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Creating a Risk Assessment Plan for Rainfall Impacts on Heritage Buildings Façades via Quantitative Methods

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Abstract: The unstable climate causes many related risks, including heavy rainfall. In the past, Egypt experienced rainfall over time. Although Egypt is still classified as a low-precipitation country, it can experience extreme rainfall events, resulting in flash floods. Many fragile materials related to heritage building façades may be affected by the change in rainfall rates without any risk assessment plan. This research aims to confront the hazards of raindrop strikes, as the need for making a risk management plan has arisen in order to preserve heritage buildings from heavy rainfall. The research methodology uses the ABC risk assessment quantitative method in addition to experts' multi-round assessments and tornado diagrams to analyze the magnitude of risks in order to create a risk assessment plan for a group of heritage buildings in Historic Cairo as a pilot study that can be generalized for similar cases. The final output is framed into a cause-and-effect model for rainfall risk problem solving, generated by rainfall risk causes and effects on the heritage building facades.

Keywords: rainfall; historic Cairo; risk assessment; climate change; heritage buildings; numerical methods

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1. Introduction

As risk formulates when a hazard meets vulnerability, a predictive scenario of this risk and the solution to this problem is focused on in this research to suggest corrective action and preventive plans that can help monuments facing heavy rainfall risk.

UNESCO defines risk management as the process of the identification, evaluation, and analysis of possible and probable hazards to heritage buildings, then addressing risk strategies and prioritizing interventions to remove risks. ICCROM 2016 [1] and UNESCO 2012 [2] developed approaches to heritage building risk management. It is defined as a process of understanding impact on monuments and how specialists can deal with it in priority order and take necessary actions to reduce risk.

ICCROM defines preventive conservation as curing procedures to prevent the deterioration of urban heritage or buildings [3].

From the preventive conservation basics, ICCROM developed a risk management method and determined risk volume using algorithms, scale based on risk probability, the degree of loss of value, and the percentage of area that could have hazards. This method is called the ABC method and has three variables. A is frequency, B is the degree of loss of value for every element separately, and C is the percentage of impact [4].

The UNESCO approach contains context and scope, identifies risks, assesses the impact of each risk, identifies mitigation strategies, evaluates mitigation strategies, and implements strategies.

Some of the primary elements identified by the World Heritage Center in 2008 consist of sub-elements. Some elements are related to natural heritage, while our focus is on cultural heritage, which has different hazards related to the following elements [5]:

- Buildings and development (housing, commercial, industrial, visitor hosting and its related infrastructure, visitation facilities);
- Transportation infrastructure (impact of transportation means above and underground);
- Infrastructure services and facilities (water infrastructure, nonrenewable services, renewable services, main linear facilities, local facilities);
- Pollution (garbage, water and earth water pollution, air, extra energy pollution);
- Environmental and biological elements which contribute to heritage urban setting deterioration;
- Social use contributing to urban heritage deterioration;
- Illegal human factors, such as theft, wars, and terrorism;
- Climate change and weather phenomena;
- Sudden environmental and geological events;
- Organizational and administrative factors (systems monitoring).

Concerning risks caused by a slow cumulative process or rare events, estimating risk magnitude using a measurement point at a particular future point is not significant because this may happen in three, ten, or one hundred years. Regarding frequent or quick risks, in contrast, it is important to decide on the point set to measure the goal because it is essential for estimating the risk magnitude. In other words, we may have various priorities for several kinds of risks.

Different perspectives may arise among viewers of a pristine-colored object in an exhibition that may fade in 10 years due to lightning. While viewers after ten years may prioritize treating the object from this threat rather than any other, like theft, people after 30 or more years may prioritize theft or fire issues because the object may vanish or undergo a more dangerous threat [6].

Considering the opinion of international or local agencies that advise several heritage organizations, the concept of rare can vanish. We may perceive a fire, flood, theft, and pet incident, to mention a few, as massive threats. Furthermore, we advise individual heritage organizations as holders of monuments.

According to the preventive conservation theory, preventive actions should be enforced before the risk actuates. As stated, climate change will impact historic Cairo much more than usual, a city that receives a little more than 10 mm of precipitation yearly. Despite this, it can experience sudden extreme rainfall events resulting in flash floods [7] which could affect Cairo's Islamic monuments, especially because they are composed of multiple materials. Certain compositions mean many of the elements face hazards, especially if they already show vulnerability. Although rain is reported to be rare and controlled in this area, we are urged to be prepared for worse events over the next decades [8].

2. Materials and Methods

Mixed methods formulated the methodology adopted in this research paper, relying on the ABC risk assessment quantitative risk, combined with the DELPHI technique [9] and risk simulation by Tornado diagram [10], in multi-rounds of discussion to rate risk degrees for every element in the case of façades. A cause-and-effect problem-solving model was used to present the final output of the research, reliant on experts' ratings and ABC suggestions of response strategies concerning risks (Table 1).

Table 1. A represents how soon the risk events are expected to happen according to the following scale.

Score	Mean Time between Events	Frequency in Century
5	1 year (1:2)	100 events (60:100)
4.5	3 years (2:6)	30 events (20:60)
4	10 years (6:20)	10 events (6:20)
3.5	30 years (20:60)	3 events (2:6)
3	100 years (60:200)	1 event (0.6:2)
2.5	300 years (200:600)	0.3 events (0.2: 0.6)
2	1000 years (600:2000)	0.1 events (0.06:0.2)
1.5	3000 years (2000:6000)	0.03 events (0.02:0.06)
1	10000 years (6000:20,000)	0.01 events (0.006:0.02)
0.5	30000 years (20,000:60,000)	0.003 events (0.002:0.006)

Degree of value loss (given symbol B, Table 2).

Table 2. B represents the value loss percentage concerning the hazard.

Score	Value Loss Percentage	Range	Description	Number of Damaged Items Equivalent to One Total Loss
5	100%	100%: 60%	Total loss or almost total in each item	1
4.5	30%	60%: 20%		3
4	10%	20%: 6%	Large loss of value	10
3.5	3%	6%: 2%		30
3	1%	2%: 0. 6%	Small loss of value	100
2.5	0.3%	0.6%: 0.2%		300
2	0.1%	0.2%: 0.06%	Tiny loss	1000
1.5	0.03%	0.06%: 0.02%		3000
1	0.01%	0.02%: 0.006%	Trace loss	10,000
0.5	0.003%	0.006%: 0.002%	Minor loss	More than 10,000

Vulnerability of the area that faces risks (given symbol C, Table 3).

So, the risk was calculated from the sum of the previous three criteria. Every criterion was ranked according to the following tables from 0.5 to 5:

Magnitude of risk = Probability + value loss + vulnerability.

Table 3. C represents how much the heritage asset is affected.

Score	Percentage of the Value Pie	Range	Description
5	100%	100%: 60%	Total loss or almost total in each item
4.5	30%	60%: 20%	
4	10%	20%: 6%	Large loss of value
3.5	3%	6%: 2%	
3	1%	2%: 0. 6%	Small loss of value
2.5	0.3%	0.6%: 0.2%	
2	0.1%	0.2%: 0.06%	Tiny loss
1.5	0.03%	0.06%: 0.02%	
1	0.01%	0.02%: 0.006%	Trace loss
0.5	0.003%	0.006%: 0.002%	

Measured according to the scale shown in Tables 1–3 in addition to Figure 1.

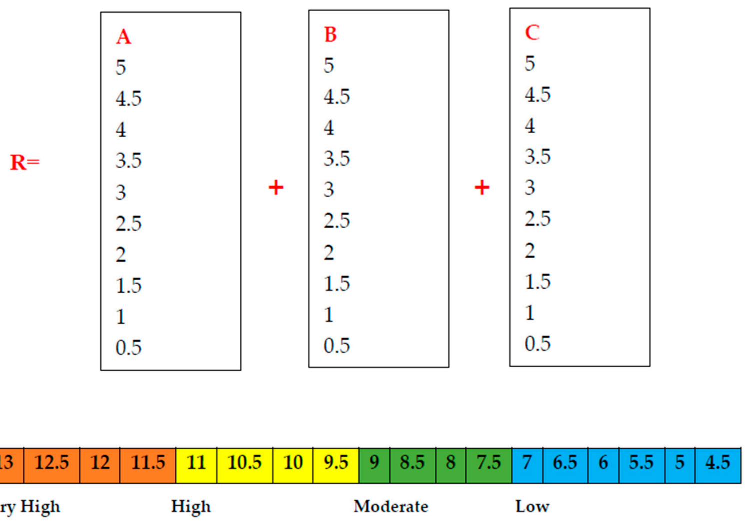

Figure 1. Risk magnitude rating by ABC method.

A represents how soon the risk events are expected or happen according to the following scale frequency:

Risk: A + B + C = magnitude of risk, according to the following tables [10].

The ABC was used to quantitate the probability of deterioration in terms of risk speed and frequency of risk (given symbol A).

The following is an example of the calculations of score A. A storage building has archeological elements with no watershed. Its roof is poorly designed, so it is guaranteed to leak during extreme rainfall. According to the local data imported from the storage administrative: "in the last 20 years, they had at least one small roof leak every rainy season in the storage area". According to the score of frequency of risks in Table 4, the storage building faces 100 events in a century, so the score risk speed and frequency of risk (A) for archeological elements equal 5 [11].

Table 4. The properties of the common materials of the selected cases in El-Moez street, Historic Cairo.

	Gypsum
1	This material is popular in Islamic monuments. It has been used in many forms, decorations, or even as mortar or ceilings in old baths. From the early beginning of construction in Egypt, gypsum was used as mortar for pyramid stones. Calcium sulfate is soluble in water, so it is affected by strong raindrops and increases in size. It flakes away from the neighboring materials, especially if the surface of the gypsum is used in external elevations.
	Lime mortar
2	Lime is made by heating limestone. Because it is composed of calcium carbonate and is a porous material, it is deformed by water. When it gets dry, cracks appear due to irregular internal mortar distribution.
	Limestone
3	Water is the main factor of stone deterioration due to its ability to penetrate. Naturally, stone has cracks and pores, which make the penetration process even easier through internal stresses at all penetrated surface areas. Solutions Cleaning can be carried out by a non-damaging method chemically, without a crusher, which removes a layer from stones. Water mist and vacuums can be used in certain cases. Crack injection and stainless-steel stables can be used in consolidation. After all steps, a protection layer of translucent material can be used.
	Brick and Clay
4	Silicone oxide forms the main components of both brick and clay. As these materials have layers of wafers, the water penetration causes increased distance between the wafers and causes flaking, or it absorbs water and increases in size. After drying, it is cracked.
	Masonry
5	Water penetrates this material easily in both liquid and vapor states, which increases the water content inside the walls and weakens the elements, especially if it has an overlay of plaster. The chemical reaction can make salts inside the materials, causing another aspect of deterioration. Solutions Consolidating by mortar, including animal hair or fibers and rice husks, mortar of the same material composition is usually used, and plastering is recommended.

3. Cases of Study

Since its establishment, historic Cairo has witnessed many historical events. It faces many hazards from natural and anthropogenic events, so it is necessary to implement measures to mitigate or prevent the rapid deterioration of historic Cairo to sustain those heritage assets for future generations [12].

The research selected and divided the northern part of El-Moez St. into seven sections according to the intersecting arteries and the number of monuments in each section (Figure 2). Then, it selected section C as a case study, including three monuments and one heritage building: three houses (Mostafaa Ghaffar, Khorazati, and El-Suhaymi) and one multi-use religious complex (the Mosque and Sabil of El-Slehdar). Section C has one of the most valuable alleys in historic Cairo, named "Hart El-darb El-asfar" (Figure 3).

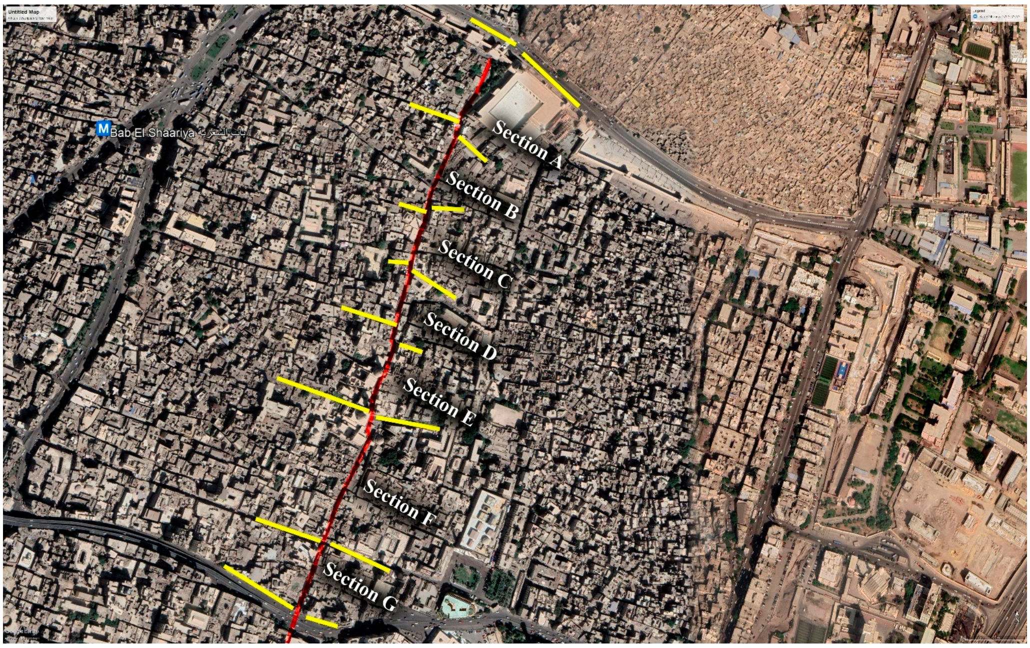

Figure 2. Historic Cairo section divisions and the main axis in red (El-Moez street) Source: research based on the image of Google Earth.

Figure 3. Section (C) of El-Moez street.

3.1. El-Slehdar Complex

Located on El-Moez street, it was established in 1837–1839 by Prince Sulayman Aga El-Slehdar (one of the princes of Mohamed Ali Basha, ruler of Egypt from 1805 to 1848). The El-Slehdar Complex consists of a mosque, a sabil (a building used for providing drinking water for the public on the city streets), and a kuttab (a small school for children). The main stone façade of the complex is characterized by its floral ornaments, marble ornaments, and oil colors on the wooden Ottoman ceilings, all influenced by the arts of Europe in the

Renaissance era of that time. The Ottoman minaret of El-Slehdar is characterized by its conical top, similar to the top of a pencil [13]. The complex is listed as a monument by the Ministry of Antiquities under number (113).

The main façade of the El-Slehdar complex overlooks El-Moez St., which is divided vertically into the El-sabil, the kuttab (school), and the mosque, while the main entrance of the mosque is at the rear façade.

The façade of the sabil consists of four round-arched windows, each covered with cast bronze and hollowed-out ornaments. This part of the façade is covered with white marble carved with floral ornaments and inscriptions. The kuttab and mosque's façade consists of ten rectangular windows: Half on the ground floor and the other five on the first floor. They are all covered with metal hollowed-out ornaments. This part of the façade is covered with limestone. A sloping wooden cornice tops the whole façade, including its two parts covered with decorative plaster (Figures 4–6). The Ottoman minaret is covered with limestone [14].

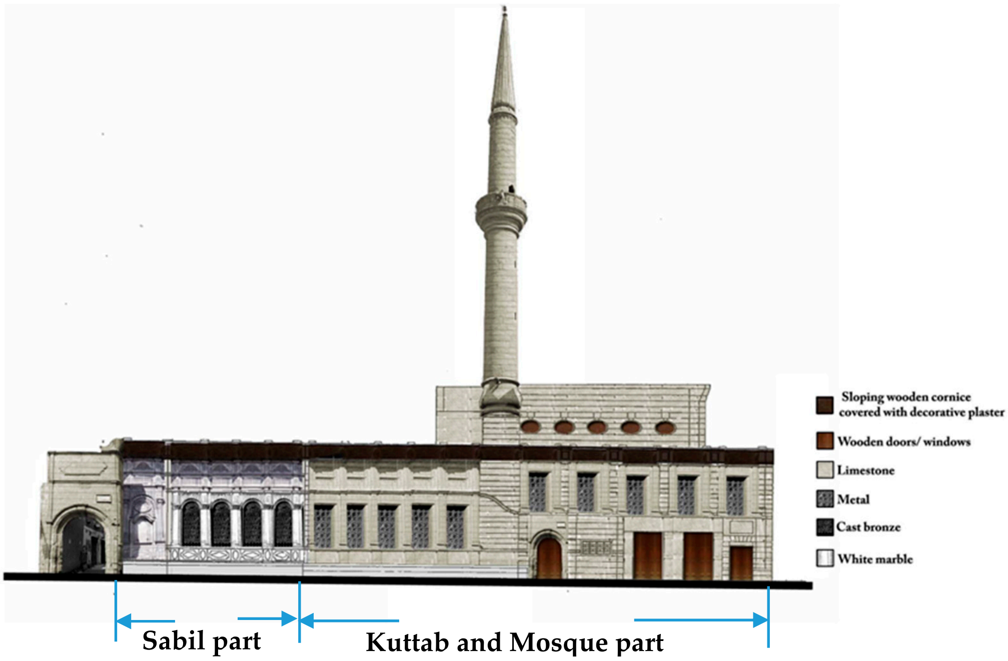

Figure 4. The front view of the main façade of El-Slehdar's complex.

Figure 5. EL-Slehdar complex's main façade.

Figure 6. The Sabil part of the EL-Slehdar façade shows the white marble carved with floral ornaments and inscriptions in the façade, and round-arched windows are covered with cast bronze with hollowed-out ornaments.

3.2. Mostafa Ghaffar House

One of the historic houses on El-Moez Street and listed in the list of antiquities as an Islamic monument under number (471). It is located at the beginning of Haret Eldarb Elasfar, next to the El-Kohrazati house. It was built in 1713 on the location of the old famous coffee shop named "El-Mawardi", which was owned by Shehab Atta (a foreign resident). Mostafa Gaffar (one of the major coffee merchants in the Dhul-Fiqar Katkhuda Wekala) bought the coffee shop and the adjacent plot to build his house that has maintained the name of the first owner until today.

The house has two main external facades. The smaller one overlooks El-Moez St., and the bigger (which has the main entrance of the house) overlooks Eldarb Elasfar street. The house consists of three stories. The ground floor has five rectangular wooden windows covered with iron grilles and a stone segmental-arched house gate with wooden doors. The two façades of the house have four wooden bay windows named "mashrabyia". Only one of them is located in the El-Moez façade. The other three are located in the façade of Eldarb Elasfar st.

The ground floor of the house's façades is covered by limestone, and the remaining parts of the façades are covered by lime plaster. The façades of the house have limestone corbels and wooden lintel that bear the prominent part of the facades of the house [15] (Figures 7–9).

Figure 7. The front view of the main façade of Mostafa Ghaffar's house overlooking Eldarb Elasfar street.

Figure 8. The main façade of Mostafa Ghaffar's house overlooking El-Darb Elasfar street.

Figure 9. The side façade of Mostafa Ghaffar's house overlooking El-Moez street.

3.3. Khorazati House

A heritage house between two listed monuments (El-Suhaymi House and Mostafa Ghaffar House). Its date of construction is 1881. Recently, the house has been adaptively reused as a cultural center. The ground floor hosts concerts, artistic performances, and poetry evenings throughout the year. The first floor is used by the National Archives of Folklore.

The architectural style of the house merged the styles of 19th-century Cairo and Turkish houses. The house consists of two stories. It has one façade that overlooks Eldarb Elasfar st., and the façade of the ground floor has ten wooden pointed arched windows covered with iron grilles and a stone round arched house gate with wooden doors. The first floor façade has 12 rectangular wooden framed windows with wooden-glassed panes (Figures 10 and 11).

Figure 10. The front view of the façade of Khorazati House overlooking Eldarb Elasfar street.

Figure 11. The façade of Khorazati House overlooking Eldarb Elasfar street.

The ground floor of the house's façade is covered with limestone (partially affected by the weather conditions), and the first floor of the façade is covered with lime plaster.

The façade has a wooden lintel, the prominent part of the house's façade, as well as a gypsum cornice that tops the façade [16].

3.4. El-Suhaymi House

El-Suhaymi house is located on Eldarb Elasfar street beside El-Khorazati House. It was built in two stages. The first stage was in 1648, when the northern part of the house was built by Abdel Wahab Eltablawy. The second stage was in 1796, when the southern part of the house was built by Ismail Shalaby, who merged the two parts into one big house. The house was named "El- Suhaymi" according to Amin El-Suhaymi, who was the last habitant of the house and was the Imam (the leader) of the Turkish part of the Al-Azhar Mosque [17]. It has been listed in the list of antiquities as an Islamic monument under number (339).

The architectural style of the external façade of El- Suhaymi house is characterized by Islamic architectural elements. It consists of eight mashrabyia windows with three different forms, rectangle windows with wooden frames, and iron grilles of different sizes. The effect of Ottoman Islamic architecture can be observed in this façade by the two stained glassed windows and single gypsum windows with wooden frames. Like the other two heritage houses of Eldarb Elasfar street, the ground floor of the façade of El-Suhaymi House is covered with limestone, and the remaining parts of the façade are covered with lime plaster. The façade has limestone corbels and wooden ones in the upper parts of the façade. There are wooden lintels that bear the prominent parts of the house's façade [18] (Figures 12–14).

3.5. Material Decay, Treatment, and Behavior

Natural factors have a dangerous impact. For instance, rainfall causes serious deterioration of many historical materials, such as brick, mortar, stone, wood, metal, and gypsum. The impact varies according to material behavior and its probable chemical reaction against weather and water. The decay increases if the material is porous.

Heritage buildings mostly contain natural porous materials, so the problem gets harder because rainwater penetrates the material itself.

Figure 12. The front view of the external façade of El-Suhaymi House overlooking Eldarb Elasfar street.

Figure 13. The external façade of El-Suhaymi House show the multi-entrances.

Figure 14. El-Suhaymi main entrance.

Most façades of historic Cairo buildings are formulated from stone, mortar, and brick, the most porous known materials, as they have carbonate crystals, silicates, and aluminates or oxides. Strong attraction happens between hydrogen and oxygen due to its electrical atoms, so water moves according to the electronic positive and negative reactions. Thus, it finds its path across the material, and the movement itself generates forces inside the material as follows:

- Suction: moves from the above level to the below level;
- Diffusion: moving according to the balance of water content;
- Osmosis: water moves from a place with fewer ions—low salt concentration—to a place with more ions with a higher salt concentration;
- Electrokinetic: water migrates toward the negative electric fields;
- Heat: water moves from the warm field to the cold field [19].

The historical materials of brick and stone can be classified from hard to fragile. The mechanical behavior of those materials is about tension and compression, and all the generated strain and stress mostly reflect the ability of the material to change its physical dimensions. If the stress is removed, the strain returns to zero, and the material returns to its original shape and dimensions.

But these elastic materials that can return to their initial shapes do not exist in heritage sites, because all natural materials are deformed by water's effects. The stress is not homogeneous in its distribution according to the different vulnerable parts. Therefore, the deviation appears, which causes an irregular material surface or cracks.

Most porous materials expand when they absorb water. If this happens at a high temperature, the generated stresses cannot be ignored. If the water evaporates and leaves salt crystals, the eternal stress increases and the material can be thrust. Additionally, it can cause material erosion as the surface desegregates rapidly, leaving holes and forming cavities [20].

Suppose a historic building, such as Slehdar, has metal elements. In that case, the metal corrodes and changes in size to appear bigger in volume, causing stress, and the change in size affects the neighboring materials via the new size and cracks.

The chemical reaction of metal corrosion requires water. It happens when the materials get wet from the rainfall.

Rainfall is considered acidic as it carries air with carbonic acid from carbon oxide. When rain meets lime materials, such as limestone and lime mortar, and marble, found in every Islamic monument and containing magnesium and calcium carbonate, they are transformed to bicarbonate and dissolve slowly.

Brick and tiles, which contain silicate, have more resistance to acidic water but deteriorate in the long run. If they have holes in the surface that keep acidic water inside for a long time, they fall suddenly under the water pressure.

In our case of Cairo, near pollution, rain carries pollutants and makes strong acids by the carbon dioxide, which react chemically very badly with the porous materials.

The operation of wet and dry make a double attack on the material as the wet causes an acid attack, while the dry causes crystallization. These attacks appear on material surfaces in the form of crust.

Bacteria and Fungi infections happen in the organic material as wooden elements, as the needed energy for this infection comes from oxidation. Rainwater is considered an important agent in generating this chemical reaction and causes the deterioration of the internal erosion of such material reaction towards rainwater [21].

The Common Material of the Selected Cases Facades

The following table shows the common materials of the selected cases, including their physical components, properties, and water porosity [22].

The action presented previously could be a preliminary step toward assessing the rainfall risks on the façades of the selected cases in the next sections of the research.

4. Results and Analysis

Two methods were used to determine the magnitude of risk.

4.1. ABC Method

Multi rounds of discussions were held with experts on-site to rate the risks that may happen to the architectural elements materials, as shown in Table 5. Ten experts, including conservators and conservation architects with 20+ years of experience, were asked to rate risks. Everyone rated the risks for the four selected cases according to the three elements A, B, and C. Then, the researchers calculated the median to express one value per each element, as shown in Table 5 and Figures 15–18. The analysis revealed the risk magnitude rates. It showed the positive risks (with low negative or no effect on the elements, such as the effect of low rainfall that can clean the element of dust) using green and blue colors, and the negative risks (with great negative effects on the elements causing deterioration), using the orange, yellow, and red colors, carried out for the four selected buildings. Every building represented one unit in the coming simulation of Tornado sensitivity analysis.

Table 5. The median of the ABC scale in relation to selected cases. The color represents the risk degree level as mentioned in Figure 1.

			Slehdar				**Mostafa Gaafar**				**Khorazaty**				**El-Suhaimy**				**Median**	**Risk Evaluation**	**Monitoring Strategies**	**Response**
	Risk elemnts classification	Risk no.	A	B	C	total	A	B	C	total	A	B	C	total	A	B	C	total	Median			
Urban	Street scape	R1	5	2	3	10	5	2	4	11	5	2	4	11	5	2	4	11	10.75	trigger	re-prior actvities	share
	Roof scape	R2	5	2	3	10	5	2	3	10	5	2	3	10	5	2	3	10	10	trigger	re-prior actvities	share
Historic buildings elements	finishes	R3	4	2	4	10	4	2	3	9	4	2	3	9	5	3	4	12	10	trigger	re-prior actvities	Enhance
	External walls	R4	5	2	5	12	2	2	4	8	3	2	4	9	4	4	5	13	10.5	trigger	re-prior actvities	Enhance
	Flooring and pavements	R5	5	2	5	12	3	2	3	8	3	2	3	9	4	4	4	12	10.25	trigger	re-prior actvities	Enhance
	Building exterior	R6	5	2	5	12	2	2	4	8	3	2	4	8	4	4	4	12	10	trigger	re-prior actvities	Enhance
	roof	R7	5	3	5	13	4	2	4	10	3	2	4	9	4	4	4	12	11	trigger	re-prior actvities	Enhance
	shade	R8	3	3	5	11	2	2	4	8	3	2	4	9	5	4	3	12	10	trigger	re-prior actvities	Enhance
	decoration	R9	5	1	3	9	2	2	4	8	3	2	4	9	3	3	3	9	8.75	residual	trainned observation	Enhance
	Windows frames	R10	5	1	3	9	2	2	3	7	3	2	4	9	4	5	3	12	9.25	residual	trainned observation	Enhance
	Balconies	R11	5	3	5	13	2	2	4	8	3	2	3	9	4	4	4	12	10.5	trigger	re-prior actvities	Enhance
	shops	R12	5	3	5	13	2	2	3	7	3	2	4	8	4	5	4	13	10.25	trigger	re-prior actvities	Enhance
	Material quality	R13	3	2	3	8	2	1	3	6	3	1	4	9	4	4	5	13	9	secondery	trainned observation	Enhance
	Material typology	R14	4	2	3	9	2	2	3	7	3	2	3	8	4	4	3	11	8.75	residual	trainned observation	Enhance
	Material degradation	R15	5	3	4	12	2	2	3	7	3	2	3	8	2	2	3	7	8.5	residual	trainned observation	Enhance
	Opening area	R16	4	3	4	11	2	2	3	7	3	2	3	8	3	2	2	7	8.25	residual	trainned observation	expolit
	Wall to wall connection	R17	3	3	5	11	4	4	4	12	5	4	4	8	3	4	4	11	10.5		re-prior actvities	Enhance
	Wall to roof	R18	5	4	5	14	5	4	4	13	4	4	4	13	5	4	5	14	13.5	trigger	technological tools	Enhance
	Wall to floor	R19	5	4	5	14	5	4	4	13	4	4	4	12	5	5	5	15	13.5	trigger	technological tools	Enhance
	Alignment with street	R20	5	4	5	14	3	3	3	9	3	3	2	12	4	4	3	11	11.5	trigger	re-prior actvities	Enhance
	Preservation condition	R21	3	3	4	10	4	2	5	11	5	2	4	8	3	5	4	12	10.25	trigger	re-prior actvities	Enhance
Geometry	Plan regularity	R22	5	3	4	12	3	2	3	8	4	2	4	10	4	4	5	13	10.75	trigger	re-prior actvities	share
	Number of stories	R23	3	3	3	9	3	2	2	7	4	2	3	9	3	3	4	10	8.75	residual	trainned observation	share
	shape	R24	4	3	2	9	3	2	2	7	4	2	3	9	4	4	4	10	8.75	residual	trainned observation	share

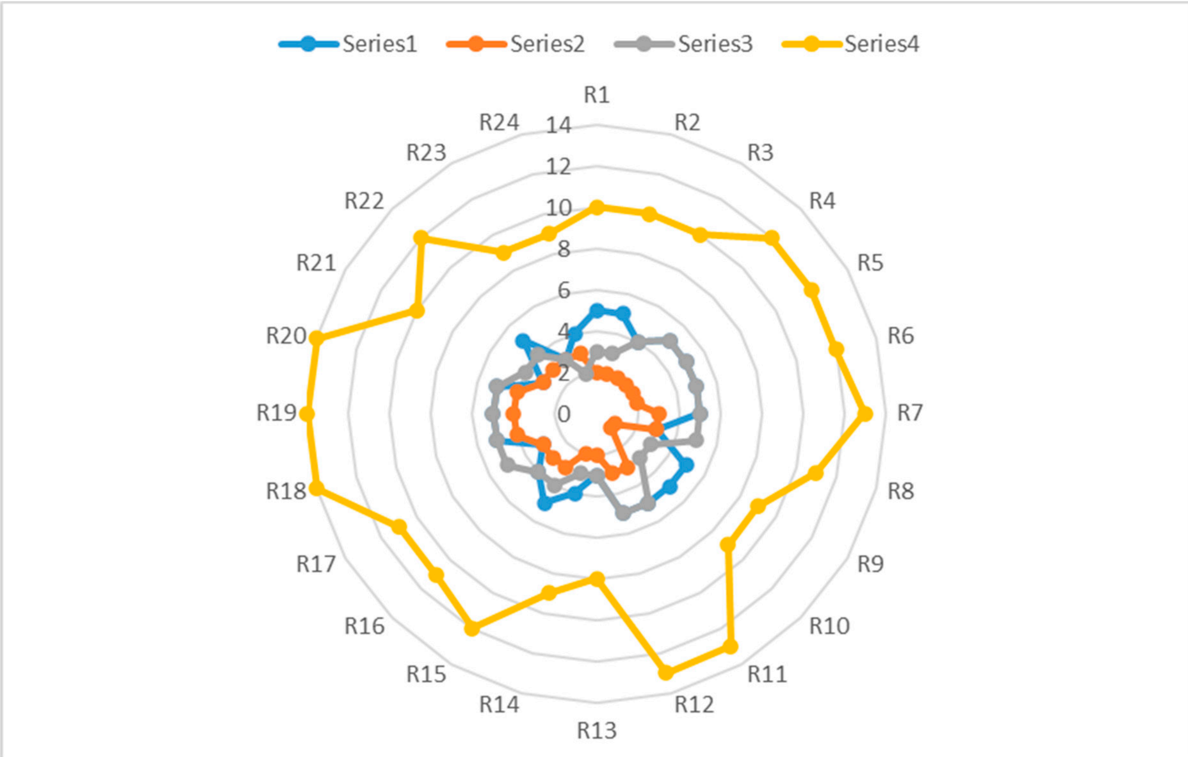

Figure 15. Graph show the rainfall risk management for the Mosque and Sabil of El-Slehdar.

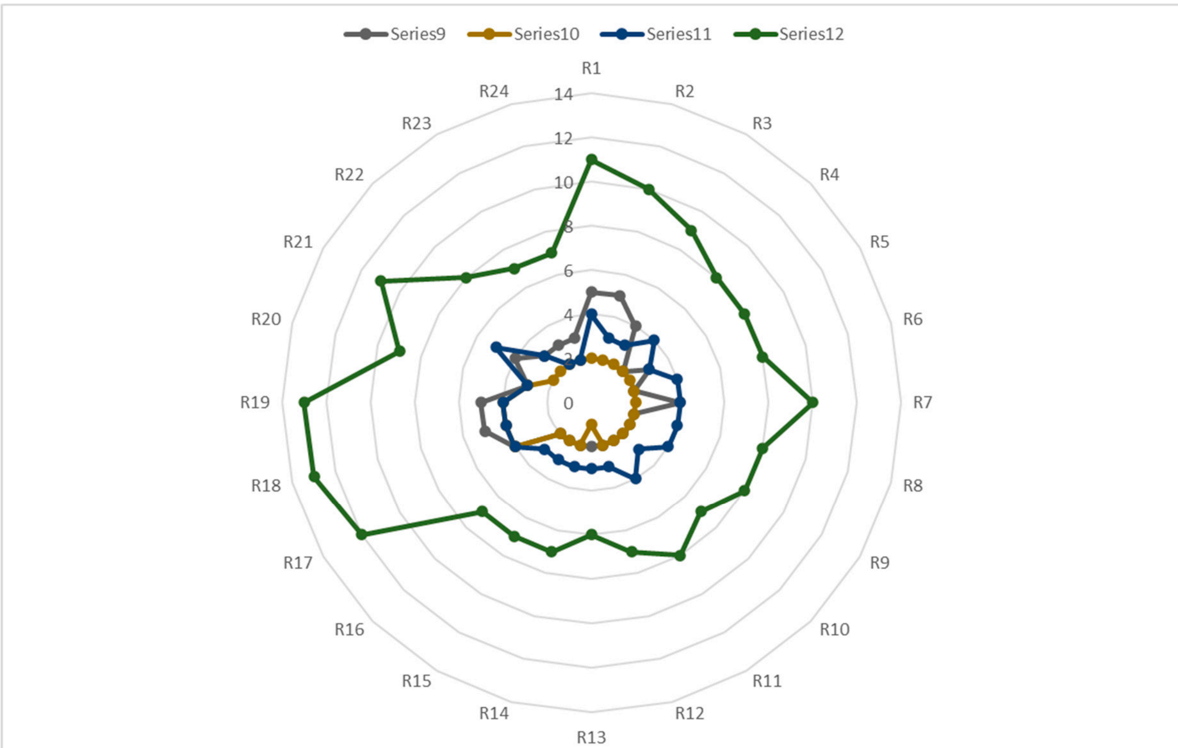

Figure 16. Graph show the rainfall risk management for Mostafaa Ghaffar.

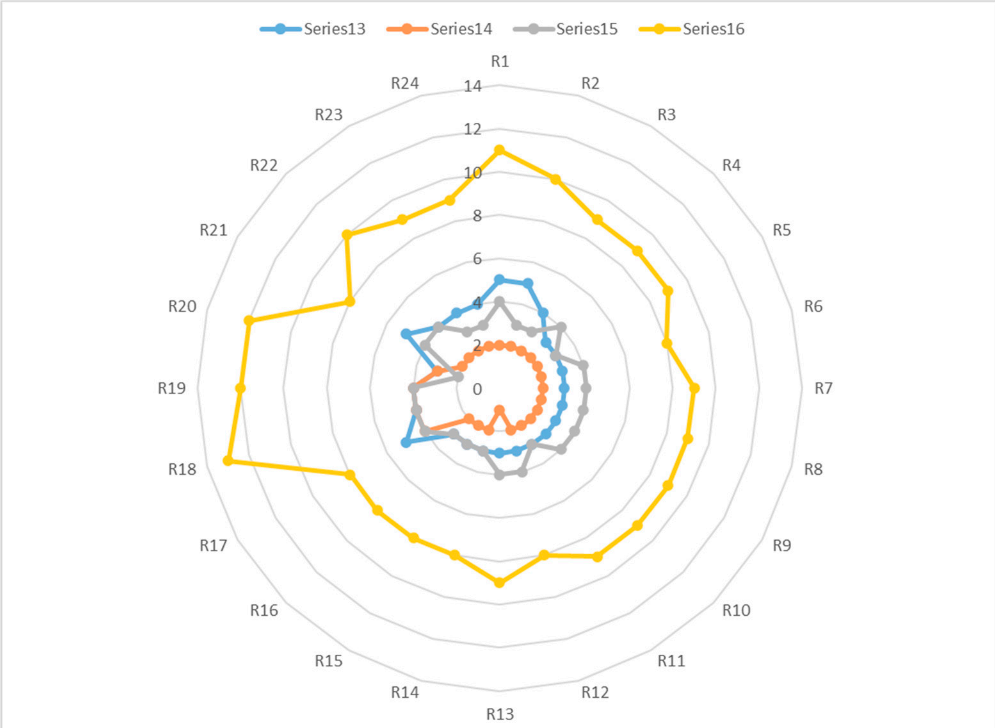

Figure 17. Graph show the rainfall risk management for Khorazati.

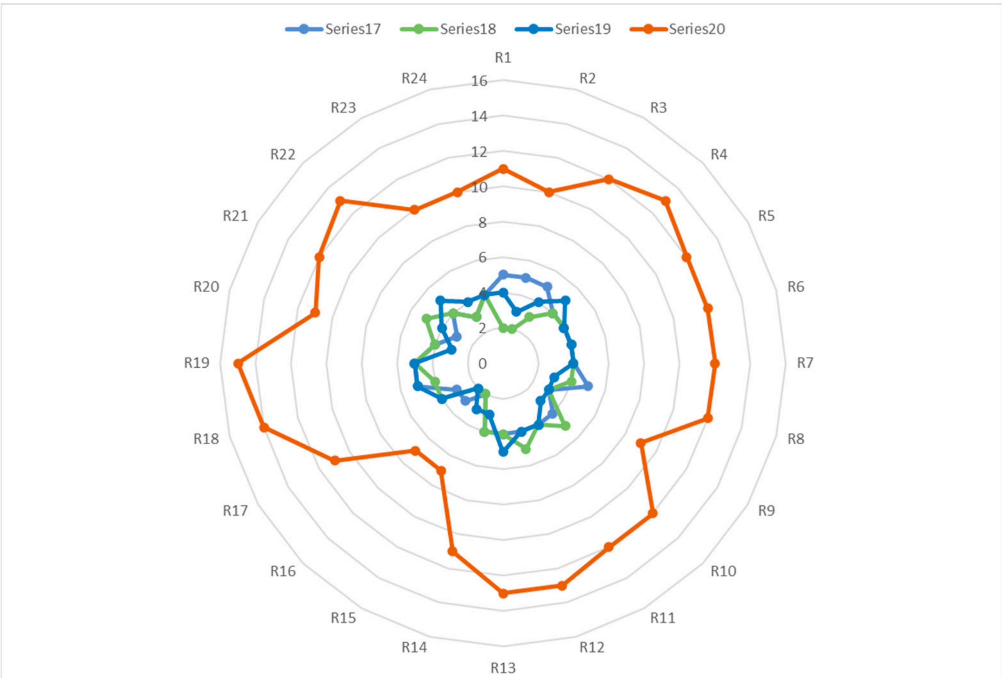

Figure 18. Graph show the rainfall risk management for El-Suhaymi.

4.2. Tornado Sensitivity Analysis Method

This tornado sensitivity analysis simulation was made using the resulting numbers from the previous quantitative analysis of the ABC method to determine risks with the most potential impact on the heritage buildings' facades for the four selected cases to compare the relative importance and impact of variables with a high degree of uncertainty to those that are more stable, depending on the set of ranged colors concerning the positive and negative risks from "blue, green, yellow, orange, and red" shown in Table 5. This analysis highlighted possible benefits which could be achieved by positive risks. For risks that could be greater than the corresponding identified negative impacts, see Figure 19, which shows the tornado simulation for the risks of the four selected cases in section C of El-Moez street in historic Cairo.

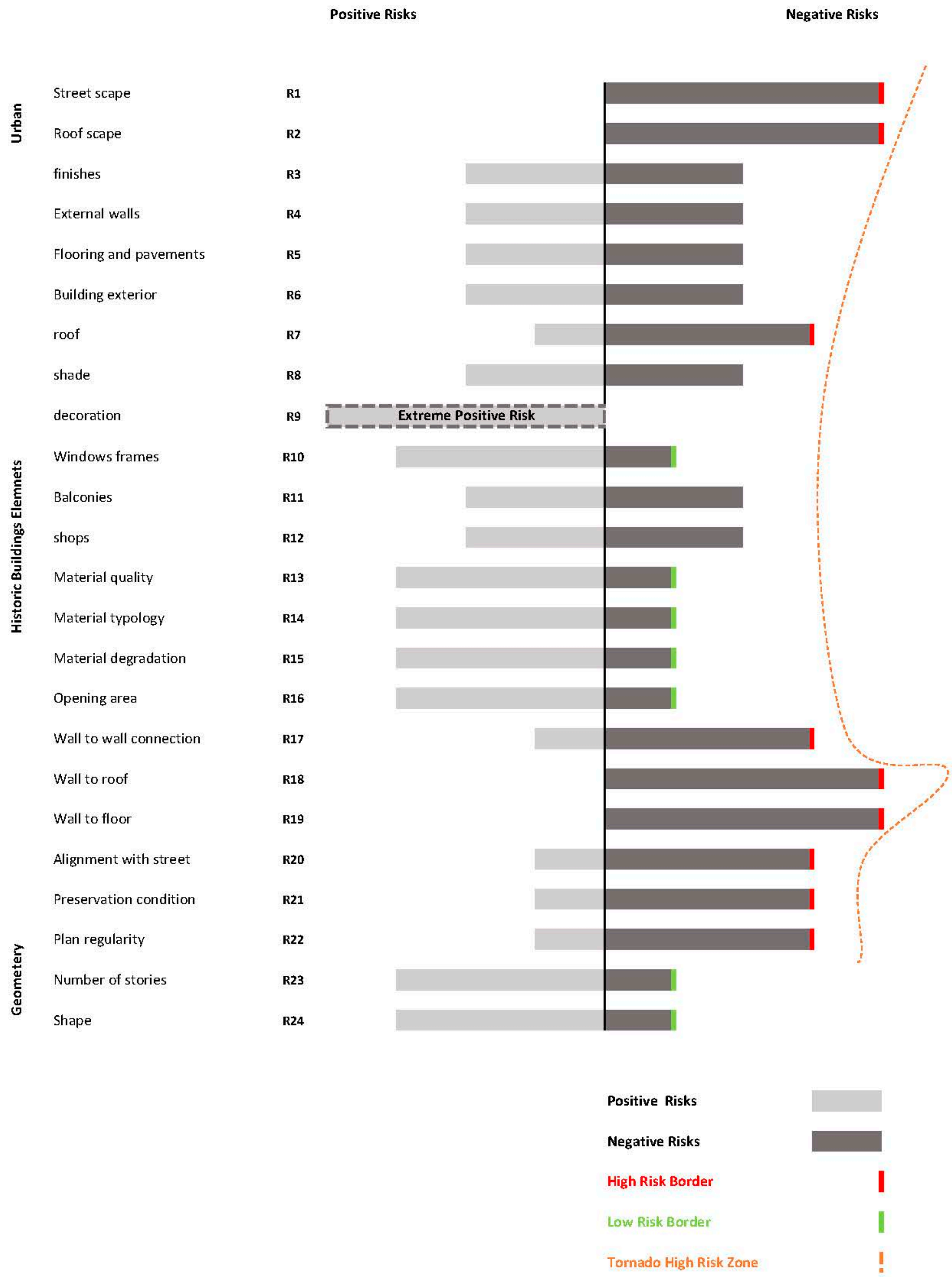

Figure 19. Tornado simulation for the risks of the four selected cases of section C of El-Moez street.

A prioritized list of quantified risks was produced from the previous two analysis methods. This list included those risks as the greatest threat or greatest opportunity concerning the heritage buildings' façades state of conservation.

4.3. Solving the Research Problem

One of the common techniques in management is the A cause-and-effect model to solve problems. It uses a fishbone diagram that introduces the risk framework, which is advised for use in historic Cairo rainfall risk assessment increase resulting from climate change impacts (Figure 20).

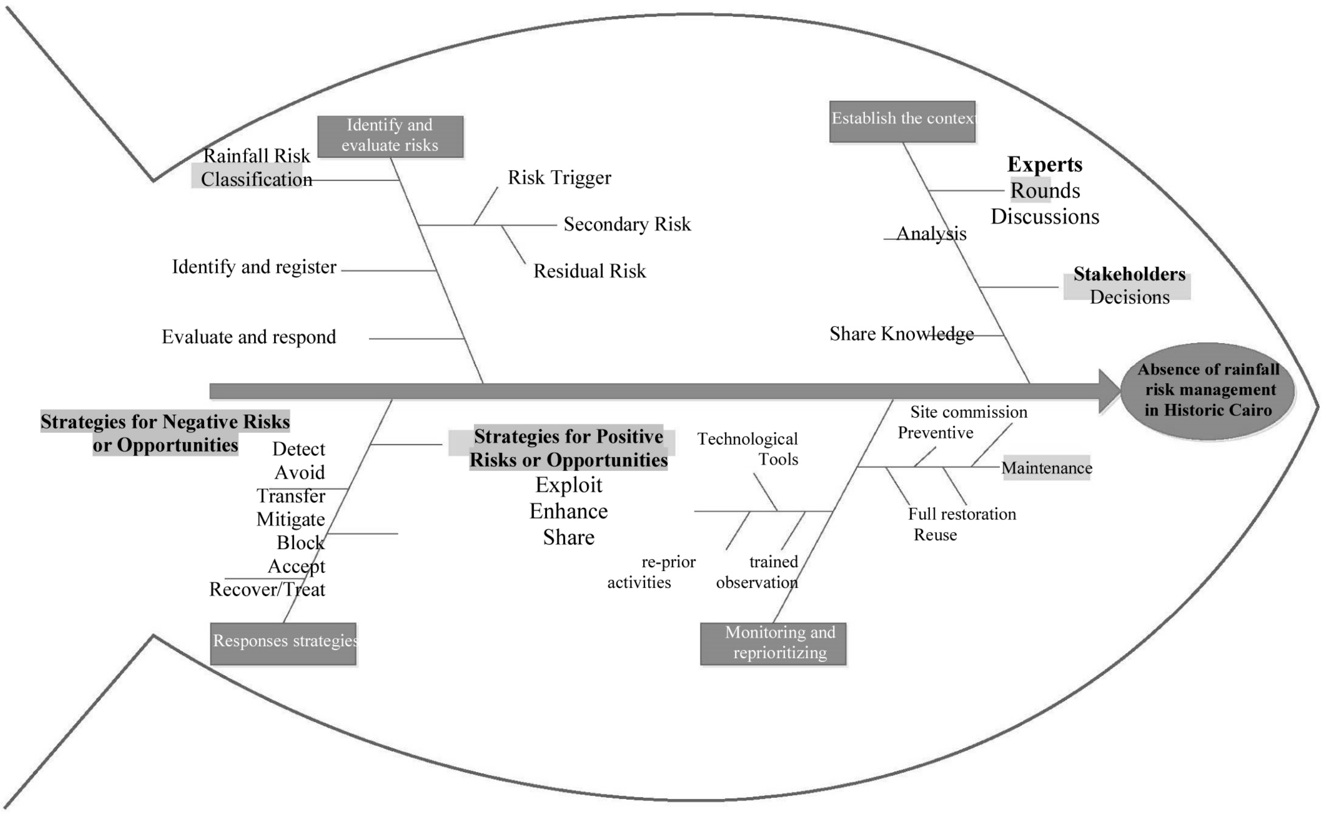

Figure 20. A cause and effect model for problem-solving the rainfall risk concerning the façades of heritage buildings in historic Cairo.

5. Research Conclusions

To be prepared for climate change risks which focused on the heavy rainfall affecting the historic building's facades in historic Cairo, a pilot study was made to identify and register the facades' elements at risk. All hazards and vulnerabilities were identified and analyzed by conservators and conservation architectural experts to rate and evaluate risks to assign response strategies and suitable monitoring to achieve risk management, which is advised to be an ongoing operation. The assessment helped highlight the risk magnitude and degree by quantifying risk by the ABC method based on the Delphi multiple rounds of discussion to rate and evaluate risk and then address the suitable strategy presented and framed by the A cause and effect model for problem-solving. This model depends on cause and effect analysis and can be tailored for every case according to the uniqueness of each heritage building. The results of the selected pilot cases can be generalized because most façades of historic Cairo buildings have the same material and design. One research limitation is the level of uncertainty in information as uncertainty enters many parts of the risk management approach; not just uncertainty in the sense that we cannot know exactly when chance events will strike, but also uncertainty regarding future context, the rate of cumulative processes, and which items are affected.

All management tools, such as the ABC method, are called decision-support tools rather than decision-making tools because they assist rather than automate decisions.

Most of the Islamic monuments in Egypt can use this approach. Those with specific construction or geographic differences may need other approaches, such as heritage buildings in mountainous sites or inside the river Nile or the coastal heritage, etc.

To achieve better results in heritage buildings under study, the integration and experimental methods with measurements are recommended because the qualitative methods can face some difficulties concerning decision making.

Climate change events that have started to impact Egypt can be controlled partly by controlling the vulnerability of those precious buildings through preventive conservation and predicting hazards to be prepared for the risks resulting from the combination of both hazard and vulnerability.

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