value.
To evaluate the value of each structure, a generic numerical rating has been developed using a scale of 1 to 5, where 5 represents the highest value and 1 represents the least value. A linguistic description for each score has been established. To develop this evaluation rating, a survey sheet has been constructed and distributed among experts in the field to collect their interpretation of each score. Figure 2 below shows the description of each score with respect to each criterion after compiling the feedback of each expert. After determining the value of each structure with respect to each criteria, an overall value score is computed, using the weighted score method, for each structure to be used later in the fund-allocation task. This method is commonly used to compute a value considering multiple criteria with different weights of influence in making decision. Accordingly, it has been adopted in this study to compute the overall value rating of each structure using Equation 1.

$$\boldsymbol{V_i = \sum_{C=1}^{N} W_c VR_{C_i}} \quad (1)$$

Where, $\boldsymbol{V_i}$ is the value score of a given structure (*i*), $\boldsymbol{W_c}$ is the weight of each criterion (*c*), $\boldsymbol{VR_{C_i}}$ is the value rating given to a structure (*i*) with respect to criterion (*c*). The sum of the weights $\boldsymbol{W_c}$ should be equal to 1. This score will be later used in the prioritization algorithm for fund-allocation.

To compute a value for each structure using the aforementioned method "weighted score method", experts in the domain have been asked to: 1) assign a weight W_c to each value criterion, and 2) evaluate each structure with respect to each criterion by assigning a value rating VR_{C_i} with respect to the developed scale shown in Figure 2. To facilitate computations, an average value for the expert's input has been calculated. It has been noticed that the Architectural value has arguably the highest weight of 25% followed by the historic value with a weight of 20%; while, the age, accessibility and geographical location values were assigned the least weight of 5%. This could be explained, that usually decision makers consider the characteristics of the structure rather than any other gains from the conservation work. Figure 3 illustrates the overall value of each structure, where it can be noted that Mosque of Abdel-Wahab El-Shaarany has the highest overall value, followed by Mosque of Prince El-Mas and El-Bardini Mosque. This could be explained by the high values that Mosque of Abdel-Wahab El-Shaarany received in the survey with respect to the religious and political values, as many prayers are being held there. On the other hand, Sabil Ibrahim El-Shorbagy has the least value, as it scored quite low in most of the criterions. It should be noted as well that the results of this task will be further validated, using the opinions of several experts. In addition, since the architectural value has the highest weight in terms of influence in the overall value of the structure, detailed architectural assessment will be conducted as well, as part of the future works.

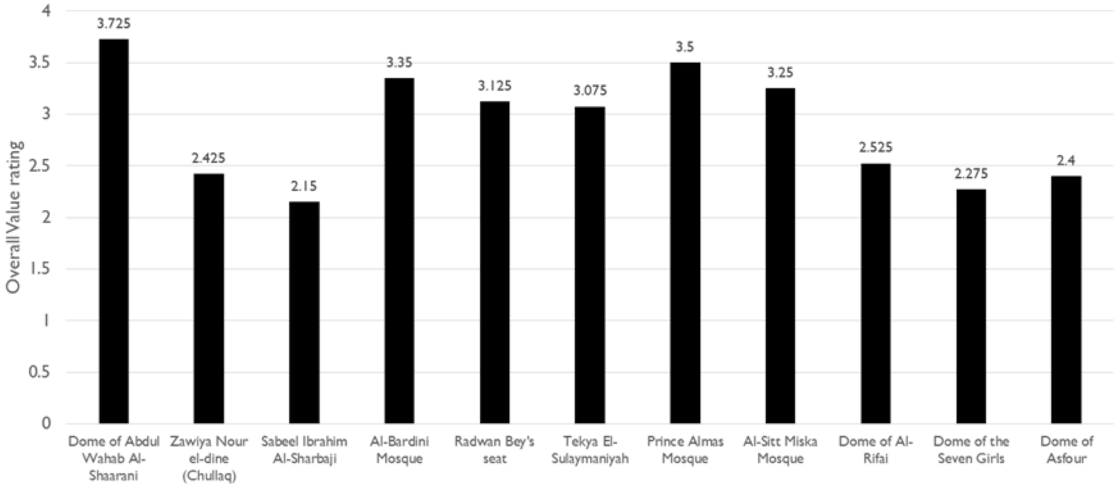

Fig.3: Overall Value Rating of each structure

(a) General view of the structure.

(b) Signs of damping and high ground water table.

(c) Signs of deterioration and missing parts.

Fig.4: Condition of Maqid Radwan Bey

Structural Condition Assessment

The objective of this step is to evaluate the condition of the inventory of the studied historic structures to determine the severity of deterioration of each component and to help with identifying the suitable rehabilitation for each structure. The assessment was conducted using extensive visual inspection in site visits for the structural elements of each structure using prepared checklists. Collected data included information regarding the inspected building, type of construction material, number of stories, footprint dimensions, type and characteristics of lateral load resisting systems, characteristics of non-structural systems…etc. The inspection depended on importance, extent, and intensity of defects within an inspected structure. It also reflects whether the building is still functional or not. Afterwards, a condition rating is computed for each structure, based on inspector judgement of building components, using a scale of 0 to 4, where 4 represented the worst condition and 0 represented the best condition, as shown in Table 2. This condition rating to be used later in the fund-allocation task. Figure 4 shows a sample of the photos taken during the visual inspection of the condition of Maqid Radwan Bey, where it shows signs of severe deterioration and signs of damping on the walls due to high underground water table.

Seismic Vulnerability Assessment

The objective of this task is to evaluate the seismic vulnerability of historic structures in case of earthquakes. Assessment of the seismic risk is a rising concern considering the deteriorated conditions of many historical structures in Old Cairo. It is considered as a major element in devising prevention strategies and forecasting damage by seismic events. Vulnerability reflects the probability of a structural system to take damage upon event occurrence. It is usually considered as the opposite of system resilience.

Table 2: Five-point scale for condition assessment of buildings

Condition Rating	General Condition Description	Detailed Description
0	Excellent State	Sound structure
1	Good State	Functionally sound structure
2	Slightly degraded	Adequate structure with some evidence of minor cracking, damping, etc.
3	Moderately degraded	Structure functioning but with problems due to significant cracking and major structural problems
4	Highly degraded	Structure has serious problems and concerns are raised for the integrity of the structure

Table 3: GNDT Method Classes and Weights for Masonry Buildings [19]

Parameters		Vulnerability Class (C_{vi})				GNDT Weight (W_i)
		A	B	C	D	
P1	Typology of resisting system	0	5	20	50	0.75
P2	Organization of the resisting system	0	5	20	50	1.00
P3	Conventional strength	0	5	20	50	1.50
P4	Maximum distance between walls	0	5	20	50	0.50
P5	Horizontal diaphragms	0	5	20	50	1.50
P6	Number of floors	0	5	20	50	0.75
P7	Location and soil conditions	0	5	20	50	1.50
P8	Aggregate position and interaction	0	5	20	50	0.75
P9	Plan regularity	0	5	20	50	0.75
P10	Vertical regularity	0	5	20	50	0.50
P11	Roof system	0	5	20	50	1.00
P12	Interventions	0	5	20	50	1.00
P13	General state of preservation	0	5	20	50	1.00
P14	Non-structural elements	0	5	20	50	0.50

The Italian GNDT vulnerability method (1993) represent one of the most common methods. In this method, a vulnerability index that relates seismic action intensity to expected damage of structure is defined. This vulnerability index is defined to reflect the capacity of a building to endure earthquake actions associated with an expected limit state. The index depends on several parameters including type and organization of resisting system, quality of resisting system, conventional strength, building position and foundation, horizontal diaphragms, etc. This index will be used as a priority index in the prioritization algorithm. The GNDT approach including 14 parameters, as shown in Table 3, was adopted for seismic vulnerability determination. Collected data include information regarding the inspected building, type of construction material, number of stories, footprint dimensions, type and characteristics of lateral load resisting systems, characteristics of non-structural systems…etc. Then, the vulnerability index is calculated as per Equation (2). Figure 5 shows a sample for the used checklist following GNDT Approach.

$$I_v^* = \sum_{i=1}^{14} C_{vi} * P_i \quad (2)$$

Where C_{vi} is the vulnerability class and P_i is the weight associated to the corresponding parameter as indicated in Table 3 for masonry buildings. The vulnerability index is then normalized as follows:

$$I_v = \frac{I_v^*}{650} * 100 \quad (3)$$

Figure 6 demonstrates both the condition rating and vulnerability index computed for each structure using the aforementioned methods. It can be noticed from the figure that Zawiya Nour el-dine (Chullaq), Sabeel Ibrahim Al-Sharbaji, and Radwan Bey's seat have the highest condition rating due to their severe condition. However, Radwan Bey's seat has the highest vulnerability index of 73.5. Figure 7 shows the GIS model that has been developed using ArcMap for the selected structures, along with attributes stored for each. The GIS model enables visualizing the structures in terms of any selected attributes. For instance, three categories have been defined for the structure's condition index: Good (Green, CI ≤ 2), Fair (Yellow, 2 < CI ≤ 3), and Poor (Red, CI > 3). Accordingly, it can be noticed that each structure has a color-code node which represents its current condition. For example, Radwan Bey's seat "مقعد رضوان بك" has a red node that corresponds to its poor condition index of 4.

Figure 8 below shows the normalized values of the condition rating, value rating, and vulnerability index for each structure in one collective chart. Having those numbers in one visual chart can act as a primary tool to help policy makers with their restoration decisions in terms of priority and funding.

Parameter 1: Type & Organization of Resisting System			
Class (A)	• Buildings built in compliance with the seismic regulations for the new buildings. • Buildings with full walls and / or repaired according to the prescriptions of repair regulations.		☐
Class (B)	Buildings presenting at all levels and on all the free sides connections made by perimeter beams or chains and clamps capable of transmitting vertical shear actions.		☐
Class (C)	Buildings that, although not presenting curbs or chains at all levels, are constituted by orthogonal walls well tightened to each other		☒
Class (D)	Buildings with orthogonal walls not effectively bound.		☐
Parameter 2: Quality of the Resisting System			
Class (A)	• Good quality brick walls, well-squared stone or tuff walls, provided they are homogeneous in all their extension; • Well-woven walls and homogeneous, provided they have connections between the two sheets.		☐
Class (B)	• Well-squared but not homogeneous brick masonry, stones or tufa. • also packed as long as they have connections between the two sheets.		☐
Class (C)	• Masonry in roughly squared stone or in brick of poor quality, in the presence of irregularities; • Sack walls, in tuff or stone, well woven but not connected between the two sheets.		☒
Class (D)	• Irregular stone masonry; • Brick walls of poor quality with inclusion of pebbles (حصى); • Badly-woven walls and without connections between the two sheets.		☐
Parameter 3: Conventional Resistance			
Number of floors (N)	1	Average Covered area (A_t)	55
Total Area of Resisting Elements in X Direction (A_x)	6	Total Area of Resisting Elements in Y Direction (A_y)	3
Average Floor Height (m)	6		
Class (A)	Building with:	$\alpha \leq 1$	☐
Class (B)	Building with:	$0.6 \leq \alpha < 1$	☐
Class (C)	Building with:	$0.4 \leq \alpha < 0.6$	☐
Class (D)	Building with:	$\alpha < 0.4$	☐

Fig.5: Sample Used Checklist following GNDT Approach

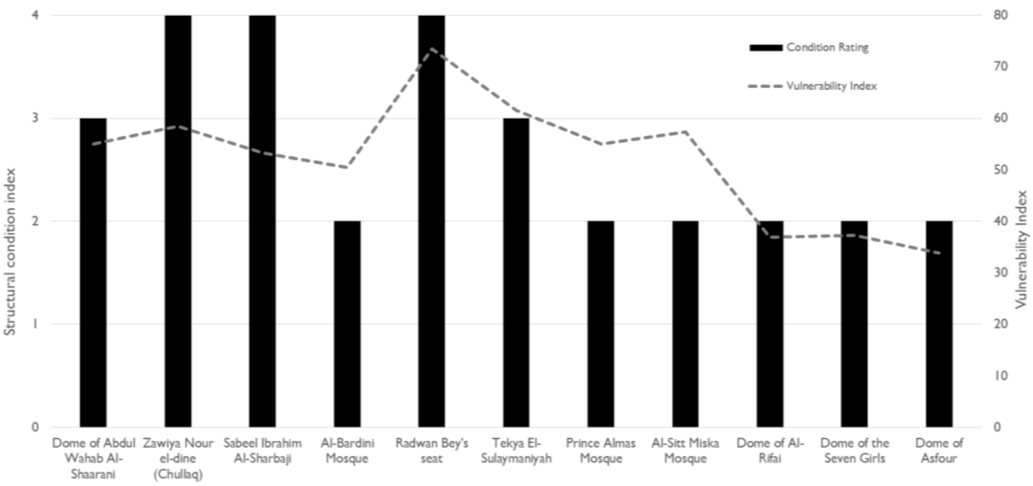

Fig.6: Condition rating and vulnerability index of each structure

For instance, as a matter of discussion, the structure of Radwan Bey's seat requires immediate action due to its high condition rating and vulnerability index. Afterwards, the structures of Zawiya Nour el-dine (Chullaq) and Sabeel Ibrahim Al-Sharbaji need intervention in a timely manner due to their critical condition rating as well. Afterwards, one can consider Dome of Abdel Wahab Al-Shaarani and Tekya El-Sulaymanayah due to their moderate condition, yet high overall value rating. Those scores can be integrated as well into one index that represents the importance of a given structure.

3. Conclusions

The paper presented the first research effort for cataloguing, evaluating, and prioritizing restoration works for the numerous old heritage buildings in Historic Cairo. The research aims at developing a comprehensive DSS to help decision makers arrive at best rational fund-allocation decisions for the hundreds of conservation projects competing for the limited budget available.

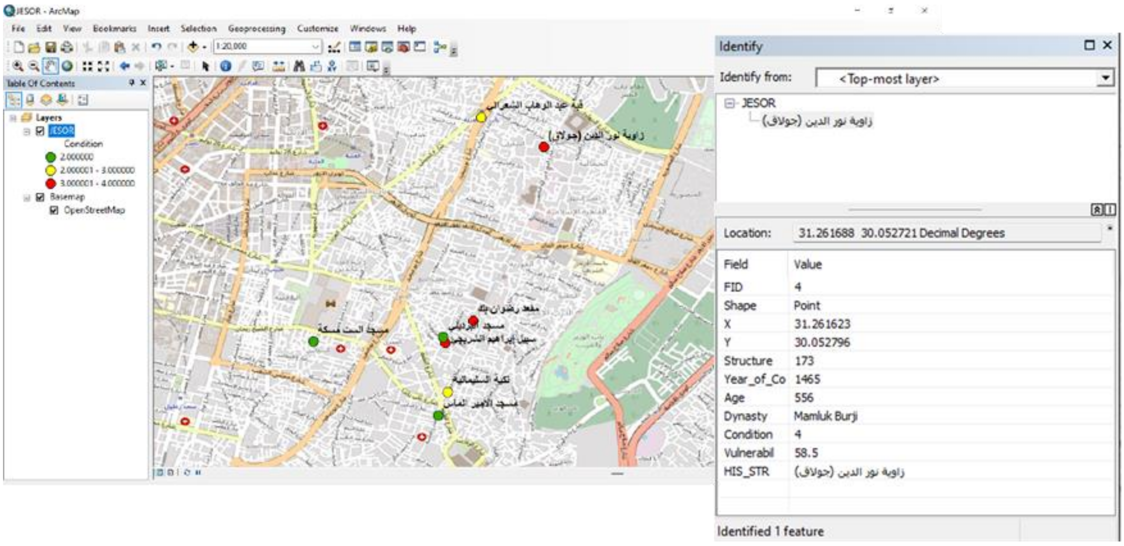

Fig.7: GIS model of the selected structures showing the stored attributes and condition

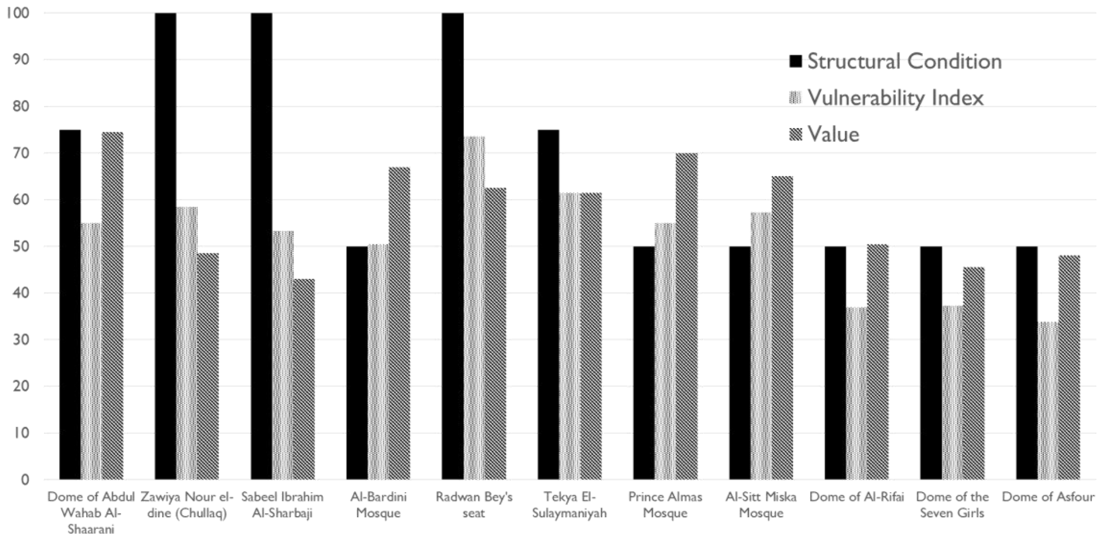

Fig.8: Visual representation showing normalized structural condition and value ratings for each structure and vulnerability index

The proposed DSS has four unique characteristics: (1) It adapts the scientific infrastructure asset management methods to the special requirements of heritage structures; (2) It provides structured steps from inventory creation up to prioritization and limited-budget allocation for restoration projects; (3) it captures the unique value of each heritage building and the socio-economic benefit of restoring each building and upgrading its surrounding area; and (4) It incorporates a structural and seismic assessment of each structure to enable modelling its deterioration behavior and estimating the cost necessary restoration work.

In this paper, the application of the first four steps of the proposed DSS on inventory and visual inspection, value assessment, condition assessment, and seismic vulnerability assessment to 11 structures have been demonstrated. Those structures are located in three areas of Historic Cairo and represent different dynasties (Mamluk and Ottoman), usages (mosque, zawya, etc), and architectural forms (domes, arches on columns, etc). According to the carried out assessments, it was found that Radwan Bey's seat requires immediate action due to its high condition rating and vulnerability index, while Abdel Wahab El-Shaarani Mosque has the highest overall value. Despite the importance of those values, there is a need to compute the potential socioeconomic benefits that will be gained once the structure is reopened to help with the decision making. Thus, an effort is being exerted as part of the ongoing works to capture those socioeconomic benefits. Extend the study to a larger number of structures, and develop an optimization model to facilitate fund-allocation decisions in this multi-dimension problem where there are hundreds of structures competing for limited budget. In essence, the proposed DSS will aid policy makers make decisions in a timely manner to save Egypt's heritage and improve tourist revenues.

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