Treasures gutted by fire. Fire safety design awareness as a consequence of historic building accidents and disasters

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Abstract. Many of the emblematic buildings of historical importance that have been constructed throughout human history still survive today. However, a significant number has been destroyed by fire. Despite the impact this loss has on cultural heritage, important lessons can also be learnt, enhancing our understanding on how fires develop in historical structures and why they occur in the first place. A review of the existing fire design approaches, in conjunction with the heritage building values and fundamental conservation principles, initiates a dialogue in terms of acceptable interventions and fire protection solutions. The aim of this study is to provide contemporary scientists, conservation professionals and building owners with an insight of how building physics affect the fire performance of historic structures, highlight common risks following a thorough literature review and discuss the role of the fire and conservation engineer.

Keywords: Heritage structures, conservation principles, causes/risks of fire, performance based design.

1. Introduction
Although heritage buildings comprise a small portion of the total building stock (indicatively 2.0% of building stock in the UK [1]), special provision for their protection against fire is of fundamental importance. These buildings, regardless of their modern function, carry a number of significant values that need to be identified and preserved accordingly. Since the early 1900’s the need for an international, coordinated approach for their protection had been identified [2]. Fire, being one of the most serious threats against building survival through time [3], needs to be considered carefully and dealt with by means of sympathetic and effective solutions.

Through an extensive literature review, the present work brings together the fundamental principles of fire engineering and conservation of historic buildings. It facilitates an essential amalgamation of the two fields and intends to provoke a fruitful discussion between the scientific community and the conservation industry practitioners as part of a wider conversation and research on the fire protection of cultural heritage. It aims to identify the different values of historic buildings, explore their relationship with fire in terms of vulnerability and methodologies of protection and finally briefly underline effective ways of protecting heritage structures against fire without conflicting with the main conservation principles.

2. Identification of heritage building values and scope of this study
Providing a strict definition for the ‘heritage building’ can be quite challenging. In reality, a plethora of different values and characteristics could justify the inclusion of a structure within the scope of heritage. Referring to historic buildings is a widely used paraphrases, and indeed highlights one of the most fundamental aspects of heritage structures; their historic significance. More often than not, this is enhanced by exceptional aesthetics or by the fact they are fine examples of a specific architectural style. Sometimes though, aesthetics are less crucial. Instead, contribution to the community along with innovative engineering design (at the time of construction) and use of building materials and techniques take priority. Industrial heritage and historic infrastructure are such examples. In these cases the community value (local, national or international) can supplement or even overpower the aforementioned [4]. The heritage building values also include, but they are not limited to:

- the evidential value when providing evidence of life customs and habits of the past, techniques and cultural elements,
- associational value when the building is associated with important events or persons of the past,
- scientific value when it provides opportunities for scientific research or archaeological findings,
- structural value as part of a larger structural system,
- symbolic value for monuments with cultural, religious or historical symbolism and
- functional value in cases where the building played an important functional role; (for example a hospital) [4].

From the above, it becomes apparent that the list of historic structures can be very extensive, and sometimes subject of discussion and debate. This study will only look at residential and community heritage buildings, excluding historic infrastructure, stand-alone memorials or extensive historic complexes.

3. Fire among the most serious threats to historic buildings
Regardless of the robustness of their structural system, the workmanship of the original builders and the quality of the materials they consist of, historic buildings are vulnerable through time due to a number of threats. These can be divided into two broad categories; natural elements and threats derived by human activity.

The elements, including rain, wind and heat, along with natural disasters which exceed 1000 serious incidents a year [5], belong to the natural threats and pose a serious danger for cultural heritage buildings. The list should be extended to include pests, rodents, fungal growth, natural weathering and ground settlements. Although the designer’s or the owner’s ability to predict and prevent the above is limited, specific measures can be implemented to mitigate their consequences [5].

On the contrary, the human derived threats can possibly be predicted and with the application of appropriate measures can be prevented [6]. Careless and unsympathetic interventions, inherent design mistakes and weaknesses, vandalism, robbery of building materials and wars are only a few of the most common ways of how humans destroy heritage buildings. Although the scale of destruction caused by war can be easily understood, fire poses a great threat resulting in some extremely expensive and, very often, non-reversible damage to heritage buildings.

Indicatively and only considering one of the most “famous” heritage building fires (Windsor Castle, England 1992), the cost of such a disaster can exceed 90m euro [7]. The indirect financial loss of losing the income generated by a building-attraction for tourists, should be added to this economical disaster [8]. Even for smaller fires though, the loss is not comparable to similar size fires in modern buildings. Apart from the damage to the original fabric of the building which can be direct or residual [9], another substantial financial and cultural loss is the damage of contents of the building [10]. This can be equally important to the loss of the building itself as in some cases contents are irreplaceable (i.e. works of art, artefacts or unique objects of historical importance).

From the above it becomes obvious that protecting historic buildings from fire is important not only in terms of preserving what represents a major part of local, national and international heritage, but also
preventing substantial financial loss. Planning their protection effectively is a complicated design issue and as such, understanding the main causes of ignition and spread of fires in historic buildings is crucial.

4. The main causes of ignition and spread of fire in historic buildings
Evidently, a number of reasons could lead to fire ignition in historic buildings; although some of them can be encountered in historic buildings and common old structures alike, herein they are specifically examined in the historic context due to their devastating cost on cultural loss. Faulty or very old electric circuits are one of the most common causes of fire ignition in historic buildings [11]. Although giving new uses to historic buildings can be one of the most sustainable ways of preserving/maintaining them [12], it can also amplify this onerous situation. This can either happen by a new use that is incompatible with their original design and purpose, and which could cause overloading of existing cabling; or by accidents during the conversion building works [6]. Poorly maintained services and appliances, disconnected alarms and lack of access to areas of the building can contribute to the ignition or growth of fire respectively, which would otherwise be possible to control and put out [13]. Depending on regulations and restrictions enforced, activities like smoking, heating through open flames (i.e. fireplaces or woodburners) and use of cooking appliances (i.e. open flame stoves) can be the cause of fire initiation [14]. Although other causes of fire exist (i.e. arson, wildfires, lightning etc. [15]), historic buildings seem to suffer more often from the factors mentioned above.

In combination with the aforementioned fire ignition causes, multiple characteristics specific to historic buildings generate onerous conditions regarding fire spread. The traditional building materials and techniques used for historic building construction are one of the main factors. The timber structural frames, timber roof and floor structures, timber stud partition walls [16], thatch roof finishes and iron or steel details and connection components contribute in the fire spread and rapid heat transfer [17]. Even stone masonry walls which can be resilient and non flammable, under these conditions suffer residual damage that can lead to further destabilization of the structure [18]. High combustion loads, including heavy wooden furniture, fabrics and textiles or decorative wall paper favour fire growth and spread through floors and walls [19]. This is largely scaled up by the lack of adequate fire compartmentation, the multiple concealed fire spread routes (i.e. confined places, undercroftes, roof voids and attics, passages through masonry walls and non fire rated openings and access hatches). Lack of efficient fire control and prevention systems (i.e. passive fire suppression systems including water or mist sprinklers systems) [8] leads to complete failure or delay in identifying the fire and preventing its spread. Finally, the location of historic buildings, usually in historic centres with narrow lanes and limited access for fire service vehicles or in remote country side areas, leads to delayed intervention from the fire service providing fire with a chance to spread to uncontrollable extents [20]. Along with the main causes of fire ignition and spread in historic buildings, knowledge and understanding of the available design codes and the conservation principles allows designers and building owners to select appropriate preventive or mitigating solutions.

5. Fire design approaches and introduction to conservation principles
There are two main fire design and regulation approaches covering the needs of modern and historic buildings alike; the prescriptive approach and the performance based approach. Although discussion regarding the benefits and weaknesses of either approach has been ongoing for well over a decade [21], many states around the world, including Greece [22], follow the prescriptive approach. Specific figures, approved methods, techniques and products “prescribe” the only acceptable design methodology. Although this might be an effective way of designing modern buildings, it usually clashes with the existing material properties, structural characteristics and architectural layout of the historic ones. Such an approach provides no design flexibility by restricting any innovative and alternative solutions that might be required in terms of respecting and protecting the unique character and intangible values of heritage buildings.

On the other hand, performance based codes, list the required fire performance standards without necessarily restricting the designers in terms of “how to” achieve them [10]. This approach, although
highlighting the required fire performance for historic buildings, it actually allows alternative methodologies and design approaches to be explored and implemented. Modelling, fire testing off site and putting together management plans for the prevention or early tackling of fires can provide effective alternatives to traditional design methods [23]. This flexibility is essential through the design process of fire protection for historic buildings where conservation principles need to be complied with as well. The following paragraphs expose the conservation principles in conjunction with the fire protection requirements.

- Interventions on historic buildings need to be sympathetic. The designer needs to be respectful towards the original fabric, form and scale of the building [1]. Compatible building materials and construction techniques need to be utilized, respecting the properties, appearance and functionality of the original building elements. Designers need to bear this in mind when specifying fire protection solutions which are either very visually intrusive, out of scale (i.e. much larger than existing elements) or just disrespectful towards the character of the building.

- Repairs, adaptations and general interventions are sometimes inevitable; when applied on heritage structures, these need to be honest. Trying to conceal and minimize the visual impact of a modern element is acceptable, however trying to imitate or fake the original fabric should not be an option as it compromises the fundamental value of authenticity [24]. In terms of fire protection and safety, signage, colour coding, lighting etc need to follow specific standards [25] and these cannot, and should not, be compromised for any reason. However, appropriate positions need to be found for their installation and the community needs to accept these interventions as honest and necessary additions for the protection of the building and its users.

- Although these additions are acceptable to a certain degree, it is necessary to remember that the building has had a long history and it will most probably carry on to serve future generations. As such, any interventions in terms of fire suppression systems, signage, alarms and miscellaneous fire safety equipment need to be reversible and easy to remove so the building can be reinstated to the pre-intervention state.

- That said, any additions and adjustments need to be kept to a minimum. Although it is acceptable to install equipment and systems, even if these are reversible, sympathetic and honest, in reality they cause disruption to the original fabric and character of the monument. This should be a fundamental principle during the fire design stage, when system types, locations and number of additions are being considered.

- The last two conservation principles mainly apply to restoration of existing buildings or ruins and although they need to be considered at all times, they probably have more of an indirect impact on fire strategy. Restoring like for like and conserving as found restricts the flexibility of a designer to improve the fire performance of a historic building by preventing the introduction of new materials and restricting any layout amendments. Although in some cases it might be tempting to upgrade the fire performance of a derelict heritage structure, the designers need to be reminded that this is incompatible with its original character, philosophy and technology at the time and they should focus on preserving rather than improving its condition [26].

6. Compatibility of available means of fire protection with conservation principles

The impact and compatibility of the various design approaches and fire protection solutions with the conservation principles is an interesting field for discussion. Usually, passive fire protection methodologies, including installation of automatic fire suppression systems (i.e. sprinklers), fire compartmentation of the building, fire coating of structural elements or protection by use of fire rated boards and installation of fire alarms and smoke/heat detectors can clash with most of the conservation principles mentioned previously. Installation of these systems usually requires extensive works (not minimum intervention), they cause disturbance of original fabric and are visually intrusive (unsympathetic) and once in place they are very difficult to remove or replace (irreversible). Of course, it can be argued that these measures are honest, as usually the distinction from the original fabric is quite obvious; this is not enough on its own though, to justify the above. The advantage of these solutions is
that they can prevent spread or quite effectively put out fires caused by all ignition sources mentioned previously.

On the other hand, measures of active fire protection can prove much more sympathetic and adequately effective when planned, used correctly and on time. Provisions for portable fire extinguishers, in combination with an early warning system, can help control and tackle a fire before it has a chance to cause significant damage (nominal intervention, reversible, honest, and generally sympathetic – see conservation principles). These systems need to be backed by an organised management plan, part of which needs to be a minimum level of staff training in use of fire extinguishing equipment and basic handling of emergency situations (no physical impact on the building). Informative notes, alarms, emergency lighting, fire extinguishers and other portable fire fighting equipment are easy to install, easy to remove and cause minimum disruption to the original fabric. Provision should be made in the management plan, for the occasion where an increased number of users is expected (either reducing the risk of fire or reinforcing the emergency response measures). Also, in situations where access of the fire service can be problematic, on-call trained staff or building users should be notified instantly through an automated system or a physical guard. These measures might also have disadvantages in terms of applicability, resourcing or efficiency, however integrated smart solutions and systems promise to enhance their effectiveness [27]. In principal, they appear to be much more compatible with the sensitive character of most heritage buildings.

7. The role of the fire and conservation engineer

Decisions made in the design stage, relating to appropriate fire protection measures, should be informed by a thorough desk study regarding the significance of the structure as well as an assessment of its needs in terms of fire vulnerability. This process becomes more complicated due to the unique character of each historic structure and the looser levels of standardization in construction followed at the time. Use of an Analytic Hierarchy approach can contribute in fine tuning the process and can result in an “optimized fire protection” plan [28]. Additionally, experts and various stakeholders should be consulted and their input should be used by designers [29] to achieve a more holistic and complete assessment of the required measures.

Although “traditional wisdom” and historic architectural or engineering fire compartmentation and disaster mitigation solutions seem to have saved many heritage sites [30], things nowadays seem to be more convoluted. Despite the range of tools currently available, the restrictions imposed by fire codes and conservation principles, make finding a perfectly acceptable and ideal solution unlikely [31]. However, a professional should exercise their engineering judgment and put their conservation philosophy into practice. Understanding the context of the building, its special and unique needs, weighting all the relevant factors and finally putting together an appropriate policy and management plan are instrumental in this process. The correct implementation of the plan and a detailed and regular review of its performance should allow the achievement of the best possible outcome in terms of fire protection and fire safety in historic buildings [32].

8. Conclusion

No historic building is similar to another and as such the fire risk assessment, as well as the relevant fire protection measures, need to be considered separately with each case. With a very wide selection of products available, and provided that a flexible design methodology can be followed (i.e. performance based codes), more appropriate solutions can be found. Ideally, the required standards of fire safety will be satisfied while respecting the values embedded in each historic building. A very wide field for research is available, extending from development of more sympathetic fire protection solutions, to development of more accurate analysis modelling methods and information recording systems. In a wider movement of sustainability, the engineers ought to focus their efforts on the above, to provide the current, as well as the future generations, with environmentally friendly, culturally respectful and technically viable solutions. These should prevent financial loss, minimise waste of resources by
preserving the existing heritage building stock [33], mitigate damage or devaluation of heritage assets, and enhance their significance [34].

In this study, the relationship of the basic fire engineering and conservation principles was explored. By reviewing a considerable amount of previous research papers, design codes, building regulations, and conservation charters and publications, a compilation of valuable material became available, providing a solid foundation to those who wish to thoroughly research the area of fire protection of historic buildings. The most common fire causes and possible fire protection strategies were considered in conjunction with the modern design codes and were examined through the prism of historic building conservation. The significance of the fire and conservation engineer was also discussed, stimulating not only the scientific community, but also seasoned conservation practitioners to clearly define responsibilities, the extents of field of expertise and the working interface between the two specialists. This investigation aims to bridge the gap that currently occurs between the modern fire engineering technology and traditional conservation principles, and envisages it can be the initiation of a wider dialogue between the two fields.

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