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Review Article

Fire Risk Assessment in Cultural Heritage and Museums

Arezoo Izadi*

Ph.D. in Conservation and Restoration of Historical Buildings and Contexts, Faculty of Conservation and Restoration, Art University of Isfahan, Iran

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ABSTRACT

Cultural heritage, as a representation of a society's identity and culture, necessitates protection and preservation. Among the various risks that pose a threat to cultural heritage, fire stands out as one of the most significant. Fire poses diverse forms of damage to cultural heritage, making the protection of such heritage against fire a matter of great importance. To develop a fire risk management plan, one of the crucial steps is conducting a fire risk assessment, which differs in their approach when applied to cultural heritage and museums due to their intrinsic value. This article seeks to introduce two fire risk assessment models specific to cultural heritage and museums. Firstly, the CPRAM model quantitatively evaluates fire risk based on four criteria, considering factors such as usage type and accessibility for firefighters. Secondly, the ABC model qualitatively ranks fire risk by considering frequency, value lost in each affected item, and the value pie ratio. By emphasizing the significance of safeguarding cultural heritage and museums from fire, this article underscores the necessity of comprehensive programs and modeling in this particular domain.

* Corresponding author: **E-mail:** Izadi_arezoo@yahoo.com

Introduction

The cultural heritage of a country, characterized by its historical, cultural, social, and symbolic value, serves as a reflection of a society's identity and requires safeguarding and preservation. Protection and maintenance of tangible cultural heritage entail measures to prevent damage and mitigate risks. Natural hazards, such as earthquakes and floods, pose a significant threat to cultural heritage, subjecting them to considerable harm. Among the various risks, fire emerges as one of the most detrimental to cultural heritage and museums. The destructive consequences of fire encompass burning, heat, smoke, and damage caused by fire extinguishing efforts, resulting in irreparable harm and substantial financial burdens for museum proprietors annually. Consequently, it is imperative to establish safeguards against this peril to ensure the protection of cultural heritage and museums.

To effectively address fire risks in cultural heritage and museums, the development of a comprehensive fire risk management plan for each site becomes essential. This plan encompasses six fundamental steps, including fire risk assessment, documentation, fire risk reduction, passive and active fire protection, and the involvement of trained personnel and fire brigades (Hejazi & Izadi, 2023, 57). During the fire risk assessment stage, a thorough evaluation of the fire risk associated with all objects and components is conducted to determine the subsequent prioritization of protective measures against fire hazards.

Various fire risk assessment models are available to fire experts. In the context of cultural heritage and museums, it is crucial to consider the significance of these structures and objects. Consequently, this article will examine two fire risk assessment models applicable to museums and cultural heritage, namely the CPRAM and ABC model.

Literature Review

In the context of fire risk assessment models applicable to cultural heritage sites and museums, the evaluation of object value emerges as a crucial factor. This distinctive element of fire risk assessment accounts for the differentiation between historical and non-historical objects. To illustrate, the combustion of historical artwork, such as a painting, yields more profound repercussions compared to a non-historical painting. This disparity arises from the historical and cultural significance, in addition to the economic and aesthetic value, associated with a historical painting, whereas a non-historical painting primarily holds economic and aesthetic worth. Consequently, the susceptibility of historical paintings to fire-induced damage necessitates consideration within the framework of fire risk assessment.

In fire risk assessment, it is essential to not only understand the value of an object but also to determine the progression of the fire. This progression is influenced by the main stages of fire, namely ignition, flashover, and spread. By considering these stages, three distinct scenarios can be identified based on the extent of fire spread (Waller, 2013). The first scenario involves a fire that begins in one compartment, spreads throughout that compartment, and then spreads to other compartments. Scenario 2 pertains to a fire that starts in one compartment but remains contained within that compartment without spreading to others. Lastly, scenario 3 refers to a fire that begins within an object or artifact but does not spread to the surrounding compartment. This paper will explore two models of fire risk assessment specifically tailored for cultural heritage and museum settings.

CPRAM- Cultural Property Risk Assessment Model

CPRAM, a quantitative model introduced in 2003 by Robert Waller, assesses the magnitude of risk (MR) through the multiplication of four variables: FS, LV, P, and E (Waller, 2003). Each of these variables in the model is assigned a numerical value between 0 and 1.

$MR = FS \times LV \times P \times E$

In this model, the term "FS" refers to a specific portion of a larger complex that is exposed to the risk of fire and is vulnerable to it. "LV" represents the maximum decrease in value within the compartment. The component "P" illustrates the probability of experiencing at least one fire occurrence within a given scenario over the next 100 years. The fire risk leading to the loss of FS value within a 100-

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year timeframe is denoted by the criterion “E”, which is determined through the evaluation of two sub-criteria: E_{FS} and E_{LV}. The calculation method for this criterion is based on the following relationship:

$E = E_{FS} \times E_{LV}$

EFS is defined as the portion of FS that will potentially be affected by fire risk over the next 100 years. E_{LV} represents the extent to which the loss of value is realized within E_{FS}.

In this model, the value of the P and EFS components is determined by various influential factors, as outlined in the Harmathy model (Harmathy, 1989). These factors include the type of use, the number of floors, the compartment area, the density of furniture within the space, the presence of fire alarm and extinguishing systems, the average winter air temperature, the proximity to the fire department, the accessibility for firefighters, the presence of self-closing doors, the amount of combustible materials, and whether the building is used full-time or part-time.

For instance, in the first scenario where a fire ignites and spreads throughout the complex, resulting in its complete destruction, FS is assumed to be equal to 1. This is because, according to this scenario, the entire complex is at risk of fire. Additionally, LV, which signifies a decrease in value, is also assigned a value of 1. This is because, in the first fire scenario, the entire complex is engulfed in flames, resulting in its total destruction and loss of value. Consequently, the entire value of the complex will be lost. The probability of fire occurrence within the compartment in the first scenario, denoted by the variable P, is determined based on the research conducted by Harmathy (1989). E_{FS} represents the portion of the complex that lacks active and passive fire protection measures and is actually involved in the fire. In other words, this variable considers the sections of the complex that do not have fire protection. E_{LV}, on the other hand, measures the percentage of value lost in the compartment within E_{FS}. In the first scenario, wherein the entire complex is consumed by fire and destroyed, the entire value of E_{FS} is lost. Consequently, this variable is assigned a value of 1.

In the context of the second fire scenario, which pertains to a fire that originates and remains confined within a single compartment without spreading to other compartments, various risks can be identified and assessed based on the sensitivity of the effects within the compartment. In this particular scenario, potential damage to the artifacts can arise from the fire itself, leading to combustion, or from the smoke and heat generated by the fire, which can have detrimental effects on certain objects. Furthermore, the extinguishing agents employed to suppress the fire have the potential to physically damage historical objects or leave behind residue from fire extinguishers. Accordingly, each of these aforementioned factors, contingent upon the type of historical artifacts, can be delineated as distinct risks, and a comprehensive assessment of fire risk can be conducted. It is important to emphasize that within the third fire scenario, all the aforementioned situations can be accounted for as potential risks (Waller, 2022).

In the second scenario, let us consider the variables of the CPRAM model that pertain to the damage resulting from the burning of the targeted compartment. Firstly, the FS variable encompasses the portion of the entire complex that is exposed to the risk of fire and hence susceptible to its effects. Specifically, this variable is calculated by dividing the area of the compartment by the area of the entire complex. Secondly, the LV variable represents a proportion of the overall value of the compartment that is impacted by fire and consequently diminished. To illustrate, suppose a room’s aesthetic value accounts for 60% of its total value, while its structural value makes up the remaining 40%. If scenario 2 fire affects 5% of the aesthetic value, the LV value can be obtained by multiplying 5% by 60%, resulting in 0.03. Moving on to the P variable is derived from the compartment’s area, its quantity, and certain conditions based on the calculations made by Harmathy (1989). The E_{FS} variable encompasses the portion of the compartment that lacks active and passive fire protection measures. For instance, if fire-resistant materials are employed in certain areas of the compartment, the corresponding area is subtracted from the total area since these regions are shielded by passive protection and would remain unaffected in the event of a fire. Lastly, the E_{LV} variable can be determined

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by extrapolating the cumulative loss of value endured by the compartment over previous years, within the context of this specific scenario. For example, if the aforementioned fire had caused a 10% reduction in the enclosure's aesthetic value over the past 20 years, the total loss over this duration would be obtained by multiplying 10% by 60%, resulting in 0.06. To calculate the projected loss over 100 years, this figure would need to be multiplied by 5, indicating that 0. 3 of the value would be lost to fire in the forthcoming century.

ABC

The ABC model was introduced by the Canadian Conservation Institute and ICROM in 2016 as a risk management framework for cultural heritage (Michalski et al., 2016; Michalski & Pedersoli, 2016). This model adopts a qualitative approach and encompasses five stages for managing risks in cultural heritage: establishing the context, identifying, analyzing, evaluating, and treating risks. Within this model, the magnitude of a risk is determined by summing three scores, denoted as A, B, and C, assigned to each risk. The variables in this model range from 0. 5 to 5.

MR=A+B+C

In this model, the A score represents the frequency of risk. The B score corresponds to the proportion of the object's lost value, whereas the C score corresponds to the percentage of the affected value relative to the entire collection. For instance, when assessing the risk of fire for a historical painting, in score A, it is imperative to consider the number of times the painting may be exposed to fire within the next 100 years. This assessment takes into account the existing conditions and the historical incidence of fires. The frequency is recorded in Table 1, and the corresponding score is determined. In score B, the extent to which the painting's value would be lost if exposed to fire is considered. This information is noted in Table 2, and the corresponding B score is determined. To ascertain the C score, it is necessary to determine what proportion of the entire collection's value the designated painting represents. For example, if there are 5 paintings in the collection, each with equal value, the painting under consideration would account for 20% of the collection's value. The determined percentage is recorded in Table 3, and the corresponding score is derived. Finally, the scores from A, B, and C are combined, yielding the magnitude of risk for the specific painting.

It is worth noting that in this model, risk assessment is conducted for various works based on different fire scenarios and the requisite knowledge of the desired collection.

Conclusion

Cultural heritage holds significant historical, cultural, and social significance, serving as a representation of a society's identity. Consequently, it is imperative to safeguard and preserve cultural heritage from various threats. Among these threats, fire stands out as a particularly concerning risk, given its potential to cause extensive damage to museums. To address this issue, it is crucial to develop and implement a comprehensive fire risk management plan tailored to each individual museum. This article focuses on the first stage of this plan, which is fire risk assessment. Moreover, two fire risk assessment models, namely the CPRAM and ABC models, are introduced and discussed within this context.

The CPRAM model is a quantitative risk assessment model utilized within the field of cultural heritage. This model takes into account variables such as the probability and the lost value of the compartment to determine the magnitude of fire risk. It distinguishes between various fire scenarios and assesses the magnitude of risk independently for each scenario. In contrast, the ABC model utilizes a qualitative approach and emphasizes the identification and analysis of risks. This model assigns three risk scores: frequency, the lost value of the object, and the value pie. These scores are used to rank the magnitude of risks associated with different artifacts. As a result, the ABC model enables informed decision-making in safeguarding objects from fire. The findings of this research demonstrate that each of these models, with their distinct characteristics and variables, can serve as a viable instrument in the management of fire risks in cultural heritage and museums. Furthermore, safeguarding cultural heritage effectively not only aids in mitigating the

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financial losses resulting from fires but also plays a crucial role in the preservation of the historical and cultural identity of a society. Therefore, giving due consideration to these solutions and incorporating them into conservation programs can represent a significant stride toward the preservation and maintenance of these invaluable cultural assets.

Table 1. The A scale. Source: Michalski et al., 2016; Michalski & Pedersoli, 2016.

Frequency in 100 years	Mean time between Fire	Score
100 (60-100)	1 (1-2)	5
30 (20-60)	3 (2-6)	4.5
10 (6-10)	10 (6-20)	4
3 (2-6)	30 (20-60)	3.5
1 (0.6-2)	100 (60-200)	3
0.3 (0.2-0.6)	300 (200-600)	2.5
0.1 (0.06-0.2)	1000 (600-2000)	2
0.03 (0.02-0.06)	3000 (2000-6000)	1.5
0.01 (0.006-0.02)	10000 (6000-20000)	1
0.003 (0.002-0.006)	30000 (20000-60000)	0.5

Table 2. The B scale. Source: Michalski et al., 2016; Michalski & Pedersoli, 2016.

Range (%)	Fraction of value lost in each affected item (%)	Score
60-100	100	5
20-60	30	4.5
6-20	10	4
2-6	3	3.5
0.6-2	1	3
0.2-0.6	0.3	2.5
0.06-0.2	0.1	2
0.02-0.06	0.03	1.5
0.006-0.02	0.01	1
0.002-0.006	0.003	0.5

Table 3. The C score. Source: Michalski et al., 2016; Michalski & Pedersoli, 2016.

Range (%)	Percentage of the value pie (%)	Score
60-100	100	5
20-60	30	4.5
6-20	10	4
2-6	3	3.5
0.6-2	1	3
0.2-0.6	0.3	2.5
0.06-0.2	0.1	2
0.02-0.06	0.03	1.5
0.006-0.02	0.01	1
0.002-0.006	0.003	0.5

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