Civil Engineering and Architecture 13(3): 2006-2018, 2025 http://www.hrpub.org
DOI: 10.13189/cea.2025.130340

Climate Change Resilience in Historic Cairo: Risk Management Strategies for Built Cultural Heritage Preservation

Noha A. Shaheen[1,*], Khaled Dewidar[1], G. Nagy[1], Ashraf Ali Nessim[2]

[1]Department of Architecture, Faculty of Engineering, The British University in Egypt, Al Shorouk, Egypt
[2]Department of Architecture, Faculty of Engineering, Ain Shams University, Cairo, Egypt

Received December 14, 2024; Revised March 18, 2025; Accepted April 21, 2025

Cite This Paper in the Following Citation Styles

(a): *[1] Noha A. Shaheen, Khaled Dewidar, G. Nagy, Ashraf Ali Nessim , "Climate Change Resilience in Historic Cairo: Risk Management Strategies for Built Cultural Heritage Preservation," Civil Engineering and Architecture, Vol. 13, No. 3, pp. 2006 - 2018, 2025. DOI: 10.13189/cea.2025.130340.*

(b): *Noha A. Shaheen, Khaled Dewidar, G. Nagy, Ashraf Ali Nessim (2025). Climate Change Resilience in Historic Cairo: Risk Management Strategies for Built Cultural Heritage Preservation. Civil Engineering and Architecture, 13(3), 2006 - 2018. DOI: 10.13189/cea.2025.130340.*

Abstract As the globe grapples with the profound consequences of climate change, its impact on built cultural heritage has emerged as a critical concern. Rising global temperature and unpredictable weather patterns threaten the integrity of historical sites, consequently, jeopardizing our collective identity and historical narratives. This paper focuses on Historic Cairo, Egypt identifying the risks associated with climate change based on the Representative Concentration Pathway (RCP) 8.5 outlined by the IPCC. The study aims to develop risk response resilience strategies to provide a comprehensive treatment plan for the impacts of the climate change risks affecting Historic Cairo. The research methodology comprises two main phases: a theoretical phase involving a literature review on climate change-associated risks and their impacts on built cultural heritage and an analytical phase involving an expert survey questionnaire targeting heritage management stakeholders. The data collected revealed that key stressors such as the mean air temperature, extreme heat, relative humidity, changes in soil chemistry, and fire weather exhibit critical challenges requiring urgent mitigation efforts and attention. Moreover, the historic associative value, along with the architectural, aesthetic, and artistic values demonstrated significant vulnerability. Hence, these values were assigned extremely high to high-risk priority levels necessitating proactive measures to mitigate the identified risks. In contrast, precipitation and rainfall were deemed to have low-risk priority levels on the heritage communal, urban, and historic values. Consequently, the risk response strategies were developed to effectively mitigate these challenges. This research contributes to the ongoing global and local efforts to enhance resilience in built heritage management. Additionally, it aligns with the sustainable development goal (SDGs goals 13 and 11) which emphasized the need for cultural built heritage protection and addressing vulnerabilities against climate change impacts with a specific application in the Egyptian heritage context.

Keywords Climate Change, Cultural Heritage, Risk, Risk Management

1. Introduction

Climate change, natural degradation, environmental changes, and human activity all contribute to the alarming rate, at which our cultural legacy is deteriorating. Understanding the various forms of climate change risks is crucial to safeguard our physical treasures for future generations [1,2].

1.1. Climate Change and Its Impacts on Built Cultural Heritage (BCH)

The significant challenges climate change poses to build cultural heritage threaten their structural integrity and longevity worldwide. The environmental shifts pose threats including moisture infiltration, erosion, and deterioration of the building's materials [3]. The IPCC Fifth Assessment Report (AR5) [4,5] categorized the climatic stressors into atmospheric drivers, which include heat and cold changes in temperature, wind, storms, wet and dry changes like rainfall, extreme environmental changes, and Marine and aquatic drivers related to the rise in sea levels, flooding and erosion as shown in **Figure 1** [6,7].

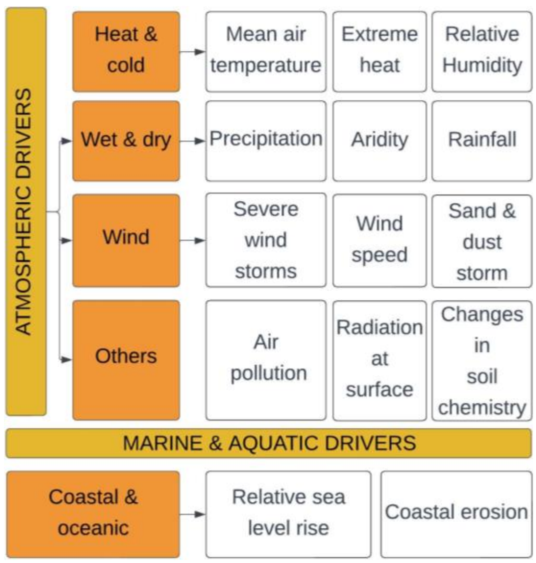

Figure 1. Climate change stressors (author, 2024)

A climate change emergency has been declared by ICOMOS since many systems will not be able to adapt to the 2℃ of warming than at 1.5℃ IPCC scenario [2]. Rising global temperature has resulted in severe weather events, clearly evident in Egypt through increased temperature, increased rainfall, water scarcity, and vulnerability to sea level rise [8]. Over the past 30 years, Egypt has experienced a temperature increase of 0.53℃ per decade. Moreover, it is predicted that there will be an average of 40 additional extremely hot days per year leading to increased heat waves and increased soil aridity and water vapor content. Amidst these changes, Egypt strives to preserve its cultural heritage. The study of comprehending how World Heritage sites in Egypt—particularly culturally built sites—will be impacted by climate change is rarely reported. Although Egypt submitted a report to the UN Framework Convention on Climate Change, prepared by the UN Development Program and the Ministry of Environment, it fails to address the impact of changing climate on built heritage [9].

For inclusion on the World Heritage list, a building must meet at least one of UNESCO's ten criteria for outstanding universal value (OUV). Recognizing the unique values/attributes, as shown in **Figure 2** that establish the significance of a building is crucial for ensuring its preservation [7, 10,11]

1.2. Risk Management for Heritage Preservation

Risk management for heritage preservation entails identifying, analyzing, assessing, and mitigating risks to guarantee its sustainability. As shown in **Figure 3**, this process typically involves (1) risk identification, determining potential climate change-associated risks, (2) risk analysis, assessment, analyzing the risk's probability of occurrence and significance, and (3) risk treatment phase, developing strategies to mitigate the identified risks. After this, risk monitoring and reviewing are required to monitor the cultural assets' resilience and maintain their historical and cultural significance [12-15].

Urgent attention and effective strategies shall be developed to address the significant challenges posed by climate change on built cultural heritage. Accordingly, implementing a robust risk management process is essential for preserving cultural legacies, especially in Historic Cairo.

1.3. Criteria of Chosen Case Study

With its diverse array of architectural wonders and cultural value, Historic Cairo stands at the crossroads of history and vulnerability. It serves as the historic core of Cairo. It entails 313 listed monuments, stretching from the Fatimid City in the north to the Salaheldin Citadel in the south. In addition, it has been a UNESCO World Heritage site since 1979 [16]. The targeted area, known as the heritage corridor stretches from El-Hakim mosque to Ahmad al Mihmandar mosque including museums, tourist attraction centers, and cultural centers as shown in **Figure 4**. Yet, this invaluable heritage is deteriorating due to climate change and human impact, requiring urgent protective actions.

This irreplaceable legacy is being acceleratedly deteriorating due to the influence of natural degradation, climate change, and increasing human activity [16]. Hence, the urgency to safeguard our built heritage is becoming mandatory as extreme weather events are becoming more intense and frequent.

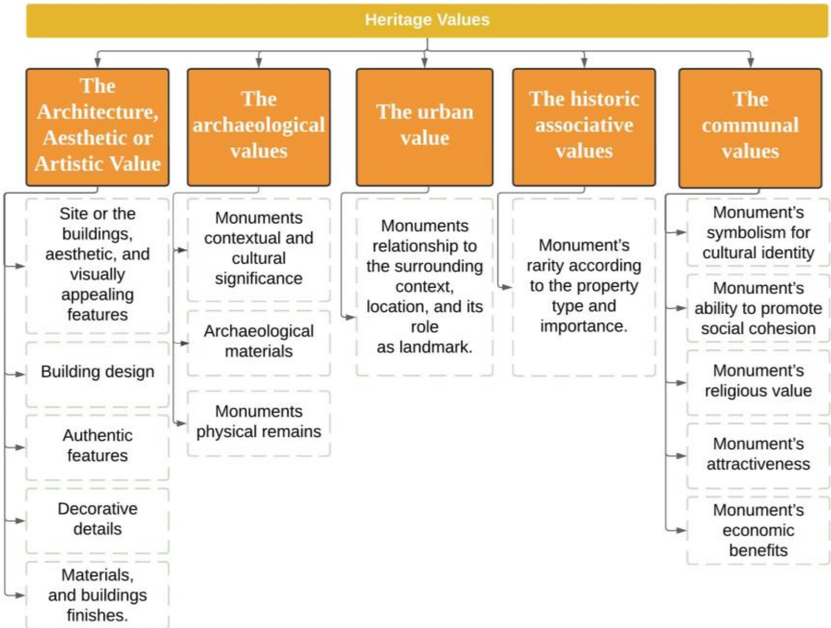

Figure 2. Heritage associated values (author, 2024)

	STAGE	DATA REQUIRED	STLAKHOLDERS	PROCESS	TOOLS REQUIRED	ASSOCIATED RISKS	OUTPUT
1	RISK IDENTIFICATION	• Historical documentation • Site condition data • Aerial imagery, • LiDAR data • Soil anlaysis • Structural assessment • Archeological survey	• Heritage experts • Conservation architects • Structural engineers • Archeologists	• Set the assessment scope and panel of expertise • Understand Heritage context & review existing information • Identifying the agents of deterioration • Identify the probability of occurrence of each agent of deterioration	• Historic record • site surveys • Remote sensing technology • Geotechniqual equipment • Ground penterating radar	• Lack of access to monument or restricted areas • Lack of data availability & quality • Incomplete or inaccurate historical information • Lack of comprehensive site surveys • Faliure to identify structural weaknesses that would affect the monument longevity • Changning climate conditions that poses new risks that was not addressed before	**Identified agents of deterioration affecting the Heritage values** **Matrix of Hazard likelihood assessment**
2	RISK ANALYSIS & EVALUATION	• Hazard indentifcation & likelihood assessment • Urban context & spatial data • Air quality, noise level • Weather data	• Risk managment specialists • Urban Planners • Environmental experts • Climate Scientists	• Quantifying the frequency of occurrence of the damaging event (occurrence rate from every 1 year to every 30000 years) • Quantifying the predicted loss of value to the heritage asset (whether total, large, small or tiny loss) • Determing the magnitude of risk	• Risk assessment software • GIS • Environmental monitoring tools • Weather Monitoring instruments	• Lack of expertise in risk analysis leading to inaccurate risk evaluation • Lack of urban risks understanding • Inadequate addressing of climate related damage	**Matrix of risk evaluation** **Identifing risk priority level based on the risk magnitude (catastrophic extreme, high medium and low priority)**
3	RISK TREATMENT	• Preservation & conservation guidelines • Evaluation & disaster prepardenss procedures	• Conservation organizations • Governmental agencies • Community members • Emergency response teams	• Applying effective measures to reduce or eliminate the identified risks • Applying 5 stages of control whether preventive or reactive measures	• Conservation materials & techniques • Legal/regulatory frameworks • Community engagment stratgies • Emergency response plans	• Inadequate funding to implement necessary meaures • Lack of conservation efforts • Lack of heritage protetion regulations • Lack of community support and awarness of monument value • Inadequate emergency response meaures • Delayed response to identified risks • Ineffective mitigation measures	**Risk treatment plan based on stages of control (AVOID, BLOCK, DETECT, RESPOND, RECOVER), layers of protection required and timeframe**

Figure 3. Heritage risk management process and expected outcomes (author, 2024)

Figure 4. Historic Cairo Targeted Area [1]

2. Methodology

2.1. Data Collection Phases

The research methodology employed a set of data collection phases from a literature review analysis of the existing body of knowledge on climate change's potential impacts on built cultural heritage and a survey questionnaire that aimed to identify and analyze the climate stressors impacting Historic Cairo and accordingly develop risk response strategies for risk mitigation. A flowchart summarizing this process is presented in **Figure 5**.

The questionnaire included closed-ended questions:

1. Section I (an introductory section) included general information about the respondents.
2. Section II (analytical survey) presented 12 climatic stressors related to the climate change risks in historic Cairo where the respondents were asked to rank the probability of occurrence of the risks that are likely to impact Historic Cairo. This will be further detailed in the risk-assessing section.
3. Section III (analytical survey) entailed asking the respondents to rank the significance of the impact of each climate change stressor on the heritage OUVs.

2.2. Probability and Impact Scale

The respondents used a Likert scale from 1 to 5 to rank the risks based on the scale defined by ICCROM [18], where the probability scale was Certainly occurring (5), Likely to occur (4), Unlikely to occur (3), Rare to occur (2), Extremely rare to occur (1). While the significance of the impact scale was Catastrophic (5), Major (4), Moderate (3), Minor (2), or Insignificant (1), these scales aimed to quantify the risks associated with each climate stressor and the severity of their impacts on the heritage OUVs. It also facilitated the risk magnitude calculations based on the ABC method [17,18] which is illustrated in **Figure 5.** It consists of numeric scales to quantify the probability of risk occurrence (value A), the significance of its impact (value B), and the expected loss of value per event (value C)**,** those three components define the risk magnitude (RM), upon which the risk priority levels are determined.

The ABC method evaluates the risk magnitudes and assigns a priority level by classifying the RM values into specific ranges. A catastrophic priority level (in red color) is assigned to values between 15 and 13.5 indicating the loss of all or most of the heritage OUVs within a few years. An extreme priority level (orange) is assigned to values between 13 and 11.5 indicating significant damage to the heritage OUVs or total loss of parts of the heritage asset in one decade. A high priority level (yellow) is assigned to values between 11 and 9.5 indicating a small fraction of the heritage OUVs will be significantly lost in one century. A medium priority level (green) is assigned to values between 9 and 7.5 indicating small damage might occur over centuries to the heritage OUVs, yet over many millennia a significant loss of a significant fraction of the heritage asset will occur. Low priority (blue) for values below 7 indicates insignificant damage to the heritage asset.

This classification will inform the risk response strategies development. The data were analyzed using Social Sciences (SPSS) statistical analysis for mean and correlation tests to assess the risks and formulate the required mitigation strategies.

2.3. Target Groups

The study targeted members from institutions working on heritage preservation with expertise in climate change impacts on built heritage.

Two groups of variables were used to test the different opinions of the respondents which are their occupation status and their years of experience in the field varying from 1-5 or 6-10 or 11-15 or 16+ years.

2.3.1. Occupation Status Variable Group

The questionnaire was completed by four categories of respondents: Archaeologists, cultural heritage specialists, architects, consultants, and specialists in the restoration and conservation of cultural heritage which means that the respondents acquired the necessary professional qualifications.

2.3.2. Work Experience Variable Group

These study respondents had two categories of work experience where the first had from 6-10, while the others had 16+ years of experience.

2.4. Sampling

The study adopted a non-probability stratified purposive sampling approach to seize knowledge in a specific type of expertise [19]. This study required particular expertise in heritage preservation and climate change phenomena.

2.5. Data Analysis

A total of 115 questionnaires were distributed among the mentioned target groups. The response rate was about 55.7% having a variety of occupations in the required field and a majority of 16+ years of experience as shown in **Figure 6**. Thus, it was inferred that the respondents have adequate knowledge of heritage management specifically related to Historic Cairo-associated risks.

In addition, a reliability test was run by the SPSS software in order to evaluate the reliability measurement of each variable, and it was found that the average value for reliability measurement was 0.977 which indicated adequate reliability of measurement.

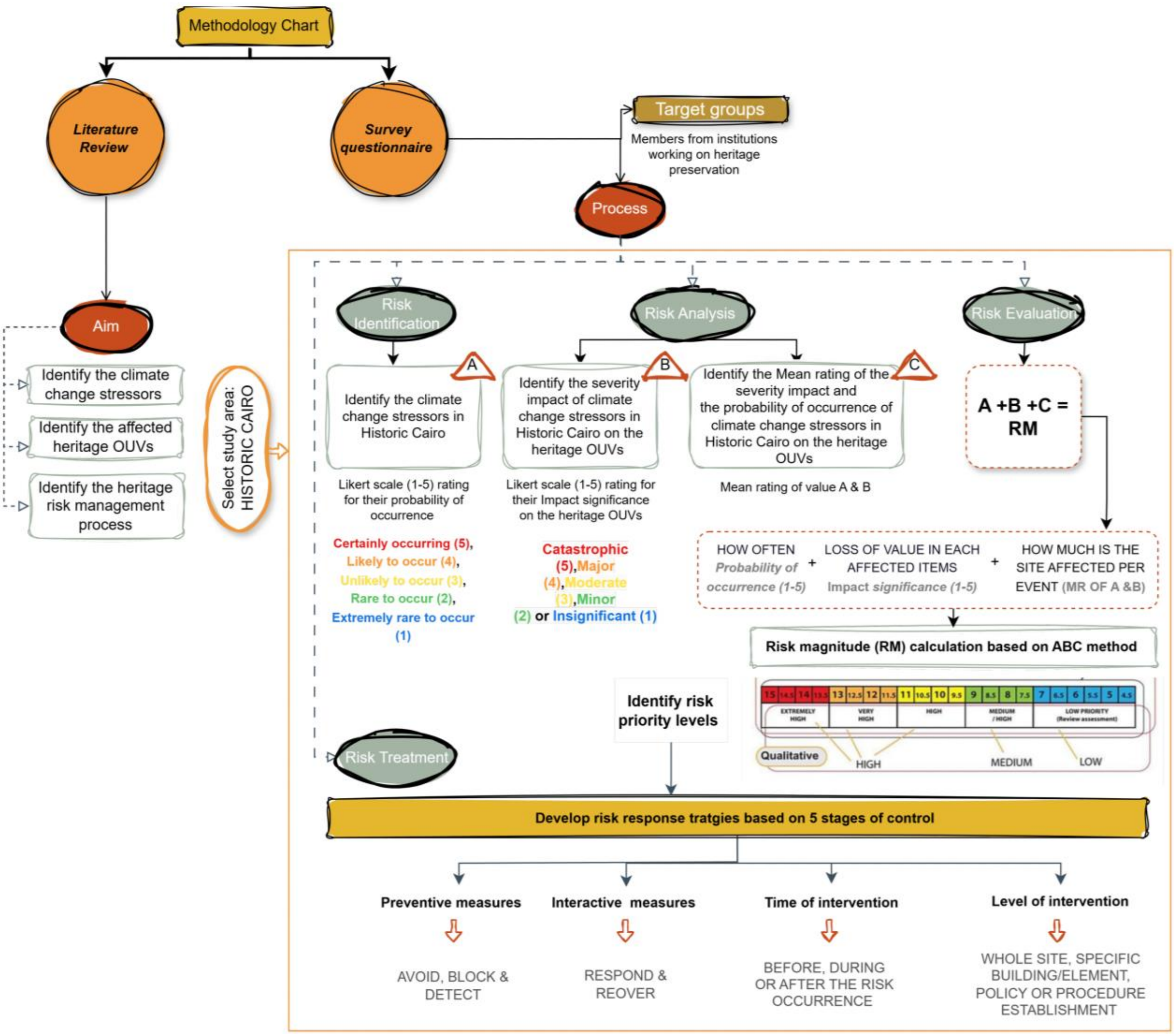

Figure 5. Flowchart of research methodology (author, 2024)

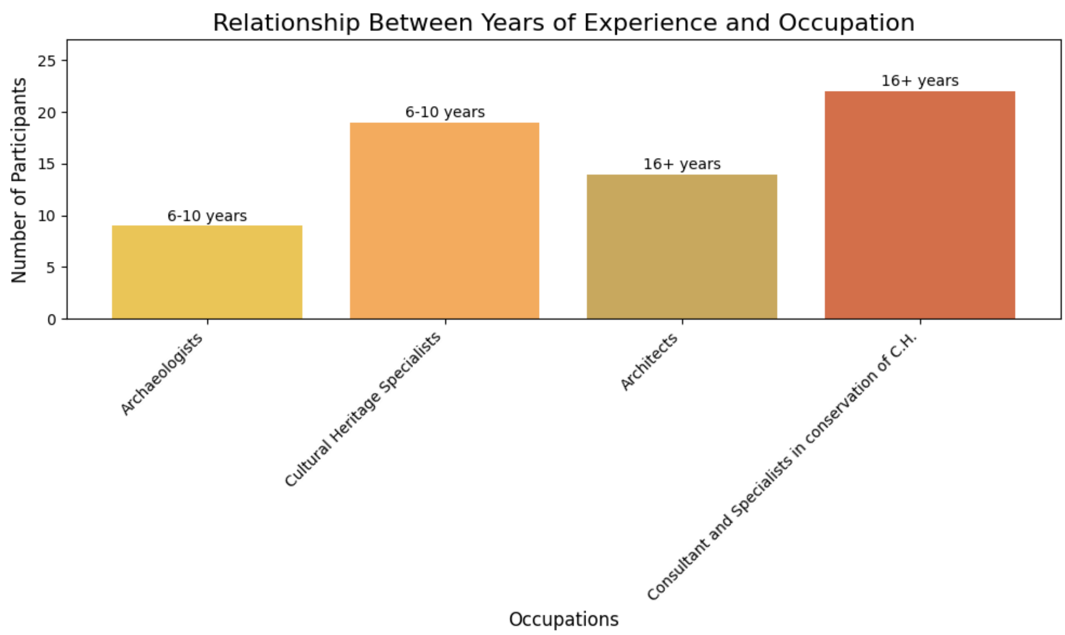

Figure 6. Distribution of occupation status and years of participants' experience (author, 2024)

3. Results

The findings of this paper present developed risk response strategies towards a resilient built heritage for protecting Historic Cairo from climate change.

3.1. Determination of Expected Climate Change-Related Risks on Historic Cairo

Table 1 indicates the climate stressors identified by the experts, rated according to their likelihood of occurrence (1 to 5). The experts assigned the following ratings:

- **Certainly occurring risks:** mean air temperature, extreme heat waves, relative humidity, changes in fire weather, and underground soil chemistry changes.
- **Likely to occur risks:** rainfall, precipitation, aridity, wind speed changes, sand and dust storms, air pollution, and increase in radiation at the surface.
- **Extremely rare to occur risks:** marine and aquatic drivers' category.

3.2. Analyzing and Evaluating Identified Risks

The significance of the impact severity of the climate stressors on the heritage values (OUV attributes) was quantitatively assessed based on a Likert scale from 1 to 5, hence a mean rating was calculated for the severity impact on each heritage OUV category as shown in **Figure 7**.

According to the outcome of **Table 1** and **Figure 7**, the mean rating of the probability of occurrence and significance of the climate stressors' impact on the heritage categories was calculated to inform the calculation of the risk magnitudes based on the ABC method [18] and **Figure 5** which sums the mean ratings (Frequency distribution) of the probability of occurrence of each climate stressor on Historic Cairo, the climate stressor significance on each heritage value category and the mean rating of both of them.

Table 2 displays the calculated risk magnitudes where the red cells indicated the risks that require immediate attention (catastrophic risk priority) and mitigation strategies, while the orange cells might require responsive and proactive planning (extreme and high-risk priority).

3.3. Risk Treatment Towards a Resilient Built Heritage for Protecting Historic Cairo from Climate Change

The treatment strategies displayed in **Table 3** were formulated upon this criterion, which was informed by the literature review analysis and the outcomes of previous risk management phases [20,21].

- Focuses on the IPCC scenario of RCP 8.5 which is the high emission scenario, the current situation where emissions continue to rise throughout the century, thus leading to severe climate changes and impacts causing significant risks.
- Encompasses applying the ICCROM 5 stages of control principles to have preventive (avoid, block, detect) or interactive (respond, recover) methods.
- Addresses the level of control considering the level of the whole site, particular element/feature, procedure, or policy establishment.
- Categorized by urgency:
    - Short-term (immediate to one year) that focuses on immediate hazard prevention
    - Medium-term (one to five years) for proactive measures and boosting resilience
    - Long-term (five years and beyond) for developing long-term resilience, strategic planning, and recovery.
- Specifies the timing of intervention whether before, during, or after the risk occurrence.

Table 1. Hazards likelihood of occurrence in the selected study area

	Heat & cold	Wet & dry	Wind	Others	Coastal & Oceanic
	Atmospheric drivers				Marine & aquatic drivers
Climate stressors	Mean air temperature	Precipitation & rainfall	Wind speed	Air pollution	Relative sea level rise
	Prop.	Prop.	Prop.	Prop.	Prop.
	5	4	4	4	1
	Extreme heat	Aridity	Sand & dust storm	Radiation at surface	Coastal erosion
	Prop.	Prop.	Prop.	Prop.	Prop.
	5	4	4	4	1
	Relative humidity	Fire weather	Severe wind storms	Changes in soil chemistry	
	Prop.	Prop.	Prop.	Prop.	
	5	5	4	5	

PROBABILITY OF OCCURANCE (Number Coded) → Certainly occurring (5), Likely to occur (4), Unlikely to occur (3), Rare to occur (2), Extremely rare to occur (1)

CLIMATE STRESSORS / OUV ATTRIBUTES			Heat & cold			Wet & dry			Wind			Others		
			ATMOSPHERIC DRIVERS											
			Mean air temperature	Extreme heat	Relative Humidity	Precipitation & Rainfall	Aridity	Fire weather	wind speed	Sand & dust storm	Severe wind storms	Air pollution	Radiation at surface	Changes in soil chemistry
			IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT	IMPACT
Architectural, Aesthetic or artistic value	Architectural Excellence	Architecture design elements	4	4	4	4	3	5	4	4	4	4	4	2
		Structural Integrity	3	3	4	3	3	5	4	4	4	2	2	5
		Architectural Features (Elements that serve structural or functional purposes)	4	4	4	4	3	5	4	4	4	4	4	4
		Feautres Representing the Architectural Style of its time	4	4	4	4	3	5	4	4	4	4	4	4
	Historical Significance	Historical Context	4	4	2	3	3	5	4	4	4	3	4	4
		Role of Monument in Shaping History	4	4	4	3	3	5	3	3	3	3	3	3
		Monument Cultural Symbolism	4	4	4	3	3	5	3	3	3	3	3	3
	Artistic Details	Sculpture Details	4	4	5	4	4	5	4	4	4	4	4	4
		Carvings	4	4	5	4	4	5	4	4	4	4	4	2
		Decorative Elements (ornamental additions)	4	4	5	4	4	5	4	4	4	4	4	2
		MEAN RATING	**3.9**	**3.9**	**4.1**	**3.6**	**3.3**	**5**	**3.8**	**3.8**	**3.8**	**3.5**	**3.6**	**3.3**
Archaeological value		Historical Context & Cultural Significance	3	3	3	2	2	4	2	2	2	3	2	2
		Layers of soil and deposits	4	4	4	2	4	2	2	2	2	2	2	5
		Archeological materials & survived remains	4	4	4	4	3	5	4	4	4	4	4	5
		MEAN RATING	**3.67**	**3.67**	**3.67**	**2.67**	**3.00**	**3.67**	**2.67**	**2.67**	**2.67**	**3.00**	**2.67**	**4.00**
Communal value		Monument Symbolism for Cultural Identity	4	4	4	4	3	4	3	4	4	4	4	4
		Monument's ability to promote Social Cohesion & Inclusivity	2	2	2	2	2	4	2	2	2	2	2	2
		Provide Economic Benefit	2	2	2	1	1	4	2	2	2	2	2	2
		Monument's Attractiveness	4	4	4	2	2	5	4	4	4	4	4	4
		MEAN RATING	**3**	**3**	**3**	**2.25**	**2**	**4.25**	**2.75**	**3**	**3**	**3**	**3**	**3**
The Historic associative value		Monument's Importance & Rarity of the property's type	4	4	4	2	2	5	4	4	4	4	4	4
		MEAN RATING	**4**	**4**	**4**	**2**	**2**	**5**	**4**	**4**	**4**	**4**	**4**	**4**
Urban value	Urban Context	Relation with surrounding urban fabric	3	3	3	2	1	5	4	4	4	2	2	3
		Monument Location	2	2	2	2	1	2	3	3	3	2	2	4
		Role of Monument as Focal point / landmark	4	4	4	2	2	5	3	3	3	4	2	4
		MEAN RATING	**3.00**	**3.00**	**3.00**	**2.00**	**1.33**	**4.00**	**3.33**	**3.33**	**3.33**	**2.67**	**2.00**	**3.67**

Insignificant (1) | Minor (2) | Moderate (3) | Major (4) | Catastrophic (5) — Significance Impact Severity

Figure 7. OUV vulnerability index matrix of Historic Cairo

Table 2. Risk magnitudes for climate stressors impact on each heritage value (OUV attributes)

CLIMATE STRESSORS / OUV ATTRIBUTES	Heat & Cold			Wet & Dry			Wind			Others		
	ATMOSPHERIC DRIVERS											
	Mean air temperature	**Extreme heat**	**Relative humidity**	**Precipitation & rainfall**	**Aridity**	**Fire Weather**	**Wind Speed**	**Sand & Dust storm**	**Severe wind storms**	**Air Pollution**	**Radiation at Surface**	**Changes in Soil Chemistry**
	RISK MAGNITUDE											
Architectural, Aesthetic, or Artistic value	13.35	13.35	13.65	11.4	10.95	15	11.7	11.7	11.7	11.25	11.4	12.45
Archaeological value	13.01	13.01	13.01	10.01	10.5	13.03	10.01	10.01	10.01	12	13.01	13.01
Communal value	12.00	12.00	12.00	9.38	9.00	13.88	10.13	10.50	10.50	10.50	10.50	12.00
The Historic Associative value	13.50	13.50	13.50	9.00	9.00	15	12.00	12.00	12.00	12.00	12.00	13.50
Urban value	12.00	12.00	12.00	9.00	8.00	13.5	11.00	11.00	11.00	10.01	9.00	13.01

Risk Priority Level [17]
Catastrophic Extreme High Medium Low

Table 3. Risk response strategies towards Protecting Historic Cairo Built Heritage from Climate Change based on the RCP 8.5 outlined by the IPCC

Climate change stressors				
Heat and cold category: Mean air temperature, Extreme heat, Relative humidity				
Stages of control		**Time of intervention**	**Level of intervention**	**Risk Response Strategies**
Preventive	Interactive			
Detect		Before risk occurrence	Whole site	Use hygrometers to monitor humidity levels in sensitive areas.
				Carry out an evaluation to determine the extent of damage and degradation resulting from climate change.
			Specific building	Install temperature sensors to monitor heat waves in key areas.
Block		Before risk occurrence	Whole site	Increase vegetation and green spaces to provide natural cooling.
		Before risk occurrence	Specific building	Implement dehumidification systems in critical indoor spaces.
	Respond	During risk occurrence	Procedure establishment	Encourage public education initiatives regarding how climate change affects historic places.
		After risk occurrence	Specific elements	Address and restore the affected damaged parts
	Recover	After risk occurrence	Procedure establishment	Invest in moisture-resistant materials for repairs and restorations.
				Identify historic buildings' vulnerability to water, humidity, and heat damage by conducting regular assessments.
				Encourage local communities to participate in conservation initiatives by teaching them the value of conserving their cultural heritage and involving them in preventative measures.
				Install energy-efficient cooling systems when retrofitting historic buildings with better insulation and passive solar design.
Wet & Dry category: Rainfall and precipitation				

Table 3 continued

Detect		Before risk occurrence	Whole site	Set up rain gauges to track precipitation levels.
		During risk occurrence		Restore and maintain traditional drainage systems to manage groundwater and reduce humidity impacts.
	Respond	During risk occurrence	Procedure establishment	Establish a fast response team to take prompt action to safeguard heritage sites during flooding incidents.
Wet & Dry category: Fire Weather				
Avoid		Before risk occurrence	Procedure establishment	Launch awareness campaigns for local residents about fire prevention techniques and safe behaviors.
			Policy establishment	Establish zoning regulations that restrict the kinds of activities that are allowed in the area.
Detect		Before risk occurrence	Whole site	Restrict the use of any fireworks, or open flames near or in the site.
				Install advanced fire detection systems, including smoke detectors.
Block		Before risk occurrence	Whole site	Develop a comprehensive management plan focused on on-site cleaning and maintenance for controlling and clearing the site from garbage and dry brush to maintain healthy landscaping and reduce fire risk.
	Respond	During risk occurrence	Procedure establishment	Establishing emergency response teams specifically for heritage sites through collaborating with local firefighting authorities
		After risk occurrence		To guarantee preparedness and familiarity with emergency procedures, conduct frequent fire drills for both locals and guests.
	Recover	After risk occurrence	Procedure establishment	After a fire incident, create a damage assessment and schedule restoration activities, in addition to involving the community in recovery activities.
Wind category: Wind speed, sand and dust storms				
Avoid		During risk occurrence	Policy establishment	Reduce wind tunnel effects by establishing zoning regulations that restrict the height of construction projects close to the site.
			Procedure establishment	Develop a landscape plan that encourages windbreaks such as trees that would reduce wind speed and protect buildings from erosion and sand deposition.
Detect		Before risk occurrence	Whole site	Install weather monitoring systems to track the wind speed and sand concentrations.
			Procedure establishment	Conduct regular assessments for buildings' structural vulnerability to wind and dust.
Others category: Air pollution				
Avoid		Before risk occurrence	Policy establishment	Limit the construction of heavy highways near the site to reduce pollution sources.
Detect		During risk occurrence	Whole site	Install an air quality monitoring network across the site to track pollutants such as Nitrogen and Sulphur Oxides and fine particles.
Others category: Solar Radiation on surface				
Detect		Before risk occurrence	Whole site	Install solar radiation monitoring devices to measure the UV levels of radiation on the surface.
Others category: Changes in soil chemistry:				
Detect		Before risk occurrence	Whole site	Install a soil monitoring program that can detect any alteration in the soil compositions and pH levels in the area to identify changes over time (soil analysis).
		During risk occurrence	Procedure establishment	Conduct regular inspections for buildings to identify any signs of soil erosion, settlements, or any other soil change indications.
Block		Before risk occurrence	Whole site	Enhance the existing drainage systems to avoid waterlogging and reduce chemical penetration into the soil.
	Respond	During risk occurrence	Whole site	Artificial drying through soil injection.

4. Discussion

In the face of inevitable climate change, there is still much work to be done to promote resilient built cultural heritage, and certain losses appear inevitable. Climate change stressors have been threatening our heritage structures, fostering the need for management strategies that address the vulnerabilities for effective preservation and safeguarding of these structures' integrity.

This research focused on the study of the impact of climate change on the tangible built heritage categorizing climate change drivers into two main groups: atmospheric drivers encompassing hot and cold, wet and dry, wind-related and others, and marine and aquatic drivers that include sea level rise, coastal erosion, flooding and water intrusions. In addition, the values and heritage attributes affected by those stressors have been identified, with the architecture, artistic, and aesthetic values comprising the majority of the heritage building significant features. Furtherly, the historic associative values along with the urban, communal, and archeological values encompass elements that interact with climate change stressors leading to deterioration and loss of significance.

Identifying these stressors and values was crucial to developing tailored risk response strategies, particularly for historic Cairo. In the context of heritage preservation, the key theories either examine the exposure, sensitivity, and adaptive capacity or focus on studying the risk assessment model through analyzing the potential risks, their significance, and the likelihood of occurrence. This theory informed the development of the risk response strategies through identifying the potential stressors in the area, analyzing their probability of occurrence, and evaluating their severity impact on the heritage values identified. Hence, a risk magnitude was generated, allowing for each risk prioritization.

The experts indicated that the site's unique context was subjected to numerous atmospheric drivers' categories, where there is a certain probability of rising mean air temperature, extreme heat waves, rising relative humidity, changes in soil chemistry, and fire weather occurrence. Additionally, wind-related stressors, air pollution, increasing surface radiation, and rainfall are likely to occur.

The experts evaluated the catastrophic impact significance of the relative humidity on the artistic details of the heritage OUVs, as well as the impact of the fire weather on the whole architecture, aesthetic, and artistic attributes of the heritage OUVs. They also assessed the impacts on archeological materials or survived remains, the monument's importance and types of rarity, the urban context, and the monument's role as an urban landmark. A major to high significance was identified for the majority of the stressors on the overall architecture, aesthetic, and artistic category. However, the majority of the communal values received minor significance regarding the impact of the identified climate change stressors. The heritage associative value was indicated to have major impacts from all climate stressors except for rainfall and aridity which were deemed to have minor impacts.

Accordingly, the risk magnitude was calculated based on the ABD method to establish risk priority levels. This analysis showed that extremely high-risk priority should be assigned to the impacts of relative humidity, and fire weather on the architecture, aesthetic, and artistic category, along with the impacts of rising mean air temperature, extreme heat waves, relative humidity, fire weather and changes in soil chemistry on the historic associate values. Likewise, extremely high-risk priority should be given to the impact of fire weather on the communal value, and urban value. Yet, very high priority to medium priority should be assigned to the impact of all climate stressors identified on all the heritage OUVs categories, except for the impact of precipitation and rainfall on the communal, urban and heritage associative values, which require low priority, as does the impact of increasing radiation at surface on the urban value.

The risk response strategies were then developed based on treatment control stages that involve preventive and interactive measures. The developed strategies were tailored for application before, during, or after the risk occurrence and intervention at the level of the whole site, specific buildings or elements, or for establishing a policy or a procedure.

Some limitations were encountered through the research that might have influenced its findings, including the limited access to the heritage site documentation and weather data, as well as potential subjectivity in the collected data as the research relied on expert survey questionnaire which might be influenced by personal bias. However, the sample size may justify the analysis. Also, the dynamic nature of climate change may require continuous updates to reflect the changes happening in the area of study, thus, continuously updating the risk response strategies. Additionally, the absence of standardized accepted frameworks in Egypt for heritage risk assessment may lead to various data interpretations and methodological applications. Eventually, preserving our built cultural heritage requires collaborative efforts and significant awareness of climate change locally and globally.

5. Conclusions

In conclusion, this research highlights the significant climate change impacts on built cultural heritage, particularly in Historic Cairo. The findings revealed that rising mean air temperature, extreme heat waves, relative humidity, and changes in soil chemistry pose substantial risks to the architecture, aesthetic, and artistic heritage values of the site. Therefore, it makes the necessity for resilient preservation techniques necessary.

Implanting the developed risk response strategies along with the heritage organizations, local communities, and policymakers' collaborative efforts is crucial to effectively preserve the Historic Cairo site.

The study successfully formulated systematic risk response strategies, **Figure 8**, to analyze the vulnerabilities specific to Historic Cairo heritage preservation.

This study laid a strong foundation for resilience planning which can be replicated in various sites across the Egyptian context. However, it requires further investigation for monitoring strategies upon which the strategies shall be refined. Additionally, further research should explore the impact of the proximity of green spaces such as Al-Azhar Park that might influence the preservation of built heritage. This might provide valuable insights regarding the role of ecological green spaces in mitigating the impacts of climate change and their holistic contribution to urban environment resilience.

The study paved the way for a more resilient Egyptian-built heritage, ensuring it can continue to tell stories of its significant cultural history. By prioritizing the collective responsibility of protecting our built heritage sites, we reaffirm their significant role in narrating our human history and cultural identity.

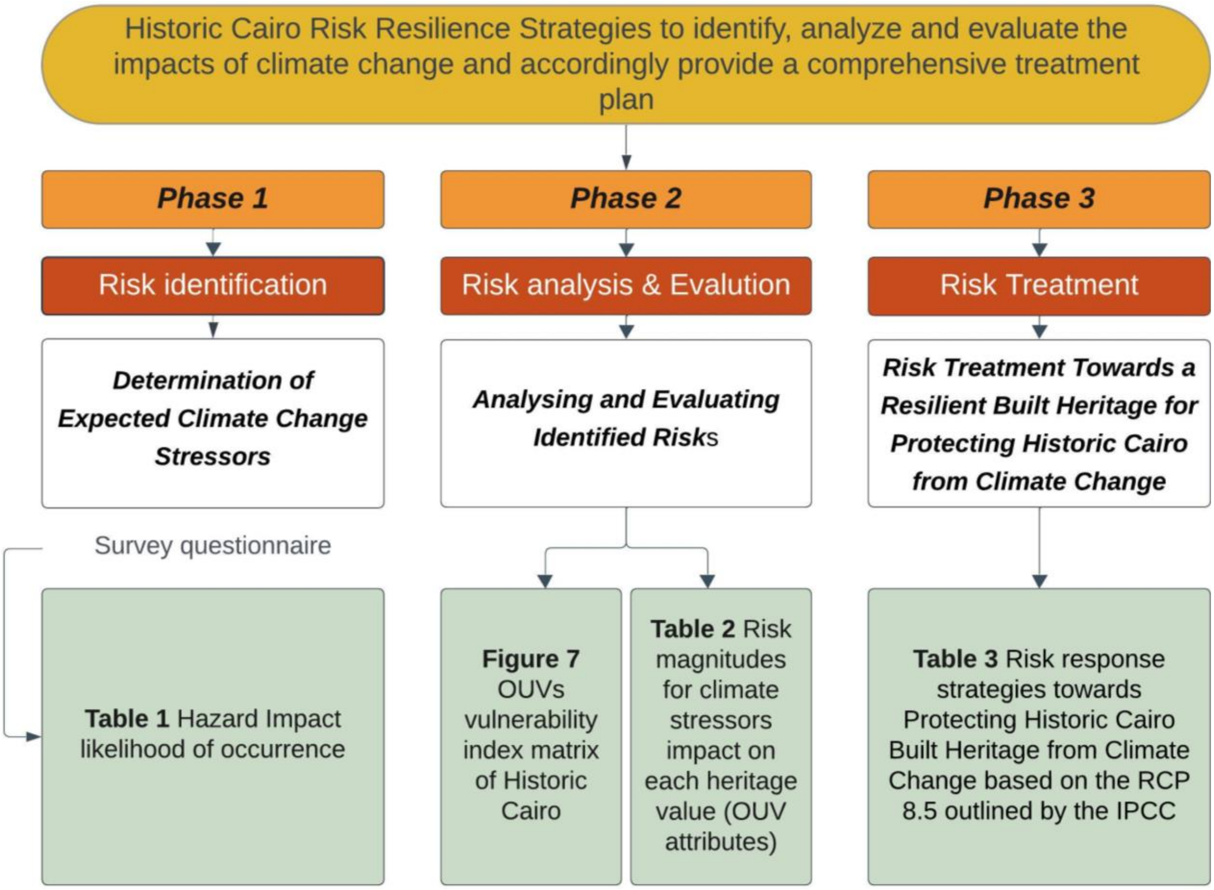

Figure 8. An overview of the generation process for Historic Cairo Risk Resilience Strategies

Acknowledgements

We are very grateful to the experts for their appropriate and constructive suggestions to improve this template.

REFERENCES

[1] Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2021 – The Physical science basis: Working Group I Contribution", in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2023, pp. 2287-2338. DOI: 10.1017/9781009157896.

[2] ICOMOS, "Agenda item 6-6-1. Resolution 20GA/15 - Cultural Heritage and the Climate Emergency." ICOMOS -GA2020/12 – 6. https://www.icomos.org/images/DOCUMENTS/Secretariat/2020/Cultural_Heritage_and_theClimate_Emergency-Resoltion_20GA_15_.pdf (accessed Nov. 21, 2023).

[3] UNESCO World Heritage Convention, "Twenty-Fourth Session of the General Assembly of States Parties to The Convention Concerning the Protection of the World Cultural and Natural Heritage." Updating of The Policy Document On Climate Action for World Heritage. https://whc.unesco.org/document/203725 (accessed Jan. 21, 2021).

[4] Garcia, B. M., "Resilient Cultural Heritage for a Future of Climate Change," Journal of international affairs, vol. 73, no. 1, pp. 101-120, 2020. DOI: 10.2307/26872781.

[5] Day, J. C., Heron, S. F., & Markham, A., "Assessing the climate vulnerability of the world's natural and cultural heritage," Parks Stewardship Forum, vol. 36, no. 1, pp. 144-153, 2020. DOI: 10.5070/p536146384.

[6] Simpson, N. P., Orr, Michael R., Poonam V., Jean B., Luckson T. Z., "White Paper II: Impacts, vulnerability, and understanding risks of climate change for Culture and Heritage: Contribution of Impacts Group II to the International Co-Sponsored Meeting on Culture, Heritage and Climate Change," in Discussion Paper ICOMOS & ISCM CHC, Charenton-le-Pont, 1st ed., 2022, pp. 109. ISBN 978-2-918086-72-7.

[7] Sesana, E., Gagnon, A.S., Ciantelli, C., Cassar, J. and Hughes, J.J., "Climate change impacts on cultural heritage: A literature review," Wiley Interdisciplinary Reviews: Climate Change, vol. 12, no. 4, pp. e710, 2021. DOI: 10.1002/wcc.710.

[8] Trisos, CH., Adelekan, IO., Totin, A., Efitre, J., Gemeda, A., Kalaba, K., Lennard,C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, NP., Zakieldeen, S., "Chapter 9: Africa. In: Climate Change 2022: Impacts, Adaptation and Vulnerability," in Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2022, pp. 1285–1455. DOI: 10.1017/9781009325844.011.

[9] World Bank Group, "World Bank Group: Country and Climate Development Report (EGYPT)," in Egypt - Country Climate and Development Report. Washington, D.C: World Bank Group., 1st ed., 2022, pp. 1-88.

[10] Climate Change and Cultural Heritage Working Group. "Future of Our Pasts: Engaging Cultural Heritage in Climate Action," in Report of the ICOMOS Workings Group on Climate Change and Cultural Heritage, 1st ed., International Council on Monuments and Sites – ICOMOS, 2019, pp. 1-62.

[11] Ravankhah, M., De Wit, R., Argyriou, A. V., Chliaoutakis, A., Revez, M. J., Birkmann, J., Žuvela-Aloise, M., Sarris, A., Tzigounaki, A., & Giapitsoglou, K., "Integrated assessment of natural hazards, including climate change's influences, for cultural heritage sites: the case of the historic Centre of Rethymno in Greece," International Journal of Disaster Risk Science, vol. 10, no. 3, pp. 343–361, 2019. DOI: 10.1007/s13753-019-00235-z.

[12] Forino, G., MacKee, J., and von Meding, J., "A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia)," International Journal of Disaster Risk Reduction, vol. 19, pp. 235-248, 2016. DOI: 10.1016/j.ijdrr.2016.09.003.

[13] Paolini, A., Vafadari, A., Cesaro, G., Quintero, M. S., Van Balen, K., & Vileikis, O., "Risk management at heritage sites", in A case study of the Petra World Heritage Site, UNESCO, 2012, pp. 1-172.

[14] Mahmoud, N. A., "Public-private partnerships as an approach for alleviating risks associated with adaptive reuse of heritage buildings in Egypt," International Journal of Construction Management, vol. 22, no. 1, pp. 1-23, 2023. DOI: 10.1080/15623599.2020.1742626

[15] Pedersoli Jr, J. L., Antomarchi, C., and Michalski, S., "Doing Risk Management," in A guide to risk management of cultural heritage, ICCROM, 2016, pp.16-118.

[16] Markham, A., Osipova, E., Lafrenz Samuels, K. and Caldas, A., "World Heritage and Tourism in a Changing Climate," United Nations Environment Programme, Nairobi, Kenya and United Nations Educational, Scientific and Cultural Organization, Paris, France., 2016, pp. 33-108.

[17] Pedersoli Jr, J. L., Antomarchi, C., & Michalski, S., "Analyzing risks," in A guide to risk management of cultural heritage, ICCROM-ATHAR, 2016, pp. 62-113.

[18] ICCROM-CCI, "The ABC Method," in A risk management approach to the preservation of cultural heritage, Canadian Conservation Institute, 2016, pp. 83-130.

[19] Crossman, A., "Understanding Purposive Sampling." ThoughtCo.https://www.thoughtco.com/purposive-sampling-3026727 (accessed Nov. 13, 2023).

[20] Tahoon, D., & Hegazy, Y., "Risk management strategies of cultural heritage case study: Tel Basta archaeological site," International Design Journal, vol. 9, no. 3, pp. 281-292, 2019. DOI: 10.21608/IDJ.2019.82832.

[21] EL-HABASHI, A. & NADA, H. A.-E., "Monuments or Heritage Buildings: The Historic Water Dispensaries (Sabils) Of Cairo," IX International Forum Le Vie Dei Mercanti, Capri, Napoli, 2011, pp. 1-12. https://www.academia.edu/29630406/MONUMENTS_OR_HERITAGE_BUILDINGS_THE_HISTORIC_WATER_DISPENSARIES_SABILS_OF_CAIRO.