A FUND-ALLOCATION OPTIMIZATION FRAMEWORK FOR PRIORITIZING HISTORIC STRUCTURES' CONSERVATION PROJECTS - AN APPLICATION TO HISTORIC CAIRO

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Abstract: Egypt is famous for its cultural heritage and historic attractions that span thousands of years. This cultural heritage is one of the tourism industry motors which contributes significantly to the country's gross domestic product (GDP). Historic Cairo has been declared as a UNESCO World Heritage Site for having hundreds of mesmerizing historic Islamic and Coptic structures; however, tourism-revenues are quite small relative to the ones generated from the famous red sea resorts and Luxor and Aswan ancient sites. This is because most of these structures are partially or completely closed due to the need for restoration and/or their poor structural condition. However, conserving these structures is quite challenging due to its complexity, lack of funds for restoring hundreds of historic structures, and lack of structured funding system. Therefore, this paper proposes a framework for a new multi-objective optimization model that prioritizes competing historic structures for the limited funding available while maximizing the structural physical performance and the socioeconomic benefits over a specified planning horizon, considering: the expected deterioration behavior over the funding period, vulnerabilities to further damage, costs associated with the conservation method, and the structure's relative importance in terms of its value. In essence, the new model will help decision makers determine the optimum restoration plan to open the deteriorated historic structures to the public, and thus increase tourism-based revenue generating streams to rejuvenate the tourism sector in Historic Cairo, and have a positive impact on Egypt's economy.

1   INTRODUCTION

Travel and Tourism sector is one of the most influential economy drivers. It contributes enormously to the growth domestic product (GDP) on both the global and domestic levels. One out of ten jobs are often supported by Travel and Tourism which is around 9.9% of the global employment (WTTC, 2018). In 2017, the total contribution of Travel and Tourism to GDP was USD8,272.3bn (10.4% of GDP). Egypt is well-known for its ancient heritage and modern sea resorts; accordingly, Travel and Tourism has a great economic impact on its well-being. For instance, in 2016, Travel and Tourism sector contributed to Egypt's GDP by USD19.4bn, which is 7.2% of GDP, and provided around 1,763,000 jobs although it has been recovering from the devastating terrorists attacks (WTTC, 2017). Accordingly, Egypt relies massively on Tourism as one of its main sustainable revenue-generating streams to boost the nation's economy. However, the red sea resorts and the historic sites in Luxor and Aswan in Upper Egypt have been dominating those streams unlike Historic Cairo although it is well-known for its eye-catching historic structures (mosques, churches, mausoleums, etc.) that has been declared in 1979 as a UNESCO World

Heritage Site. This, on one hand, is due to lack of effective management plans of such sites. On the other hand, due to that several historic structures are closed or partially opened to public because they suffer from medium to severe deterioration in the form of cracks, tilting, garbage disposal at site, increased level of ground water, and exposure during the replacement of neighboring modern buildings' subsurface infrastructure. Moreover, many of these structures have experienced damaging earthquakes across their lives, which are considered one of the major hazards that can significantly shorten their lives because they were designed to support mainly gravity loads not lateral loads. Some historic structures had survived severe earthquakes because they were designed with a large safety factor to resist gravity loads. For instance, the Spire of Barcelona Cathedral (13th c.) was built with a safety factor of 10 against gravity loads (Elyamani, 2016). On the other hand, a large number of master pieces of human heritage structures have been destroyed by catastrophic earthquakes. Accordingly, historic structures need to be seismically assessed to determine whether they require strengthening against the threat of earthquakes in order to ascertain their survival in the long term.

Restoration and strengthening of historic structures located in Historic Cairo is quite challenging due to the complexity of work, the hundreds of structures in need for restoration works with a total cost of more than one billion EGP, and the limited funds available. As a result, many sites are closed and some others are partially restored yet are still closed due to the lack of funding to complete restoration works. Moreover, this funding problem is a multi-dimensional decision-making problem; such that, multiple aspects need to be examined when considering a structure for restoration, including: the physical condition; the value in terms of aesthetic architecture, age, era (Saradj, 2011); potential for tourism-based revenue generating streams; the resulting socioeconomic benefits; etc. Accordingly, a comprehensive decision support system is highly needed to optimize the distribution of funds among the required restoration works to achieve the highest socioeconomic benefits under the limited budgets available.

Allocation of limited resources/funds to structures (e.g., buildings, bridges) in need for rehabilitation has been well established in the infrastructure asset management domain. Many research efforts developed optimization models to prioritize competing assets for rehabilitation funding, examples include: Roads (Saad and Hegazy 2015a; Zhang et al. 2013; De la Garza 2011), Bridges (Bocchini and Frangopol 2012; Elbehairy et al. 2006), Buildings (Tong et al. 2001). However, less efforts have tried to address the problem of distributing budgets among a large number of competing historic structures for conservation funding. For example, Saradj et al. (2016) discussed a prioritization procedure to rank historic structures in Iran for conservation and seismic upgrading considering several factors including: value of each historic structure, vulnerability and condition assessment, and the cost of interventions. Naziris et al. (2016) developed an optimization model for allocating the limited resources available to 20 historic structures in need for fire safety upgrading, considering three criteria: population of each historic structure, building value, and contents' value. Kututa et al. (2013) developed a linear additive ranking model to prioritize buildings for conservation investment considering multiple criteria (social, archeological, economic, etc.), and select the building with the highest score for investment. Perng et al. (2007), also developed a Genetic Algorithms optimization model to determine the optimum budget allocation to packages of restoration works. The model's objective was to determine the optimum packages of restoration works considering social, political, and economic criteria along with the historic value of the building. Chatzigrigoriou and Mavrikas (2013) conducted an online survey to identify variables that influence the priority of a building for conservation.

Despite these efforts, none of them provided a comprehensive solution that can arrive at optimum funding for large number of historic buildings as the case in Historic Cairo where there are hundreds of historic structures in need for restoration, considering the multi-dimensional aspects associated with the restoration work. To find a comprehensive solution for this problem, this research proposes a fund-allocation multi-objective optimization model adopted from the well-established infrastructure asset management domain. Yet, the model will be adapted to the problem of funding the conservation works of historic structures rather than modern infrastructure considering the structure's value; vulnerability of historic structures; and socio-economic benefits associated with the conservation of each historic structure. This comprehensive decision support system will be one of the first to address such decision-making problem. It will help policy and decision makers identify optimal strategic plans for restoring historic structures to maximize the structural performance and the socioeconomic benefits under the

available limited funds. Applying this novel decision support system to Historic Cairo will help rejuvenate tourism in Historic Cairo and subsequently improve Egypt's economy and welfare, and will add to the exerted efforts in preserving Egypt's heritage.

2   PROPOSED FRAMEWORK

The proposed research approach, as previously mentioned, is adopted from the well-established infrastructure asset management domain which follows a systematic process to optimize infrastructure funding. The process consists of the following steps: Identifying an inventory of assets, condition assessment, deterioration behavior analysis, study of repair alternatives, life cycle cost analysis, and prioritization and fund-allocation. This approach will be adapted to the problem of funding the conservation works of historic structures rather than modern infrastructure, yet along with considering the value of each historic structure. Figure 1 shows the proposed framework, which starts with populating the historic structures located in Historic Cairo up to allocating funds to the competing structures through a prioritization optimization algorithm. The following subsections describe each step in the proposed framework.
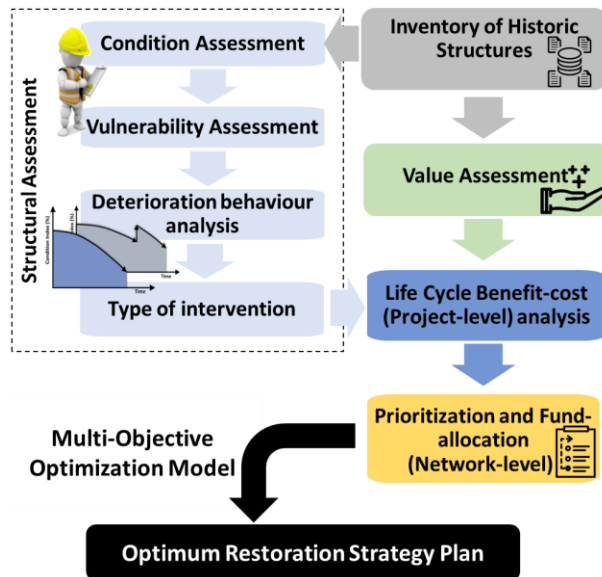

Figure 1: Framework of the optimization model for historic structures conservation

2.1   Inventory of Historic Structures

In this step, a survey will be conducted to collect information about the existing historic structures in Historic Cairo that require funding to perform the needed conservation works. The following data shall be collected: historical background (e.g., the construction date, the dynasty that the structure belongs to, date of last conservation activity, etc.); current status (opened, partially opened, closed); geographical location including the surrounding neighborhoods; typology (residential, commercial, religious, etc.); current ticket price, if any; current use, if any; and potential for tourism attraction. A concurrent survey will be conducted as well to assess the value and the physical condition of the historic structures, as described in the subsequent sections. Accordingly, a checklist form has been constructed to aid in collecting all the needed information during the site visits of these historic structures. A sample of the designed checklist is shown in Figure 2 from the actual site visits to the 15th c. historic structure of "Madraset El-Sultan Al-Ashraf Barsbay"

Figure 2: Sample of the Checklist used in site visits for Data Inventory.

State of conservation		
Date of last conservation activity:	2004	
Previously Conserved	☑	Undergoing conservation ☐

General Information on the structure		...rvation
Structure Name:	Madraset El-Sultan Al-Ashraf Barsbay	...ly dilapidated ☐
Structure Address:	Moezz Street	...rtially dilapidated ☐
Structure No.:	175	...use
Construction Date:	826 - 827 A.H / 1423 - 1424 AD	...ly Reused ☐

Time Period		Status of the structure		...ture Reuse ☐
Early Islamic period (639 – 969)	☐	Closed	☐	...tervention
Fatimid period (969 – 1171)	☐	Partially-opened	☑	
Ayubid period (1171 – 1250)	☐	Opened		
Mamluk Bahri dynasty (1250 – 1382)	☐	Entrance		
Mamluk Burji dynasty (1382 – 1517)	☑	Ticket		
Othman Period (1517 – 1848)	☐	Ticket		
Modern Period (1848 – 1945)	☐			
Unknown	☐			

Architectural Value			
Arches	☐	Peculiar cladding	☐
Wooden shade	☐	Porticos	☐
Wooden doors	☑	Balconies	☑
Masharabia	☑	Iron work	☐
Baluster	☐	Gypsum glass window	☐
Minaret	☑	Dome	☐
Sky light	☐	Corniche	☐
Buttress	☐	Loggia	☐

Typology		
Religious		
Church & cathedral	☐	Aqueduc
Mashehad & Mausoleum	☑	
Monastery	☐	
Mosque	☑	
Madrasa	☑	
Specialized		
Theatre	☐	

Uniqness of Structure	
The structure has a unique architectural style	☐
The structure was designed by distinguished architect	☐
The structure reflect special period of art or history	☐
The structure is considered a special case in construction and art	☐
The structure have a special building materials	☐
The structural system is quite unique	☐

2.2 Value Assessment

In this step, the value of each historic structure will be quantified, using the previously mentioned field survey and the historical records for previously restored structures, to help identify the various benefits associated with the rehabilitation of each structure. The value will be qualitatively assessed with respect to the following criteria:

1. Architectural value: This refers to the style, design, artistry, decoration, and aesthetic value of the buildings and their significance
2. Historic Value: This refers to the value of the structure in terms of the history behind it (e.g., the first mosque built in the Fatimid dynasty)
3. Age value: This refers to the age value as the older the structure is, the more precious it is.
4. Cultural and Religious value: This refers to the value of the historic structure with respect to any interested ethnic groups, tribes, or religious groups
5. Accessibility value: This refers to the easiness of accessibility to the historic structure and its impact on the potential number of visits.
6. Neighborhood value: This refers to whether the historic structure under study belongs to an already existing historic cluster or complex and the value of this cluster.

An overall score will be given to the structure based on the degree of satisfying the above criteria. This score will be used to set a relative importance factor among the structures in the prioritization and fund-allocation process; moreover, it can also be used to determine the expected tourism demand and the appropriate ticket pricing by comparing it against the value of previously restored historic structures.

2.3 Condition Assessment

In this step, physical condition assessment of the inventory of historic structures located in Historic Cairo will be carried out using two methods: visual inspection and in-situ non-destructive tests. Visual inspection was employed as an effective tool in describing the state of deterioration of historic structures in Egypt dating back to Islamic, Ancient Egyptian and 20th c. heritage (El-Derby and Elyamani 2016; Elyamani, 2018). The visual inspection will be conducted using a checklist form that includes: type of element,

number of deteriorated components within each structure (e.g., minaret, walls, columns, flooring), surface cracks: location and length, type of construction material and the severity of deterioration of each component. The in-situ non-destructive tests will be conducted to obtain qualitative and quantitative data on the global and local levels of the structure to provide sufficient knowledge about the internal composition of structural elements and the strengths of the used construction materials. Using this data, three-dimensional (3D) finite element models will be developed to simulate the current behavior of the structure. Dynamic identification tests shall be used, as well, to calibrate the developed numerical models (Zaki et al., 2008; Abbas and Hassan 2016; Hassan et al. 2017).

2.4   Vulnerability Assessment

In the proposed framework, vulnerability of historic structures to further damage due to earthquakes and ground water is considered in the prioritization algorithm for funding. Historic structures in the zone under study are characterized by main architectural aspects such as large span domes, tall minarets and wooden roofs. Accordingly, they may experience degradation in both stiffness and strength under seismic influences leading to severe deterioration and damages including: collapse of top of minarets, wall cracks, dome cracks, collapse of wooden roofs, (Osman, 2010). However, the structure's behaviour depends on the current condition index and the seismic vulnerability assessment of each structure. Accordingly, the vulnerability index method proposed by the Italian research institution Gruppo Nazionale per la Difesa dai Terremoti (GNDT 1999) will be employed. The output of this method is the earthquake vulnerability index I_v^* evaluated for each structure under consideration inside the area of study. This index will be used as a priority index in the prioritization algorithm as discussed later, it will be computed using the following empirical equation:

[1] $I_v^* = \sum_{j=1}^{m} C_{vj} \cdot w_j$

Where, C_{vj} is the score assigned to each class (A, B, C and D) and w_j is the weight (0.25, 0.5, 0.75, 1,1.5) according to the construction material of the investigated structure (masonry or reinforced concrete).

Moreover, one of the major problems affecting structures in Historic Cairo is the high level of ground water table due to improper drainage, leading to submergence of the structure's flooring, and subsequently, the exposure of the supporting walls and the foundations to impurities and salts leading to further deterioration. The ground water problem can be directly spotted by visual inspection in addition to excavation works around the concerned structure. In this research, its impact will be considered in the deterioration behaviour of the historic structure as discussed in the next subsection.

2.5   Deterioration Behavior Analysis

Structural resistance decreases as time passes due to aging, deterioration and neglect. Accordingly, in the proposed framework, a deterioration model will be developed to simulate the behavior of historic structures over a given planning horizon considering the current physical condition and the vulnerability to further damage due to high groundwater table effect. Since natural hazards are not certain events, therefore, a probabilistic deterioration model will be developed to consider the impact of the uncertain events that may negatively affect the structure performance, and accordingly determine the structure's priority and appropriate time for intervention, if needed, to avoid severe deterioration and reaching an unacceptable condition. Based on historical records, historic structures may experience mild deterioration over a short planning horizon of 5 years in case of no occurrence of natural hazards. However, under the impact of high underground water table, they may experience degradation in both stiffness and strength. To avoid deterioration to an unacceptable level for any historic structure, an analysis should be conducted to study different types of interventions and their impact on the deterioration behavior of the structure along with the associated costs, as shown in Figure 3 below.
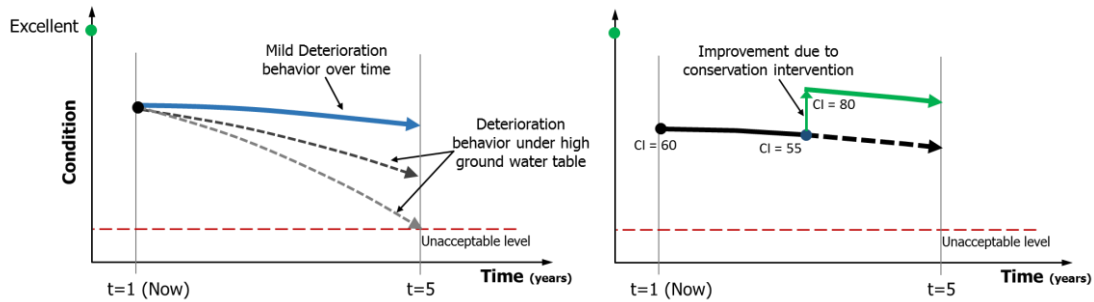
Figure 3: Deterioration behavior of a historic structure with and without intervention

2.6   Type of Intervention

After determining the physical condition and the expected deterioration of each historic structure over a given planning horizon/funding period, alternative conservation interventions employed in Egypt, will be investigated and evaluated considering their applicability, cost-effectiveness, and short and long-term impact on the structure's life cycle. These methods aim mainly at preserving the authentic features to the extent possible, and are designated according to the manifested damage in the structure's elements (e.g., bearing walls, floors, arches, etc.). For instance, interventions for bearing elements (walls, columns, piers, etc.) may include: injection of cracks with hydraulic mortars, stitching of cracks, dismantling and reconstruction, application of composite materials (CFRP, GRFP, etc.), structural repointing, anchoring with ties from different materials (timber or steel), surface mounted anchored nets from different materials (steel, composite materials, etc.). While for covering elements (e.g., floors, arches, vaults, domes, etc.), interventions for restoring floors may include: improvement of the in-plane stiffness for floors using orthogonal or diagonal planking, or timber flange connected by wooden dowels to main beams, and improvement interventions through the use of steel elements like metallic plates and metallic diagonals. For vaults, arches and domes, various techniques are available such as: buttressing; counter elements; tie at the intrados; tie at the extrados; cross ties at the extrados; overcoat with composite material strips; reinforcement arches; etc. For improving the connections between bearing elements and covering elements such techniques could be used: reinforced masonry or steel ring beams, steel connectors timber floors to walls, metallic ties with end plates, anchoring systems without end plates, energy dissipation systems. Some structures suffer from high groundwater table and foundation related problems, thus, dewatering techniques to lower ground water level can be applied, along with other remedial measures.

2.7   Benefit-Cost Analysis

After identifying the most cost-effective type of intervention for each historic structure, benefits associated with the restoration of each of these structures need to be measured over a specific life span to justify the costs associated with the restoration project. In this research, the benefits associated with the restoration project are defined in terms of: 1) Structural performance (SP) benefit in terms of improvement in the structures' physical condition, and 2) Socioeconomic (SE) benefits associated with the expected tourism demand on any given historic structure, and subsequently the potential tourism revenues that will be generated from opening the historic structure to the public to attract both domestic and foreign tourists. The structural performance benefit (B_{SP}) will be formulated as the difference between structures' average condition index before and after restoration considering the deterioration behaviour over a specified time horizon (Saad and Hegazy, 2015a). Accordingly, a condition index that reflects the structure physical performance will be developed to facilitate measuring the condition of the structure before and after restoration in any given year in the funding period, as illustrated in Figure 3.

Socioeconomic benefits (B$_{SE}$), on the other hand, are divided into tangible (monetary) and non-tangible (non-monetary) benefits. The tangible ones reflect the direct tourism revenues (WTTC, 2018), including: structure entrance ticket sales, and increased income to the surrounding local businesses that deal directly with the tourist (e.g., hotels, restaurants, bazars, and other leisure and recreational services), while the non-tangible benefits are the ones gained by the neighbourhood of the historic structure (e.g., reopening a closed cathedral or mosque after restoration and its spiritual impact on the residents). Accordingly to integrate both benefits, this research proposes utilizing well-established microeconomic methods to monetize the non-monetary benefits (e.g., contingent and hedonic methods) whenever it is feasible, along with a multi-criteria method to integrate both monetary and non-monetary benefits associated with the rehabilitation of the historic structures under study. In addition to that, the analysis will consider any possible social dis-benefits (costs) due to the activities associated with the restoration works (e.g., preventing unauthorized sellers from accessing the historic site, removing any activities that might disturb the surrounding of the historic structure or impact its structural safety).

2.8   Prioritization and Fund-allocation

Once the various benefits and costs associated with the conservation of each structure are identified, a fund-allocation optimization algorithm will be employed, to prioritize the competing structures for restoration work and determine the optimum timing within the specified funding period, while maximizing the overall benefits under the limited budget available. To solve this decision-making problem, hundreds of combinations of restoration intervention timings need to be analyzed. Accordingly, to solve this complex combinatorial problem, a mathematical optimization will be developed to determine the optimum fund-allocation to the competing historic structures over a planning horizon considering the physical condition and the socioeconomic benefits under the limited budget available. However, since there are two types of benefits need to be maximized, a multi-objective function will be formulated using the Penalty method or the weighted sum method (Saad et al. 2018). Accordingly, the parameters of the proposed multi-objective optimization model are as follows:

Decision Variable: a 2-dimensional binary decision variable x_{ij} is used to represent whether a given historic structure (i) will be restored in a given year (j) in the given funding period or not. For example, if x_{23}=1, it means that the 2nd structure will be restored in year 3 of the funding period.

Objective function: to minimise the deviation of each objective from its targeted goal. This targeted goal is determined by running standalone optimization models for each objective to determine the maximum achievable values under the limited funds available. These deviations are relatively weighted according to the decision-maker preference, as shown in Equation 4 below. Such that, there weights acts like penalties for not meeting the goal. The sum of the penalties' weights should be equal to 1. To add these deviations in the objective function, they have been normalized as shown in Equations 5 and 6.

[2] Minimize $Dv_t = W_{SE}Dv_{SE} + W_{SP}Dv_{SP}$

[3] $Dv_{SE} = (B_{SE_g} - \sum_{i=1}^{N} x_{ij} \times B_{SE_i})/B_{SE_g}$

[4] $Dv_{SP} = (B_{SP_g} - B_{SP})/B_{SP_g}$

[5] $B_{SE_i} = V_i \times (B_{T_i} + B_{NT_i})$

[6] $B_{SP} = [\sum_{i=1}^{N} CI_i \times (I_v^*)_i] /N - [\sum_{i=1}^{N} CIo_i \times (I_v^*)_i]/N$

Where, B_{SE_i} refers to the socioeconomic benefits associated with any given structure (i), B_{T_i} refers to the tangible benefits, and B_{NT_i} refers to the non-tangible benefits. B_{SP} refers to the structural performance

benefit, B_{SE_g} and B_{SP_g} are the goals for the SE and SP benefits, respectively, Dv_t is the total deviation, W_{SE} and W_{SP} are the relative weights of importance of the SE benefit and SP benefit, respectively. While, CIo_i refers to the initial current condition index of any given structure, and CI_i refers to the average condition index of the structure at the end of the pre-defined time horizon considering its deterioration behaviour and whether it has been selected for restoration or not. I_v^* is the earthquake vulnerability index of each structure, V_i is importance factor of each structure according to its value.

Constraints: The total costs TC in any given year (j), which is the sum of all assets' rehabilitation costs (RC_{ij}), should not exceed the available annual budget B_j, as shown in Equation 7. The historic structure's physical average condition (CI_i) should not fall beyond an acceptable condition index (CI_A) in order to avoid overlooking critical structures, as formulated in Equation 8. Each structure will only be visited once for intervention during the funding period as shown in Equation 9.

$$[7]\ TC_j = \sum_i (RC_{ij} \times x_{ij}) \le B_j$$

$$[8]\ CI_i \ge CI_A$$

$$[9]\ \sum_j x_{ij} \le 1 \quad for\ i = 1\ to\ N\ assets$$

3   APPLICATION

Since the proposed framework includes multiple stages of lengthy work and extensive data gathering, the newly developed optimization model has been tested out first on ten historic structures, to validate it and prove its applicability. These structures are dating back to Mamluk and Ottoman eras, they include 5 Mosques, 2 Mausoleum domes, 2 Wekala, and one Bayt. In this study, the socioeconomic benefits are limited to the revenues gained from tourism, domestic and foreign, once these historic structures are restored and opened to the public. The planning horizon is 3 years with an annual budget of 70 million EGP. Figure 4 illustrates the setup of the optimization model using a spreadsheet; such that, it shows each historic structure in a separate row along with: the expected annual domestic and foreign tourism demand (in terms of number of visitors), the expected restoration cost after identifying the type of intervention as previously described, the value assessment (V_i) with respect to 6 weighted criteria (Architecture, Historic, Age, Culture & Religion, Accessibility, Neighbourhood), expected annual tourism revenues based on the expected demand and ticket prices, vulnerability factors in terms of the earthquake (EQ) priority index (I_v^*) and groundwater (GW) index, and the deterioration behaviour over time. The EQ priority index is used to determine the relative importance among the structures considering the expected damages under seismic impact, while the GW index is incorporated in the deterioration behaviour to reflect the expected degradation in performance under high level underground water table. In this study, the deterioration behaviour is deterministically modelled. The optimization setup shows as well for each structure the restoration timing decision variable (x_{ij}), the structural performance (SP) and socio-economic (SE) benefit associated with the restoration work of any given structure, and the annual restoration cost and budget over the predefined funding period.

To formulate the multi-objective function; as previously described in Equation (2), the B_{SP_g} and B_{SE_g} goals need to be computed. Accordingly, two standalone single objective optimization experiments have been conducted separately to determine the highest achievable values. The first model resulted in a value of 13.65 for the B_{SP_g} goal where all the needy structures were given higher priority over the other ones, while the second model resulted in a value of 84 million EGP for the B_{SE_g} goal as it targeted the structures that would generate more tourism-based revenues. To implement the multi-objective optimization formulation,

the weights W_{SP} and W_{SE} were given values of 0.7 and 0.3, respectively in this paper as an initial experiment. After running the model, the results showed an optimum solution of 13.53 and 77.5 million EGP for the B_{SP} and B_{SE} benefits, respectively; along with optimum restoration timing for each structure. Such that, conservation interventions will be performed for structures 8, and 9 in year 1, structures 1, 6, 7, and 10 in year 2, and structures 2 and 3 in year 3. These results can be explained by that the model tried to satisfy both objectives, yet it gave more importance to the SP as it gave priority to the more physically critical structures, yet without sacrificing much the tourism-based stream of revenues (i.e., structures with high expected tourism demand). Thus, using this study, the model proves the applicability of the proposed multi-objective optimization model, and its capability to reach optimum fund-allocation decisions for competing historic structures for funding, and its extendibility to larger case studies.
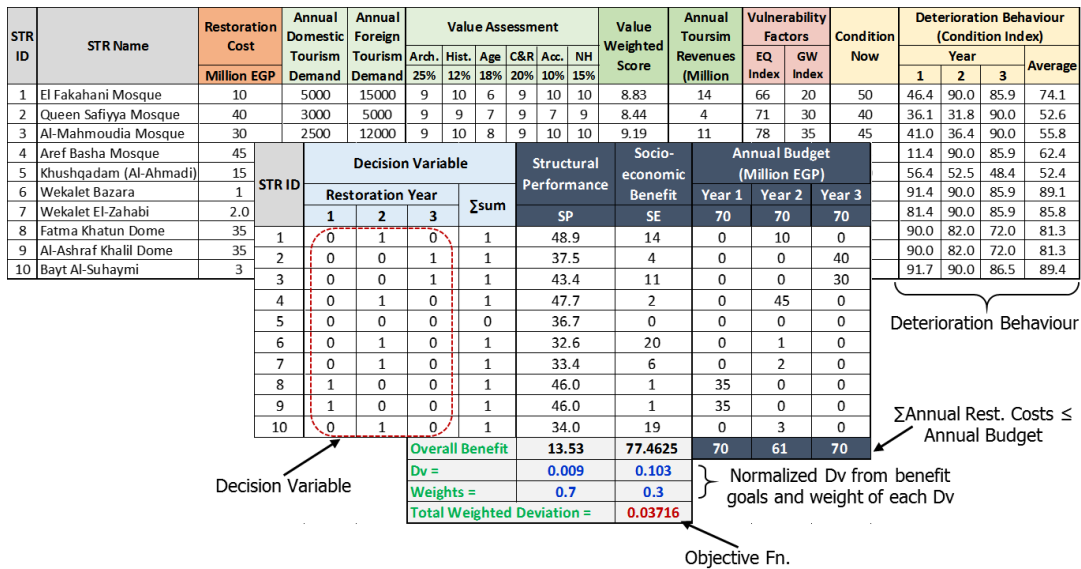
STR ID	STR Name	Restoration Cost (Million EGP)	Annual Domestic Tourism Demand	Annual Foreign Tourism Demand	Arch. 25%	Hist. 12%	Age 18%	C&R 20%	Acc. 10%	NH 15%	Value Weighted Score	Annual Tourism Revenues (Million)	EQ Index	GW Index	Condition Now	Year 1	Year 2	Year 3	Average
1	El Fakahani Mosque	10	5000	15000	9	10	6	9	10	10	8.83	14	66	20	50	46.4	90.0	85.9	74.1
2	Queen Safiyya Mosque	40	3000	5000	9	9	7	9	7	9	8.44	4	71	30	40	36.1	31.8	90.0	52.6
3	Al-Mahmoudia Mosque	30	2500	12000	9	10	8	9	10	10	9.19	11	78	35	45	41.0	36.4	90.0	55.8
4	Aref Basha Mosque	45														11.4	90.0	85.9	62.4
5	Khushqadam (Al-Ahmadi)	15														56.4	52.5	48.4	52.4
6	Wekalet Bazara	1														91.4	90.0	85.9	89.1
7	Wekalet El-Zahabi	2.0														81.4	90.0	85.9	85.8
8	Fatma Khatun Dome	35														90.0	82.0	72.0	81.3
9	Al-Ashraf Khalil Dome	35														90.0	82.0	72.0	81.3
10	Bayt Al-Suhaymi	3														91.7	90.0	86.5	89.4

Decision Variable table:

STR ID	Rest. Year 1	Rest. Year 2	Rest. Year 3	Σsum	Structural Performance (SP)	Socio-economic Benefit (SE)	Annual Budget Year 1	Year 2	Year 3
					SP	SE	70	70	70
1	0	1	0	1	48.9	14	0	10	0
2	0	0	1	1	37.5	4	0	0	40
3	0	0	1	1	43.4	11	0	0	30
4	0	1	0	1	47.7	2	0	45	0
5	0	0	0	0	36.7	0	0	0	0
6	0	1	0	1	32.6	20	0	1	0
7	0	1	0	1	33.4	6	0	2	0
8	1	0	0	1	46.0	1	35	0	0
9	1	0	0	1	46.0	1	35	0	0
10	0	1	0	1	34.0	19	0	3	0
Overall Benefit					13.53	77.4625	70	61	70
Dv =					0.009	0.103			
Weights =					0.7	0.3			
Total Weighted Deviation =						0.03716			

Decision Variable · Deterioration Behaviour · ΣAnnual Rest. Costs ≤ Annual Budget · Normalized Dv from benefit goals and weight of each Dv · Objective Fn.

Figure 4: Optimization Model Setup and Validation

4 SUMMARY AND CONCLUDING REMARKS

Egypt's heritage is one of its sustainable revenue-generating streams. Historic Cairo includes hundreds of key historic structures dating back thousands of years ago. However, many of these structures are severely deteriorated due to aging, negligence, and absence of structured funding system to support conservation works. Accordingly, this paper presents the framework of a newly developed multi-objective fund-allocation optimization model for prioritizing the competing historic structures for the limited funds available, while maximizing both the structural physical performance and the socioeconomic benefits associated with opening any historic structure to the public. Moreover, it explains rigorously the main steps of the framework starting by data inventory, assessment of the structure's condition; value; and vulnerability to further damage, benefit-cost analysis, and ending by the fund-allocation optimization model. This paper presents, as well, the mathematical formulations of the proposed multi-objective optimization model. The goal of this research is to implement the new model on large-scale conservation projects; however, real data gathering and processing is a quite lengthy process. Accordingly to validate and test drive the proposed optimization model, a study of 10 real historic structures has been utilized in this paper. Using this study, the model proved its capability of arriving at optimum fund-allocations decisions, and its potential applicability to larger-scale real case studies. In essence, the proposed new optimization model can help policy makers take sound decisions in the complex problem of funding historic structures, and subsequently have sustainable tourism income that can rejuvenate the country's economy.

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