Survey of Vulnerability Indicators for Fire Risk Assessment in Cultural Heritage

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Abstract: Few approaches have been developed to assess the fire safety of cultural heritage (CH). Most available methods for fire safety assessment involve an index-based approach, were not thought for this type of constructions, and involve certain factors connected to minimum provisions defined by standards that are only valid in certain countries. In light of this, the proposed paper summarizes the qualitative selection of vulnerability indicators, which was performed for the purpose of developing a fire risk index applicable to different types of immovable CH assets. These indicators were identified through an extensive literature review that includes qualitative, semi-qualitative methods, simplified and complex approaches, manuals, codes, and standards addressing fire vulnerability for new, existing, and historic constructions, in urban or rural contexts. The review resulted in the selection of twenty-two vulnerability indicators grouped in four categories (building properties; utilities; firefighting measures; and emergency preparedness planning).

Keywords: Fire Vulnerability Indicators; Cultural Heritage; Vulnerability; Fire risk

1. Introduction

Vulnerability indicators for fire risk assessment in cultural heritage (CH) were selected by considering the analysis of existing methodologies developed for fire prevention bearing in mind conservation principles, the conceptual definition of vulnerability, and the available information concerning previous incidents. Therefore, through an extensive literature review of existing qualitative, semi-qualitative methods, simplified and complex approaches, manuals, codes, and standards that accounted for the referred aspects, twenty-two vulnerability indicators were established for fire risk assessment in CH. Given the objective of developing a fire risk index suitable for fire risk assessment in CH, the presented analysis focuses on semi-quantitative approaches and identifies the relevant characteristics of the selected indicators. The proposed list of indicators is distributed into four groups, which could follow specific features according to different architectural classes.

2. Analysis and discussion of methods for fire risk assessment and CH

The scope of the following analysis supports the definition of the proposed vulnerability indicators for fire risk assessment proposed in Section 3 by discussing existing methods developed for different types of constructions. The analysed methods were categorised in three groups. The category (a) methods discuss methods developed for ordinary buildings that were applied to cultural heritage assets or that consider factors/criteria relevant for cultural heritage assets. The category (b) methods are those developed for historic or older constructions based on existing methodologies. The category (c) methods involve those specifically developed for cultural heritage and historic constructions. A summary of the timeline of all the referred methods is shown in **Figure 1.** Some of the methods of category (a) are discussed in Aranđelović *et al.* (2017) such as the TRVB (*Technische Richtlinien Vorbeugender Brandschutz*), PURT-EURALARM, FRAME (Fire Risk Assessment Method for Engineering) and ERIC (*Evaluation du risqué d'incendie par le calcul*) methods, which can be seen as tailored versions of the GRETENER method to fulfil specific assessment requirements. The GRETENER method was created for industrial buildings that is similar to the MESERI (*Método Simplificado de Evaluación del Riesgo de Incendio*) method, although it involves simplified criteria addressing buildings with low risk industrial activities (Salazar *et al.,* 2021). These six methods propose different estimates for movable fire loads and have different risk assessment equations, even though they all base their risk reduction approach on fire protection measures. Similarly, the EURALARM, TRVB and ERIC methods define a fire risk reduction approach that defines fire safety measures as a function of a graphical matrix. As referred by Aranđelović *et al.* (2017), FRAME incorporates technical aspects from international standards and various methods. Unlike ERIC and GRETENER, FRAME includes additional elements such as the type of function of the construction, the access characteristics, factors related to the ventilation and the fire propagation. By analysing Dobbernack (2003), GRETENER and FRAME is seen to involve the protection of the property and the occupants, accounting for the function of the construction. Unlike these methods, the BOCA (Building Officials and Code Administrators International) and FSES (Fire Safety Evaluation System) methods address mostly the safety of users based on USA standards valid at the time. However, the difference between these last two is that FSES is applicable to new and existing constructions while BOCA is only applicable to existing buildings. Salazar *et al.* (2021) refer that MESERI, GRETENER, PURT-EURALARM and FRAME have been applied to cultural heritage assets. Similar applications were not found for BOCA, FSES, FRIM-MAB, ERIC and TRVB, but BOCA and FSES have been suggested for fire safety assessment in rehabilitation projects for historic dwellings and museums (Watts *et al.*, 1998). In addition, these methods, along with FRIM-MAB, were relevant to the development of methods considered in category (b).

In category (b), the method of Chapter ILHR 70 of the Wisconsin Administrative Code (ILHR) is based on BOCA as an alternative for listed buildings and historic places in the Wisconsin State, while HFRI (Historic Fire Risk Index) combines several factors from the ILHR, BOCA and FSES methods. HFRI introduced historical significance and security fire prevention parameters that were also considered by Arborea *et al.* (2014) in the FRIM-HB (Fire Risk Index Method for Historical Buildings) method, by considering Italian rules and validation based on numerical simulations. This method was derived from the one developed by Karlsson (2000), i.e. FRIM-MAB (Fire Risk Index Method for Multi-storey Apartment Buildings). Thus, HFRI, ILHR, and FRIM-HB are methods adapted from existing methodologies, created especially for immovable CH. The methods presented by Lopes *et al.* (2012) (i.e. MARIU - *Método de Avaliação do Risco de Incêndio Urbano*), Vicente *et al.* (2010) (i.e. a simplified the method ARICA - *Análise do Risco de Incêndio em Centros Urbanos Antigos*) and Chichorro *et al.* (2016) (i.e. CHICHORRO - *Cálculo Holístico do risco de Incêndio da Construção e Habilitada Otimização da sua Redução com Obras*) are similar approaches developed for historic urban areas but their factors are based on Portuguese regulations. While CHICHORRO considers several factors related to technical facilities and mitigation strategies, MARIU was developed to provide results for urban risk mapping based on building typologies. With respect to ARICA, several alternative versions have been proposed, particularly for large scale applications.

The category (c) methods involve five approaches. The HFRI (Historic Fire Risk Index) and FRACM (Fire Risk Assessment for Collections in Museums) methods were developed by Watts *et al.* (2000) and Tréteault (2008), respectively, for properties with valuable cultural assets. While HFRI focusses on the characteristics of the property (i.e. house museums or libraries) and uses an empirical multi-attribute evaluation, FRACM focusses on the safeguard of museum collections based on the likelihood and consequences of loss by analysing the fire resistance, combustibility and fire load characteristics. SEPC (Fire Safety Evaluation for the Property Protection of Parish Churches) (Copping, 2002) and RAGER (2004) are methods for the fast assessment of religious CH. RAGER considers lightning rods to prevent fires caused by lightning in religious buildings, due to the significant number of fire incidents that occurred in France. While RAGER focusses more on fire prevention over movable contents (similar to the FRACM method) using a 'yes/no' questionnaire, SEPC defines the risk for the building materials and contents of parish churches by an index system. The FETAM (Fire safety Evaluation for Taiwan's Monuments) (Wen *et al.,* 2013) method establishes a specific approach by considering statistics, codes, and empirical data with a multicriteria approach. FETAM is an index method with characteristics similar to those of HFRI, ILHR, and FRIM-HB that involve expert judgement to define the parameter weights, and that consider fire suppression systems, building properties, and risk management procedures.

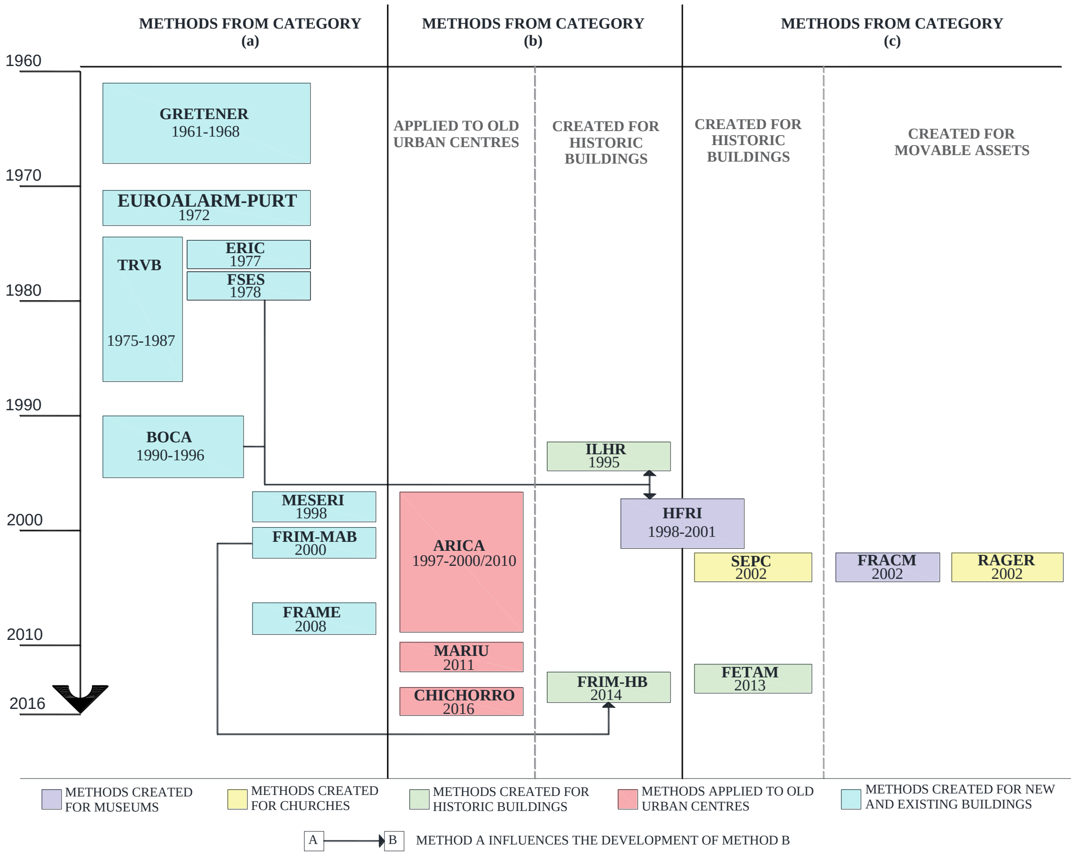

Figure 1 – Summary of the analysed methods (Salazar *et al.,* 2021).

3. Selection of indicators and relevance for different architectural classes

By analysing the previous methods, along with other documents (Salazar *et al.,* 2021), twenty-two indicators were defined according to four groups, as reported in Salazar *et al.* (2021). *Properties of the built elements*, refers to the physical features such as the fire load (FVI-1), fire resistance (FVI-2), finishes and linings (FVI-3), compartmentalisation (FVI-4), the properties of the adjacent buildings (FVI-5), the likelihood of vertical fire propagation (FVI-6), the quality of combustible materials (FVI-7) and the existence of firebreaks or buffer zones (FVI-8). The *Utilities* group involves the properties of electrical (FVI-9), gas (FVI-10), HVAC (FVI-11) and CCTV (FVI-12) facilities or equipment that require a special treatment since historic buildings were, in many cases, designed without considering them. *Firefighting Measures* consider the integration of auxiliary fire suppression systems and elements that contribute to the prevention, containment, alert, or combat in case of fire (i.e. alarm and detection (FVI-13), smoke control (FVI-14) and active suppression system (FVI-15), water supply (FVI-16) and fire rescue services (FVI-17)). Finally, *Emergency Preparedness Planning* integrates the strategies and plans contributing to the safety of people and the safeguard of movable assets considering the emergency planning (FVI-18), compartment height level (FVI-19), evacuation and egress routes (FVI-20), signage and emergency lights (FVI-21) and cultural value of movable and immovable assets (FVI-22). Given the wide variety of CH assets, as shown in Salazar *et al.* (2021), a typological classification of four categories could provide a connection between the proposed FVIs and the architectural classes for fire risk assessment. Therefore, their physical and spatial characteristics could portray their expected behaviour under fire. Still, these should be analysed case by case due to the large variability of heritage assets. For example, by analysing the characteristics and location (i.e. in an urban or rural setting) of different archaeological sites (e.g. Mahasthangarh in Bangladesh, the Roman Forum in Italy, or the Okyozuka site in Japan), it can be seen that FVIs such as FVI-4, FVI-5, FVI-6, FVI-15, FVI-20 or FVI-21 can have different levels of relevance. On the other hand, aggregates of built assets should consider characteristics of the buildings' surroundings in addition to those of the built single assets that are involved (e.g. FVI-8, FVI-9, FVI-12, FVI-13, FVI-18 or FVI-20). Finally, FVIs related to *Firefighting Measures* and *Emergency Preparedness Planning* (e.g. FVI-13, FVI-15, FVI-18, FVI-20 or FVI-21) are also likely to be different between built single assets and other types of assets.

4. Conclusions

The selection of vulnerability indicators for fire risk assessment that was carried out involved a wide variety of literature (i.e. standards, recommendations, manuals, and fire risk assessment methods). This short paper discussed some of the existing approaches for fire risk assessment, underlining methods dedicated to historic constructions. Similarities and differences between these approaches were discussed, namely those addressing new buildings and historic buildings. Although not all methods are applicable to historic buildings, several aspects of these methods are useful for the qualitative identification of fire vulnerability indicators in CH. The final list of indicators addresses the need to analyse the fire safety of CH considering both movable and immovable assets.

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