Fire Safety in Historical Theatres (Italian-Style)

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The research starts from a punctual knowledge of the theatrical typology under many aspects and in-depth analysis: from the recognition of the monumental value and qualification of a historical theater, collective heritage to be preserved for future generations, we'll investigate environmental, typological, distributive, functional, material and constructive characters in the earliest designing phases and after the adjustment and transformation interventions occurred. The main aim is identifying all the parts that are at risk of fire, the equipment implementation done to lower such a risk, with the purpose of suggesting adequate systems intended to gain a major level of fire protection in a historical theater.

In theatres, as for every building, we must guarantee the "primary safety", human lives safeguard, as well as the "secondary" one, that is to say the protection of the edifice and its intrinsic value. Beginning from the state of the studies and general and specialist documents on theatrical architecture, Italian and supranational, it be investigated the components subjected to a high risk of fire, the safety routes and fast evacuation systems. We compare the fire prevention regulations written during times in various countries, and identifying significant cases of study in order to evaluate the most appropriate actions to gain security and to reduce the risk. By means of tests and fire risk assessment, we characterize the materials used, as well as new ones, to enhance resistance to fire, the possible emergency routes, the static safe places, the existing fire systems implementation, as well as a fast emergency services access. We consider guidelines and protocols to a better design of fire systems in a historical theatre, considering both the safety of people and the building-monument.

The scientific goal that aimed this research, is applying a multidisciplinary approach to recognize the original characters of the historical theatres, certifying a quality that won't compromise their valorization. The fire systems strengthening design, to protect people and objects from possible fires, must be interpreted in its scientific, cultural and operative valences in order to gain a high fire-protection performance, without renouncing to the monumental aspect, both spatial and material-constructive.

In the first chapter; historical outline, changes in the buildings of historical theaters, focusing on fire safety, has been studied and studied. And some of these fires have been described.
The second chapter; Italian theater, is devoted to the any aspects of historical theaters. The parts of these buildings that are most exposed to fire risk have been identified and discussed about how fire safety can be improved.
The topic of chapter three is fire safety regulations, in this section, the developments and the completion of the rules are mentioned over time.
The comparison and Analysis between Performance Based Approach and Prescriptive have been done, and why performance based approach in the case of historical theaters should be

adopted.
Fourth chapter is talking about fire risk management and the process that must be conducted to manage fire at historic theaters.
Chapter Five introduces the frames method, one of the most comprehensive and up-to-date fire risk assessment software. In this section, we have tried to categorize and describe all the issues affecting fire risk.
In chapter Six, the last season, two case studies have been evaluated and studied. The Niccolini Theater and The Pergola Theater, both located in the historical district of Florence city.
One of the main reasons for choosing these two theaters was having full details of them, and also the authorities of these theaters were already working on their fire safety and had a safety plan. At the end of this chapter we suggest some solution for improving fire safety in historical theaters and reducing the fire risk level.

Acknowledgements

First, and foremost, I thank Almighty God for His love, guidance and assurance at all times during this Ph.D. program. I also give my heartfelt thanks to all those others who have helped make this accomplishment possible.

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Dedication

I would like to dedicate my thesis to my beloved husband, Majid, you never care about my achievements more than myself. It is hard to believe that I could have survived these years far from you!

To my caring parents, Maman and Baba, your unconditional love, endless support, and continuous encouragement give me the confidence to pursue my dreams. You are always an inspiration to me, and I feel really lucky to have you and all my charming siblings in my life. Especially I feel blessed to have my wonderful sister, Atefeh joon, to whom I owe a lot. It is hard to put it in words, but I am wholeheartedly thankful to you.

To my life, my daughter, Sofia who is an absolute joy to be around.

By dedication of this thesis to all of you, I would like to show my sincere love; each and every word of it stands for the moments of being away but thinking about you. I will always do my best to see the smile of satisfaction on your sweet faces.

Contents

Chapter One; Historical Outlines

The fire safety has been a very important debate, because its occurrence in public buildings has caused irreparable damage to the lives of people and public property. It should be noted that fires particularly are historically one fires plural of the main reasons for the destroying of theaters, and with the onset of it, new architectural rules were drafted. This has historically changed some aspects of architecture. As a result, fire safety can play an important role in the evolution of theatrical buildings.

In the past, uneducated and detrimental restoration and adaptation to fire protection regulations have distorted in many cases the architectonic and constructive characteristic elements. Nowadays, although many studies have been done on fires in historical theaters, we still need a better understanding of how this problem occurs, and there are issues to be addressed such as design issues, standards, methods and meanings available for safety assurance.

As for every historic building, in Italian Style Theaters, where the "ephemeral" connotes many parts of the construction, the safety issue, especially fire safety (fire protection), is very important for two reasons: protecting human life (primary security) and protecting existing assets and maintaining buildings that are very valuable (secondary security).

The process of achieving suitable levels of performance and safety, while maintaining the historical fabric, can pose many challenges for regulators, designers and contractors.

Firstly, we are trying to review the evolution of fire safety in historical theatres, the reasons of fire, the solutions and the equipment implementation done to lower such a risk. Today, as in the past, the attainment of a suitable fireproof safety level needs to take in mind different aspects into account. These problems include the combustible materials presence (wooden historical structure particularly, as well as new ones, characteristic of this typology of theatre building), to enhance the resistance to fire, the existing fire system implementation as well as a fast emergency services access and the guidelines to a better design of fire system in a historical theatre. All these aspects contribute to guaranteeing adequate levels of safety and conservation of the most fragile parts of these architectures.

1.1 The Origin of Theater Shapes

Western theater finds its origins in the forms in ancient Greece and then developed in the Roman era with the Latin theater.

As is well known, in the first theaters there was no covering, but veils to protect the spectators from the sun, because the shows were held during the day; during this time there was no fire due to the lack of coverage. But over time, because the show was performed throughout the day, and the sun was disturbing the audience, theaters were equipped with a roof. In fact, the ceiling was considered a factor in protecting viewers from sunlight.

In the Roman theater the use of wood is more usual. The most important feature of the Roman theatre as distinct from the Greek theatre was the raised stage (Fig 1.1). As every seat had to have a view of the stage, the area occupied by the seating (cavea) was limited to a semicircle. As in Greek theatre, the scene building behind the stage, the “frons scaenae”, was used both as the back scene and as the actors’ dressing room. It was no longer painted in the Greek manner but tended to have architectural decorations combined with luxurious ornamentation. The audience sat on tiers of wooden benches, spectacular, supported by scaffolding. There was no curtain; the back scene, with its three doors, faced the audience.

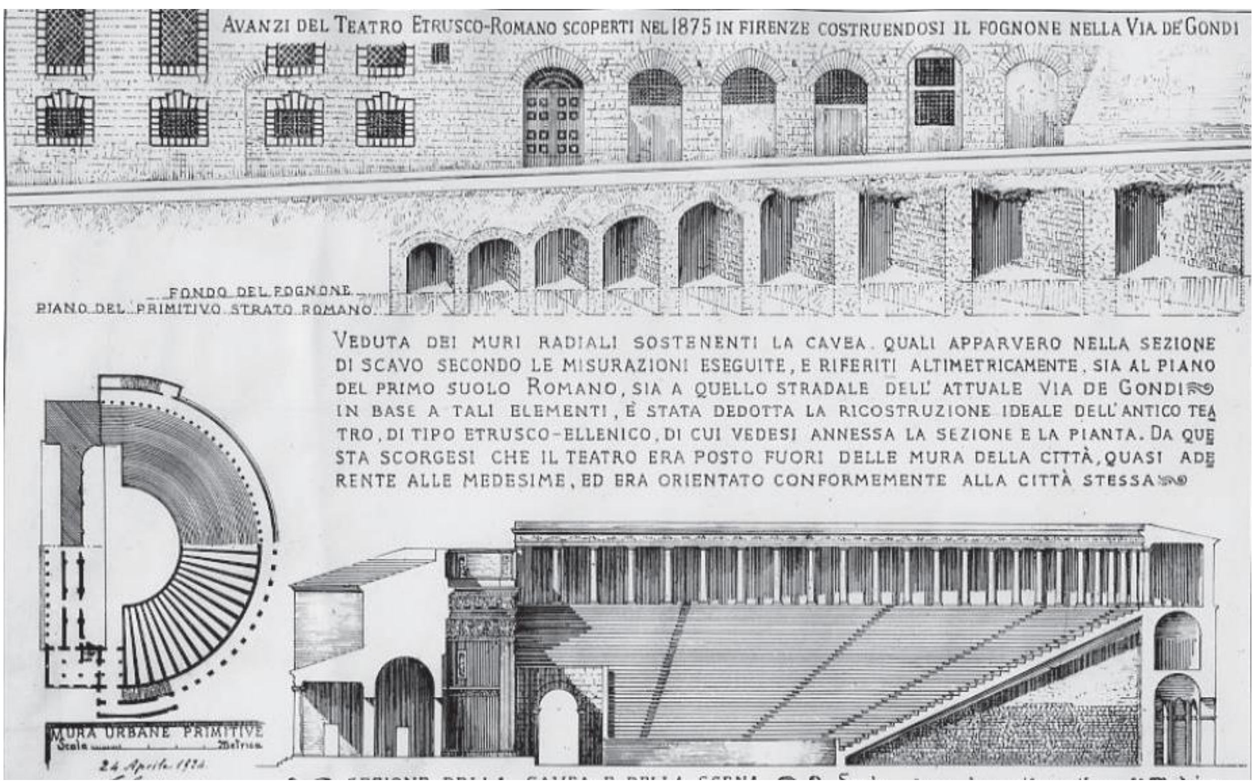

Figure 1. 1 The Roman Theatre of Florence.
Ref; Ovidio Guaita, “Teatri storici in Italia”, Mondadori Electa, Milano, 1994

The use of wood in the Roman theater is probably also influenced by the widespread use of the so-called "phlyakes stage". When the popular comedies or farces, especially popular in southern Italy in the 4th and 3rd centuries BCE, were introduced to Rome, they came with their own distinctive type of stage—the “phlyakes stage”. Comedies in Italy were mimes, usually parodies of well-known tragedies, and the actors were called phlyakes, or jesters. They used temporary stage buildings of three main forms.One was the primitive low stage, a rough platform with a wooden floor on three or four rectangular posts.

The second was a stage supported by low posts, covered with drapery or tablets; sometimes steps led up to a platform and a door was indicated.
The third type was a higher stage supported by columns, without steps but usually with a back wall. The stages often had a short flight of five to seven steps in the centre, leading to the podium. The fore wall, covered with drapery, was often decorated, and the background wall usually had objects hanging from it. The rear wall sometimes had other columns, besides the ones set at the corners, as well as doors and, in several cases, windows to indicate an upper floor.
The door was usually behind a heavily decorated porch, with a sloping or gabled roof supported by beams and cross struts. Among the furnishings there were usually trees, altars, chairs, thrones, a dining table, a money chest, and a tripod of Apollo (i.e., an oracular seat).
The stage was set up in the marketplace in the smaller towns and in the orchestras of Greek theatres in the larger cities.

Coincident with the development of the phlyakes stages, and under the inspiration of Hellenistic colonists, the Romans began to build stone theatre buildings. Beginning by remodeling Greek and Hellenistic theatres, they eventually succeeded in uniting architecturally their own concept of the auditorium with a single-level, raised stage. They did this by limiting the orchestra to a half circle and joining it to the auditorium, thereby improving on the acoustics of Greek and Hellenistic theatres. They also brought to perfection the principles of barrel and cross vaulting, penetrating the seat bank at regular intervals with “vomitoria”. This solution made it possible to improve safety through a more rational distribution of exit corridors. The raised stage was at a single, much lower level than in the Hellenistic theatre. It was roofed, and the number of entrances to it was increased to five: three, as before, in the wall at the rear of the stage and one at each side. The Romans’ love of ostentatious architecture led them to adorn the permanent background with profuse sculptures. In some theatres, a drop curtain was used to signal the beginning and end of performance. In some cases, a canvas roof was hoisted onto rope rigging in order to shade the audience from the sunlight. An important element in Roman theater was that the stage must have been clear to all the audience. There were three stages in theater: the primitive low stage, a stage supported by low posts, a higher stage supported by columns.

1.2 Changing the Appearance Form

In the Renaissance theater program was held at night. After building the theaters, they needed artificial lighting, and used candles and flames to do this.
In the 16th century, Italian architect Vincenzo Scamozzi created a theater at Sabbioneta in which there are three differentiated inputs, each of which leads to a different one area of the steps.

This design choice represents for the first time the need to correctly organize internal routes, guaranteeing an orderly outflow of the spectators. The Scamozzi theater thus marks the point of arrival of the court theater and the input for the baroque theater.

In the 17th century, private theaters were created with a general release, divided into interiors and complex rooms to increase its capacity. To increase the profits and the budget of the theaters, the development was done in a vertical direction to achieve different orders. Vertical development includes overlapping boxes. These theaters created based on these types of reasons require accurate tracking and access, but they face budget constraints.
The materials used in these theaters were as follows: the exterior was carved with rocks, while the interior was made of wood and fabric. And these internal materials required fire protection due to its flammability.
Starting from the seventeenth century, a lot of similar theaters were created throughout Europe, and theater production was developed. From this moment the Italian-style Theater spread, which will characterize the theatrical architecture, first in Italy and then in all Europe, up to the XX Century.

The first rules and “standards”, with specific reference to safety in Italian-style Theater, were written by the architect Fabrizio Carini Motta in “Trattato sopra la struttura de' teatri, e scene che à nostri giorni si costumano, e delle regole per far quelli con proportione secondo l'insignamento della pratica maestra commune” (1676) (Fig 1.2); the new primary objective is to safeguard the spectators' safety, to be implemented with a rapid and orderly displacement of the hall (access routes, and exodus, to the different areas intended for the public).


TRATTATO
SOPRA LA STRVTTVRA DE
THEATRI. E SCENE.
Che à nostri giorni si costumano, e delle Regole per far quelli con proportione secondo l'Insegnamento della pratica Maestra Commune
DI FABRICIO CARINI MOTTA
Architetto del Serenissimo di Mantova
CONSACRATO
Al Merito Sublime dell' Altezza Serenissima
ISABELLA CLARA
ARCIDVCHESSA D'AVSTRIA DVCHESSA
DI MANTOVA
IN GVASTALLA, Per Alessandro Giavazzi Stampator Ducale.
Con licenza de' Superiori. 1676.

Figure 1. 2 The first standards with specific reference to safety in Italian-style theater.

In the 18th century Francesco Milizia ("Trattato completo, formale e materiale del teatro, Venezia 1794).

focuses on the protection of people by increasing the number of exit routes, without losing the shape and interior of the wood for a better acoustic condition.

1.2.1 Changing the Structure

In fact, all theaters until the end of the nineteenth century had wooden roofs, at the end of the nineteenth century, attention also begins to focus on the incombustibility of different parts of the theater building. To protect the wooden structures of the theater building, a new idea emerges in the UK. The first idea of the Hartley English Parliament is to cover the ceiling and walls with very thin sheets of iron to protect them from the fire. The purpose of this plan is to inhale objects against the air, but again, these coatings were flammable. It also suggested that instead of covering the wood in the building, a cement layer should be used to prevent airborne particles from reaching the wood. In general, the purpose was to prevent the air from reaching the wood and thus prevent fire from it. Along with all ideas, in the 19^{th} century, other ideas are being developed. Swedish cardboard rods consist of panels made of iron and cardboard for not penetrating air, as well as a kind of gypsum for making non-combustible fabrics.

Regarding the first fire-fighting system equipment, in the reconstruction of Opera Paris, the first installation of this equipment was carried out.
At the end of the 19^{th} century, awareness of fire prevention was developed, for example for the first time in the Paris Opera, arrangements were made to delay the development of fire, and water pipes and fire tanks were installed. In fact, from this date on, a topic called the delay in the development of fire to help people save their lives, and the time it takes to resist the structure of the building against the fire, so that people flee and save, it is important.

In those years, one of the most important things that made it possible to control the risk was urban access, which required the proper planning of the city for easy access to the theater. For the precise construction techniques of the theater from the 18^{th} and 19^{th} centuries, the development of machines that were capable of confronting fire and fire suppression.

After 1860 the "Commissioni di vigilanza sui teatri" were established in Italy. The Commissions had made the controls more and more assiduous and, since very often the theaters were not found in order, they were forced to close up to the realization of the works of adjustment required by the Commission.
Technological advancements in both stagecraft and fire protection systems have led to a need in the theater community to study the current state of theater fire protection requirements.

Although the fire curtain restricts air movement reducing the rate of smoke spread to the auditorium, a fire safety curtain alone is inadequate to stop smoke completely. The fire safety curtain and roof vents are fire and life safety systems that are intended to work in tandem. Alternate strategies that employ only ventilation or stage exhaust in lieu of a fire safety curtain require a thorough analysis to be completed to establish acceptable fuel loads and fire sizes. Such an approach would also likely call for a detailed fuel management program that might in turn reduce the flexibility in theatrical use of the space. As scenic elements are changed, such spaces should require special analysis for each production as to whether the modified arrangement would produce smoke/fire exceeding the capacity of a smoke control system provided. Theaters falling into the ‘‘large’’ classification require special consideration because of the potential delays in system activation owing to the height of the stage.

Another issue that is important in fire safety of historical theaters are Exit routes that need to be carefully evaluated. Because the characteristic of exit paths such as; the number of exit unites, the widths of exit doors, the direct of paths, even the vertical or horizontal ways, it will determine the time it takes to evacuate people which is one of the most effective risk reduction factors.

There are already established methods; signs and exit guidance, determine the number of people according to the capacity of the outgoing routes and etc, that constitute an excellent practice to improve safety in the fast exodus

1.2.2.1 The Diagram of the Changes in the Italian Style Theaters in Terms of Shape and Structure

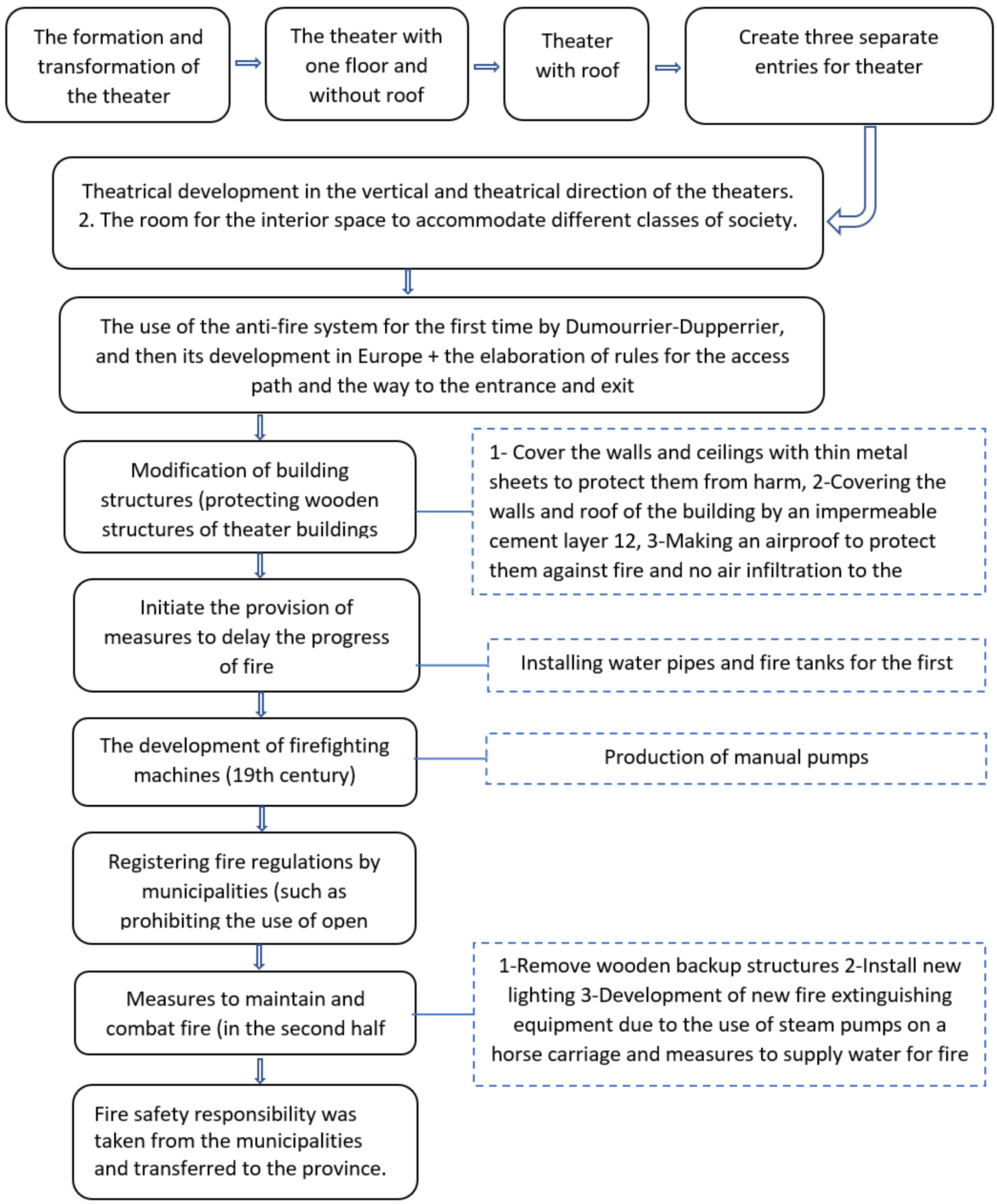

Diagram 1. 1 The changes that occurred in theaters for fire protection: 2018: Writer

As will be specified later, the fire suppresser was first introduced only at the end of the seventeenth century. Later the application of innovative regulations and technologies emerged into theaters such as: new lighting, heating and venting systems, fire fighting and transportation system with a gasoline engine.

1.3 The First Regulatory and Control on Theaters

From 1777 to 1903, there are 382 fires in the theaters of Europe that have caused more than 8000 victims.

At the end of the eighteenth century the theater was constantly monitored, the municipalities provided for custodians and systems were kept in perfect working order. The shows were controlled by a responsible technician, in addition to the ban on using open flame lights. The safety exits, new lighting installations were installed thus avoiding the use of candles and other open flames. The first powerful steam pump, mounted on a horse-drawn cart, and always within the framework of these measures were installed water mouths for water supply. In 1907 the first fire truck with petrol engines used for the towing heavy steam pumps and transporting personnel.

The intervention times were reduced drastically allowing firemen to reach the place of the accident no longer fatigued but able to operate immediately and with the right determination. Finally, the water did not come more thrust with physical strength or with steam, but with powerful pumps moved by engines.

At the beginning of the twentieth century, the study on the causes continued and deepened fire propagation. Prevention techniques are refined, and the studies are studied aspects of risk to people from panic to the effects of fumes. An example of the intensification of controls on public entertainment venues is the case of the Capranica Theater of Rome, built in 1679 and redone twice (1750, 1802).

In 1817 following the verification of the conditions, the execution of reinforcement of structures, as well as new doors and new stairs. The Commission of the Council of Art grants the usability only of 1847 and obliges to controls on all wooden theaters for interventions and replacement of masonry structures. Theater Capranica was forced to close in 1881 as a result of new imposed interventions.

The second half of the nineteenth century therefore brings continuous maintenance work. In theaters with the increasing awareness of the authorities towards the safety problems and fire prevention. Increasingly more precautions they are hired for this purpose: the wooden supporting structures have to disappear.

The expansion of the railways in the nineteenth century enabled urban populations to travel to the coast. These visitors liked to take in the sea air, promenading along the sea front and the lengthy piers that stretched ever further into the sea and which were being built in greater numbers from the 1860s. Several of these commercial enterprises had theatres or variety halls built on them and became an important element of the local seaside economy. Following the outbreak of World War II, though, many began to be neglected, and by the 1960s changing holiday patterns and rising costs led to many being closed, to be replaced by lucrative amusement arcades.

Hippodromes or circuses, too, were a popular form of entertainment in the Victorian period and developed from the interest in equestrian entertainment in the late-eighteenth century, which took place in circular enclosures. They were built in major cities and seaside resorts in theatre-like buildings to present live animal acts, though their shows would often include human acts. The 18th century was a period that theater was more controlled by municipalities, the technician teams, and new equipment. In fact, they came up with strengthening the prevention of fire.

As it is clear, in various countries fire experts and those who are supporting the conservation of heritage buildings, great emphasis on fire safety has been arisen. And because of the speculating urban development, which places the man in the margin of social life giving priorities to the "market laws" the global is among one of many reasons for the consideration to the safety of buildings.
While referring to the fire suppression, the presence of relevant number of people and/or the quantity of the burning materials, and other numerous and interrelated aspects, must be considered.

Although the escaping possibility while being rapid and safe is a key point in fire protection, the condition for the perseverance of the building and its content. Efficiency of escape routes, fire behavior of materials, structural fire resistance are the themes that have been considered, for years, as those to take care of or, at least, the main ones.
It is noted that while natural events are a determining factor in increasing the size of fire, mechanical ventilation system also regulates the pressures and the quantities of oxygen thus the sort of control on fire.

1.4 The First Protective System in the Italian Style Theater

At the end of the eighteenth century the need to face the fires in theatrical buildings, not only by architectural solution, with greater attention to the protection of people with more routes exit, is obvious. Already at the end of the seventeenth century, in these years of great diffusion of theaters throughout Europe, in 1699, the French industrialist Dumourrier-Duperrier proposed and obtained to constitute, himself, a complete and autonomous fire-fighting service, availing himself of his workers. Over a century later, the organization of the Sapeurs-Pompiers of Paris was created from this organization, which was the typical organization to which, in the following years, all the civilized countries were inspired as a model. The Sapeurs Regiment Pompiers of Paris is still today in France the technical and organizational hub around which takes place and from which comes all the fire defense of the country to life.

The unity of Italy (1861) found a situation in the field of fire service to the few local bodies a voluntary and limited to the municipal districts, they were broadly supported areas, even entire regions, completely devoid of any defense organized against fire. The municipal firemen, where they existed, they were still organized with almost medieval conceptions and arrangements and the whole complex Italian firefighting appeared anachronistic, insufficient, poorly distributed, to mercy of local means and traditions.
In 1935, the organization on a basis municipal fire service were abandoned to lay the groundwork for the birth of the bodies Provincial. Subsequently, in 1939, the Body was born National Fire Brigade and, finally, in 1941 the institutional tasks are fixed the territorial organization of the Corps.

Figure 1. 4 Illustration of the great fire of the Opera Comique in Paris (1887).
Ref; Barbier, Patrick (1995). *Opera in Paris, 1800–1850: A Lively History*. Portland, Oregon: Amadeus Press.

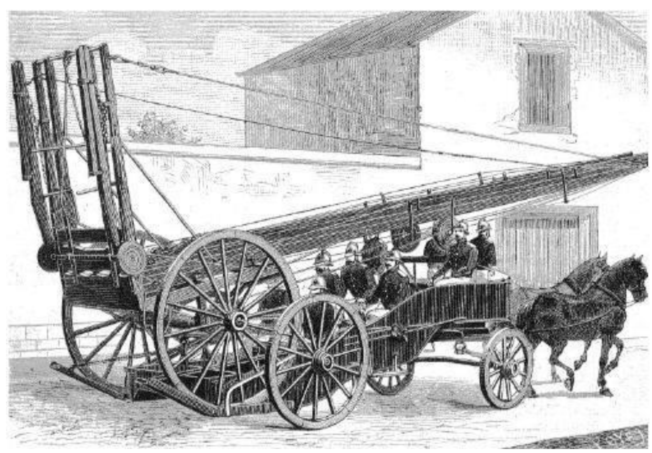

Figure 1. 3 "Bayley" ladder carried on horseback by the Paris brigade. Ref; “l'Incendie de l'Opéra-Comique de 1887” available on site; www.artlyriquefr.fr

For the first time, it is noting the usefulness of delaying "progress of fire", by fire brigade intervention, so have time to bring help to people(Fig 1.3). The goal is therefore to ensure an adequate resistance time of structures to fire, ensuring durability necessary for the escape and rescue intervention.

Figure 1.5 Illustration of the interior of the Covent Garden Theater during the fire (1808).
Ref; Covent Garden Theatre from Microcosm of London, 1808-10, London

As the most attentive construction methods of the theaters, between the 18th and 19th centuries, they developed machines capable of dealing with fire better and more successfully: the hand pumps. These gave rise to a first real change of the extinction techniques thus allowing to get the first real hits against the fire. This invention, although important, did not yet create a service capable of face the most demanding situations in the best way. The little effective hand pumps did not allow an adequate response because theirs transport was still entrusted to the physical strength of men. There are therefore the first precautions and experiments for fire safety but there is still no reference legislation.
Club theatres were set up in response to the conservative nature of commercial theatre. To keep the safety of buildings and attracting more visitors the contributors had to care about the budget as well. So, the new primary objective is the safeguarding of the spectators' safety, from implementing with a quick and orderly displacement of the hall. While they emphasized the safety of people with more exit routes, they also insisted on keeping the interior acoustic sound by preserving the shape and the wooden interior.

1.4.1 Causes of Fire and Precautionary Measures in Historical Buildings

There are various causes of fire in historical buildings, including flaws and electrical failures, maintenance of the building, sabotage, smoking, spark, and crash, lights. We recall that the latter is the case of the Bellini theater in Palermo which burned down in 1964 because some very hot stage lamps burned tools or perhaps curtains placed adjacent to them.

The existence and enforcement of non-smoking policies must be made known to all visitors and contractors and included in contract documents. Carelessly discarded smoking materials are one of the main causes of fire, particularly in living accommodation. Whenever practicable, and this will depend on the use to which the building is put, smoking should be banned, and this fact should be made known to visitors. Consideration should be given to the need for "no smoking" signs and ashtrays at entrances to buildings. If smoking is permitted, it should be restricted to specific areas and strict attention should be exercised under careful control.

There are many cases on record of serious fires in historic buildings being caused by the careless actions of building contractors. A stringent prohibition procedure must be operated before commencement of any hot work, with 'permit' procedures stated clearly in writing for any authorization. Assignment of responsibility to a named member of staff for enforcement of the permit system is essential. In the latter case, the arrangements must include the provision of any additional fire-fighting equipment together with implementation of other necessary fire precautions. Competent monitoring of the possible spread of fire during the whole period such tools or equipment are in use, and for a period not less than two hours after cessation of such use is essential. Due regard to weather conditions, wind speed and direction, must be paid.

Occupiers must be fully aware of the vulnerability of an historic building to damage by fire during repair or conversion work and all possible precautions should be taken while the work is in progress. The Regulatory Reform (Fire Safety) [7] Order requires that “emergency routes and exits must lead as directly as possible to a place of safety” and that procedures for serious and imminent danger must enable the persons concerned to “immediately proceed to a place of safety in the event of their being exposed to serious, imminent and unavoidable danger”.

These precautions: Initial consultations with architect, surveyor, local planning authority and insurer. This should include clear allocation of responsibilities; non-flammable solvent-type paint stripper should be used wherever possible (in preference to the use of blowlamps or electric hot air blowers). Combustible material in the vicinity of any work should be removed. If this is not possible, for example due to the presence of decorations in prestigious historical buildings, it should be protected by these days technologies and knowledge. At least two fire extinguishers of the right type should be provided close at hand during these operations. Special care is required when work involves hot bitumen or similar material; if work makes it necessary to block corridors, stairways and exits forming a means of escape, then an adequate alternative must be provided and signposted. Ensure that access to fire-fighting facilities, such as fire extinguishers, hoses, hydrants and emergency water tanks, are not obstructed by building materials, equipment and scaffolding.

The work of the contractor should be carefully supervised by a responsible member of staff who has the authority to dictate the fire precautions which will be taken, ensure work is not carried out carelessly and operate the fire-fighting equipment. All contractor personnel must be conversant with the method of raising the alarm in the event of a fire and locations of telephones or other equipment for calling the fire brigade.

Heating installations: It is strongly recommended that, whenever structural conditions permit, historic buildings should be heated by means of modern central heating systems using gas or oil-fired boilers. Before to making any decisions about changing heating systems, insurers should be consulted, and specialist advice obtained. The presence of water may cause a hazard to the fabric of buildings and it is essential that a high standard of maintenance is carried out by qualified and competent contractors.

- Wood-burning stoves
- Portable heaters
- Chimneys and flues
- Lightning

Generally, because of the many historic buildings have the similar features, including the theaters, houses and churches, many of the fire safety issues are the same for them.

Fireplaces in historic houses are often beautiful structures forming an intrinsic part of the house's design. Over the years however their flues may have become fire hazards. Open fires are not to be recommended but if they are to be used, the following points should be considered: where flues have become defective as a result of decayed plaster or brickwork, these deficiencies may permit heat to pass into the roof spaces or floor voids and ignite the timbers. Floor or ceiling joists may be built into the chimney's structure and timber subjected to continuous heat in this way may smolder and even burst into flames. Specialist advice should be sought on the condition of chimneys and consideration given to the installation of Hue liners before the chimneys are re-used. If in day-to-day use, they should be swept regularly, at least twice a year if wood is burnt. Spark guards should be fated.

Historically, churches have been prone to damage from lightning strike and consideration should be given to protecting all historic buildings against this possibility. The supply and installation of lightning protection equipment ('lightning arrestors' or 'rods') is a subject for specialist advice and individual considerations applied to the design of the method of protection. It should be emphasized that a poorly installed or maintained lighting protection system poses dangers to both people and the building. Regular maintenance by a specialist engineer is essential.

1.4.2 The Purpose of Fire Safety

Although fire safety objectives have been expressed in different ways by different authorities in different countries, generally there are accepted two main aspects of fire protection for modern buildings: life safety and property protection. For historic buildings it must be added the protection of cultural values either for the buildings or for their contents. It is not possible to achieve an absolute fire safety. In most cases, a proper fire safety design assumes that a limited unwanted fire will occur and means shall be provided to minimize the losses from fire till an acceptable level.

The Building Regulations and Codes prescribe the minimum fire safety requirements. Generally, the national or the municipal fire legislation concerns for life safety, whereas insurance-orientated Codes are designed to minimize loss property.

1.5 The Significant Fires

1.5.1 Statistics and Necessity

The most significant cases of fires occurred in theaters of different nations in the last 200 years have been collected. They are shown in chronological order in the table below. There have been numerous fires in European history that have destroyed theaters. More precisely, over the past 300 years, it has been estimated that about 400 fires in Europe have had more than 8,000 victims. For example, in 2011, fire burned the 200-year-old Paris Theater. Following, we briefly discuss the reasons behind the fire occurred in some of the historical theaters.

Name of Theatre	Location	Year	Victims
Stadsschouwburg	Amsterdam	1772	25
Coliseo Theatre		1778	77
-		1794	1000
Richmond Theatre		1811	72
Teatro Concordia		1824	-
Chestnut Street Theatre		1829	97
La Fenice		1836	0
Lehmann Theatre	St.Pietroburgo	1836	800
-	Canton	1845	1670
Royal Theatre	Quebec	1846	200
Grand Ducal Theatre	Karlsruhe	1847	63
Teatro Degli Aquidotti	Livorno	1857	43
Liceu	Barcelona	1861	-
Teatro Comunale	Treviso	1868	-
-	Shanghai	1871	120
-	Tientsin	1872	600
Conway's Theatre	New York	1876	283
-	Sacramento	1876	0
Des Arts	Rouen	1876	8
-	Ahmednuggur	1878	40

Teatro Municipale	Nizza	1881	70
Ring Theatre	Vienna	1881	450
Circus Ferroni	Berditscheff	1883	268
Opera Comique Theatre	Paris	1887	70
Theatre Royal	Exeter	1887	200
Oporto Theatre	Oporto	1888	240
Iroquois Theater	Chicago	1903	600
Rhoads Theater	Boyertown	1908	170
Flores Theater	Acapulco	1909	250
Mayaguez Theater	Puerto Rico	1919	150
Laurier Palace	Montreal	1927	77
Teatro De Novedades	Madrid	1928	68
Teatro Regio	Torino	1936	0
China Theater	Antoung	1937	658
Hoteiza Theater	Kucchan	1943	205
Al-Duniya	Kano	1951	100
Teatro Dell'Opera	Dublino	1951	-
Alhambra	Belfast	1959	-
Syria Movie Theater	Amuda	1960	-
Le Monde Theater	Diourbel	1963	64
Kensigton Theater	Buffalo	1983	-
Cinema Statuto	Torino	1983	64
Teatro Petruzzelli	Bari	1991	0
Drammen Theater	Oslo	1993	0
Liceu	Barcelona	1994	0
La Fenice	Venice	1996	0
Duchess Theater	Long Eaton	2003	0
Beni Suef Theater	Beni Suef	2005	32
Teatro Nicola Vaccaj	Tolentino	2008	0
Montmartre Theatre	Paris	2011	0
The Playhouse	Helmond	2011	0
Golden State Theatre	Monterey	2012	0
Academy Theatre	Chicago	2012	2
Saratov Youth Theatre	Moscow	2012	0
Madison Union Theatre	Madison	2012	0

Table1. 1 Theater's fire events over 300 years in all over the world
Ref; Pietro De Marco Cervino, Giovanni Di Debba, *La sicurezza al fuoco nei Teatri Storici:* Adeguamento delle opere strutturali alla normative antincendio, Politecnico di Milano, 2013.

This table is well seen with the passing of years, the number of fires in theaters has decreased, as well as the number of victims has dropped to zero (Fire incidents in the present century, often have been occurred in the restoration of building).
This indicates that fire safety measures and regulations have been affected, however, it still works to improve the condition.

1.5.1.1 Ring Theatre – Vienna, Austria

Year of the fire: 1881
Capacity: 1800 people
Type of construction: masonry perimeter structure and use of wood inside
Causes of the fire: not fully ascertained
Number of victims: 620 people
Main issues: unused fire curtain, fire-fighting procedures not taken, doors for emergency exits locked, emergency lighting off, insufficient outputs. The fire at the Ring Theater in Vienna occurred in December 1881, just before of the beginning of the evening show. The theater was already full when a machinist inadvertently touched the stage curtains with a flashlight used for turning on the gas lights. The flames quickly blazed on the stage, but the fire curtain was not lowered so the fire spread rapidly over the entire wooden structure. The piping system for water use was not immediately usable and the directors switched off the gas lights system, leaving the theater in darkness. At this point chaos was created, also due to the lack of an emergency lighting

Figure 1. 6 The remains of the Vienna theater immediately after the fire. Ref; Blickfänge einer Reise nach Wien-Fotografien 1860-1910; Ausstellungskatalog des Wien Museums, 2000/2006

system. The panicked public headed for the exits that were partly closed and therefore unusable. The corridors full of people did not allow the emptying of the balconies, also the ladders of the firemen present were too short to reach even the first balcony. Corridors and tunnels thus became deadly traps. The few exits of the theater had doors opening inwards and were therefore unusable. Firefighting procedures were not followed.

1.5.1.2 Royal Theatre – Exeter, United Kingdom

Year of the fire: 1887
Capacity: 1500 people
Type of construction: masonry perimeter structure and use of wood inside
Causes of the fire: the scene caught fire due to gas lighting
Number of victims: 200 people
Main issues: lack of fire curtain and emergency exits, non-existent fire-fighting procedures, insufficient outputs, fire-fighting equipment insufficient.

The Fire of the Theater Royal took place on September 5, 1887, starting from the scene due to gas lighting. The flames spread rapidly inside the theater, destroying the entire wooden structure

Figure 1.7 Image of the London News showing the inside of the destroyed theater

in a short time. The emergency exits were insufficient and poorly organized, as were the few extinguishing systems, given the complete lack of an evacuation and fire safety plan. The most affected area was the tunnel that had only one exit door which was blocked in a short time by people intoxicated by thick smoke. Many tried to escape jumping from the balconies but only found death. The intervention of firefighters was almost useless because the water had no effect on the great fire. The Theater Royal event led to the introduction of new fire safety systems in public places, such as the obligation to use a security curtain in the theaters.

1.5.1.3 Opera Comique – Paris, France

Year of the fire: 1887
Capacity: 1600 people
Type of construction: masonry perimeter structure and use of wood inside
Causes of the fire: defect of gas lighting above the stage
Number of victims: 70 people
Main issues: fire curtain and non-fire protection equipment used, non-existent emergency exits, inadequate fire-fighting procedures.

Figure 1. 8 The interior of the Paris theater after the fire.
Ref; Barbier, Patrick (1995). *Opera in Paris, 1800–1850: A Lively History*. Portland, Oregon: Amadeus Press.

The Opera Comique in Paris was the victim of a first fire in 1838, caused by the malfunction of a heater in the heating system. The May 1887 event was of far greater proportions. During the evening representation of the incandescent material fell from the gas lighting system on the stage, generating in a few seconds great flames that lapped the scene and quickly invaded the whole theater. Public and professionals rushed to the exits, but the flight was slowed by the narrow corridors and the few available exit routes. The fire-fighting procedure foreseen by the Theater was not followed. Many people tried to take refuge in the upper balconies but still did not escape the dense smoke due to the burning of seats and furnishings. The roof structure began to yield an hour after the start of the fire. The event of the Comique Opera rekindled the security debate in theaters in France and led to the obligation to use electric lighting and fire curtains in public entertainment venues.

Figure 1.9 Depiction of the fire of the Opera Comique. Ref; William Paul Gerhard, "Theatre fires and panics: their causes and prevention", John Wiley & Sons, 2009.

1.5.1.4 Iroquois Theatre, Chicago, USA

Year of the fire: 1903

Capacity: 2000 people

Type of construction: on 3 levels in masonry and wood Causes of the fire: the velvet curtain caught fire with some material incandescent coming from the overlying lighting system Number of victims: 600 people

Main problems; lack of emergency exits (Fig 1.11), Fire-fighting procedures non-existent, insufficient outputs, insufficient fire-fighting equipment.

Figure 1. 10 Photograph of the interior of the Chicago Theater after the fire.
Ref; The Chicago Daily Tribune. (31, December,1903)

The Chicago theater was believed to be completely safe from any kind of fire, but this assessment was a mistake. The building was opened while the works had not yet been completed and in total absence of fire extinguishers, alarms, fire-fighting systems, emergency telephones and water connections. When the fire broke out on December 30, 1903, most of the public was made up of women and children, having happened on the morning of a holiday. In the middle of the second act a spark from the gas lighting system caught the curtains on the stage. The room staff tried to circumscribe and extinguish the fire principle but without success. The only fire-fighting vehicle available was a container called "Kilfyre" containing a chemical solution of baking soda, usually used to extinguish small fires from chimneys in residential homes. The use of this system was totally useless, as useless was the curtain cut in asbestos. The flames spread rapidly over all the wooden and fabric seats, causing dense smoke and toxic gases.
The panicked public tried to reach the few exits which, however, had the opening inwards and were partly unusable. This fire was among the most disastrous in the United States and contributed to the reform of the laws and regulations on fire safety in public places.

Figure 1.11 One of the locked exits that prevented the escape from the theatre.
Ref; William Paul Gerhard, “Theatre fires and panics: their causes and prevention”, John Wiley & Sons, 2009

1.5.1.5 Regio Theatre – Turin, Italy

Year of the fire: 1936

Capacity: 2500 people

Type of construction: reinforced concrete and wooden interiors

Causes of the fire: unknown

Number of victims: none

Main problems: lack of fire curtain, fire-fighting appliances insufficient.

The Turin fire occurred on the night of 8 February 1936, in the absence of surveillance, so the real causes are still unknown. The Firemen were warned by the caretaker but when they arrived, albeit close to the place of the serious event, they found the entire building completely enveloped in flames and for the limited effectiveness of the means available, even if numerous, could not save the theater. It is presumed that the fire started from the stage and then spread rapidly over the hall, burning seats, glasses and giving way to the iron roof, which fell on itself, stopping on the main supporting beams. The easy destruction of the theater was favored by the

Figure 1.12 The interior of the Teatro Regio after the disastrous fire.
Ref; Lynn, Karyl Charna, Italian Opera Houses and Festivals, Lanham, Maryland: The Scarecrow Press, Inc., 2005.

total lack of fire protection system and using non-fireproof materials such as wood and fabrics.

This led to an analysis of the need to predict the use of fire curtains, automatic signaling and extinguishing systems in Italian theaters.

Figure 1.13 The theater cover collapsed because of the flames.
Ref; Lynn, Karyl Charna, Italian Opera Houses and Festivals, Lanham, Maryland: The Scarecrow Press, Inc., 2005.

1.5.1.6 Petruzzelli Theatre – Bari, Italy

Year of the fire: 1991
Capacity: 1500 people
Type of construction: masonry and wood
Causes of the fire: arson
Number of victims: none
Main problems: lack of fire protection system

Figure 1.14 The effects of the fire seen from the stage.
Ref; Mario Panizza, "Edifici per lo spettacolo", Laterza, Bari, 1996

The Petruzzelli boasts the record of the largest private theater in Europe. In October 1991 a fire was started during the night closing hours. The collapse of the great dome succeeded in stifling the flames and preventing the destruction of the theater. The investigations carried out subsequently revealed the complete lack of an adequate prevention and extinguishing system.

Figure 1.13 The consequences of the devastating fire inside the theater.
Ref; Mario Panizza, "Edifici per lo spettacolo", Laterza, Bari, 1996

In fact, the fire-fighting system, although renewed only three years earlier, did not work because it was not automatic. Therefore, it could only be operated manually and not suitable for protecting the empty building. And at 4.30 in the morning there was no one in the theater could operate the machinery. If the event occurred during a show it would have had much more serious consequences, given the inadequacy of the safety rules.

1.5.1.7 Liceu Theatre – Barcelona, Spain

Year of the fire: 1861,1994

Capacity: 2000 people

Type of construction: masonry

Causes of the fire: accidental spark on a curtain during a repair

Number of victims: none

Main problems: lack of fire protection system

Figure 1. 16 The interior of the Liceu Theater after the fire.
Ref; Alier, Roger, *El gran llibre del Liceu*. Barcelona: Carroggio, DL 1999.

Figure 1. 17 The destroyed Liceu theater seen from above.
Ref; Alier, Roger, *El gran llibre del Liceu*. Barcelona: Carroggio, DL 1999.

The Liceu theater in Barcelona suffered two fires in its history. The first in 1861, a few years after its construction, almost destroyed the theater, sparing only the entrance and the hall of mirrors. The reconstruction was very rapid and probably during the planning phase no attention was paid to the possibility of a second fire. In 1994, during maintenance work, a tent burnt with a spark. In just over an hour the flames destroyed the hall, the stage and all the roof. Coincidentally, as in the fire of 1861, the entrance and the hall of mirrors were saved from the fire. The theater in Barcelona was not prepared to undergo such an event exits and corridors would not have been able to sort out a fleeing crowd, also lacked an appropriate automatic shutdown system. The theater was reopened in 1999 after a major restructuring that placed the question of security at the center.

1.5.1.8 Critical Considerations on the Studied Cases

The study of previous significant cases shows that, in the recent past, the main causes of fire were the malfunctioning of the gas or short-circuit lighting system that took place during the works. The fires have almost always taken place in the area of the stage or above it, where the installations pass, and quickly spread to the rest of the theater, quickly destroying all the internal wooden structures and in some cases causing the premature collapse of the coverage. It is evident that in all these cases no type of passive protection has been foreseen to delay the spread of flames and to guarantee a safer evacuation of the theater. This fact shows the total lack of attention, in the past, to the problem of the fire inside the theater.

1.6 Summary

Growing awareness and knowledge on smoke and fire has begun to be appreciable because of its influence on design solution. In this chapter, after presenting the historical overview of fire safety in theaters, the origin of theater is elaborated which has its start in ancient Greece, Rome, and later Latin. Fire Safety in "Italian style" theatres, one of the most common structures in our country, which should be dealt in terms of public safety as well as preservation of cultural and historical heritage. It is also stated that Renaissance was pioneer in the representation of nocturnal shows. Regarding the simple constructions of early theaters as there were no roofs, there was no possibility of fire. However, because the Renaissance plays were shown at night, there was a fire to illuminate the interior of the theater. Besides, some reports on fire in theaters throughout history is presented as constructions began to change and undergo complex design and the requirement of different facilities, the potential of fire grew more which lead to the contribution of municipals’ control and numbers of technicians’ assistants.

The analysis carried out on fire safety in historic theaters has shown that the risk of fire in buildings of this type is a significant problem. To date, in fact, there is not yet a precise knowledge of the typical problems of the subject, of the rules, but also of the methods and the means available to ensure safety in this kind of buildings. It has been highlighted that the current legislation on fire safety is not always applicable, for the internal structures of historical theaters. Adaptations in historic buildings, in fact, are much more complex than the new buildings, as we must deal with the opinion of the Soprintendenze of Cultural Heritage, which deals with the preservation of the artistic heritage. For this reason, it is necessary to interpret the fire regulations using a performance approach, which has as its main objective the safeguarding of human life but while of existing assets of value.

The knowledge of architectural heritage and respect for its historical and artistic value is the starting point to ensure a synthesis between the needs of safety and conservation. The adjustment of the structures of a historical theater must therefore take into account the context in which it is operating, momentarily leaving out the normal only regulatory approach and focusing on flexibility in adapting solutions to different contexts, trying to interpret the project and not being condition the rigid reading and interpretation of the rules. What emerges is that the best solution to solve the problem of fire safety in historic theaters, and more generally in historic buildings, would be a critical integration between passive protection measures and active protection measures, aimed at both the protection of human lives and that of the present artistic heritage. For these reasons it may be useful for the designer to refer to homogeneous and repeatable guidelines, to be consulted in case of adaptation interventions, which provide a critical approach method, which allows to define the intervention criteria for fire safety in historical theaters. To sum up, they stressed the preventions of fire, the safety of people, and property, and quick routes to avoid danger.

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Chapter Two; Italian Theater

2.1 Introduction

Few theaters, of the over one thousand registered in the years following the Italy's unification and of the many that were added in the following decades, remain to testify the characters and the widespread diffusion of the Italian theater just in Italy, in the magniloquent examples or in the more modest ones often connoted by provisional nature and precariousness.
If the perimeter masonry envelope and the wooden covering were made according to the codified building tradition, many of the elements characterizing the historic theater, such as the boxes, the scenic machine and the same decorative apparatus, followed very original construction criteria, often simplified or ephemeral.

In fact, if every historical theater wanted to show the importance of its social role outside and in representative spaces, only a few of these in the hidden parts renounced the economy.
Within a "classic" masonry box, especially in theaters of lesser importance, in the internal elements characterizing the typology, the system of the stages, the scenic and decorative apparatus, wood used for large roof structures but also to simulate precious materials.

Due to the intrinsic "fragility" caused by the use of very poor materials and construction techniques, in many cases only the "urban memory", an anonymous cinema, or a wall box devoid of its original content and waiting for a new, problematic "scenography".

Tampering and upheavals that have affected theatrical structures of all levels, from demolitions to conversions to cinemas or other destinations that are not compatible, show that the parts most at risk are precisely those ephemeral elements that often contribute to defining the architecture and the typology, it is important to know the typological organization of the Italian theater, to highlight its current problems and identify solutions for a vast group of this type, although with the due differences within the typology itself.

The certainty remains that it is necessary to deepen the knowledge on unconventional building techniques, using the few examples that survived the destruction and the neglect of time.
Even in more recent times, some fire-fighting interventions have proved to be incompatible with historical theaters, both from the aesthetic and conservation point of view.
Whilst modern fire protection installations can readily be designed to be technically efficient, there is a tendency for many systems to be less than sympathetic in their appearance following installation in a sensitive historic building interior. This is largely because the engineering design

profession and manufacturers do not think laterally about the conservation issues that are involved.
As described in Chapter 1, fire is always among the greatest threats to historical structures.

2.2 Birth of the Italian Theater “a palchetti”

The architectural structure of the theater building, which prevailed over the eighteenth century, is constructed so that there is the ability to change and use the showroom when needed, and most importantly, the operatic success of music in the last decade of the 17th century has attracted a large audience. The architectural structure prevailing in the 18th-century theater's buildings was consisted of a change in the operation of the hall, and above that, the opera, in the 17th century, was a great success and it was able to reach the audience across Europe.

These theaters were made up of different boxes for the different social classes. These boxes were intrinsically different in terms of visual visibility, as well as the interior furniture, commensurate with the economic facilities of their owners, so that the upper classes were specially designed for the nobility. Better floors, and the upper floors were allocated to the middle-class rest. Private boxes were independent and their entry, exit and distribution were carried out through a separate corridor. The rest of the people were standing or sitting on the couch in the pit to the orchestra or at the gallery (Fig 2.1).

Figure 2. 1 Ordine of Palchi in the Great Theatre of Brescia.
Ref; Ovidio Guaita, “Teatri storici in Italia”, Mondadori Electa, Milano, 1994

In addition to these spaces, good services were created for the people, such as dressing rooms in the surrounding area. Larger boxes were used for various functions such as gambling, which reduced their number and social life did not only happen in theater boxes. For some reason, such as economic issues and more profitability, ordinary people can also use boxes, and in many theaters, only a few boxes were reserved for the nobles. There fore there was a space that had a view to the halls and allowed the viewer to see what's happening on the scene. Due to the angle of view of spectators in boxes, people welcomed these places, which could be watched better on what happens on the scene.

Then it leads to extend to a long set at the fifth level. It is concluded that the venue had three distinct floors would be held (1) the overlapping and distinctive (2) sub-area (3) the stage and the attic are used differently.
In addition, there were rooms for storage and equipment, and the protection of machines, clothes and tools (Fig 2.2).

Figure 2. 2 The Illuminati Theater, City of Castello.
Ref; Mario Panizza, "Edifici per lo spettacolo", Laterza, Bari, 1996

During the 17th century, changes occurred in all parts of the theater, in the furnishing, the design, and the functions. In fact, the success in music led to the attraction of the audience and it is noted that the social class determined the visual visibility term, in that those people with higher status were located in lower and closer floors and upper floors were allocated to the middle classes.

2.3 Horseshoe Structure

In a rectangular theater building, during the 18th century, the horseshoe structure was used. In fact, the problems caused by the placement of spectators in the lateral areas were created, including the lack of proper view of the scene and the lack of complete scene used to remove it from the structure U-shape.

The conventional shapes and structures of the theater of that time included (1) horse hollow structure, (2) rectangular structure, (3) elliptic structure, and (4) egg structure. The horseshoe structure quickly developed in all the buildings of the opera and forms the dominant structure of the theatrical buildings in the 18th century and later. The advantages of this structure included the vision and the prospect for the general audience to be on the scene. The most famous example is the Teatro Argentina in Rome (Fig 2.3), which is one of the oldest theaters. It was built by Girolamo Theodoli in 1732, with a capacity of 2,500 spectators, and the horseshoe structure was used in the theater.

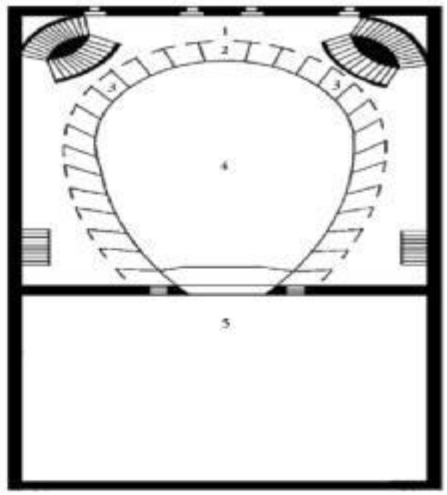

Figure 2. 3 Plan of the Teatro Argentina in Rome.
1) Entrance, 2) Central Stage, 3) Palettes, 4) Plateaus, and 5) Stage.
Ref; Diderot's Encyclopédie, 1772

The Scala theater was built in Milan in the neoclassical style, and its architect Giuseppe Piermarini built the theater in 1778 with a gallery and a space for 2800 seats. The theater featured intelligent interiors and the most advanced production techniques.

Another important example is San Carlo in Napoli (Fig 2.4), designed by Giovanni Antonio Medrano and Angelo Carasale in 1737. The theater is characterized by a double staircase placed on the sides of the royal box for allow the sovereign to reach the floor directly.

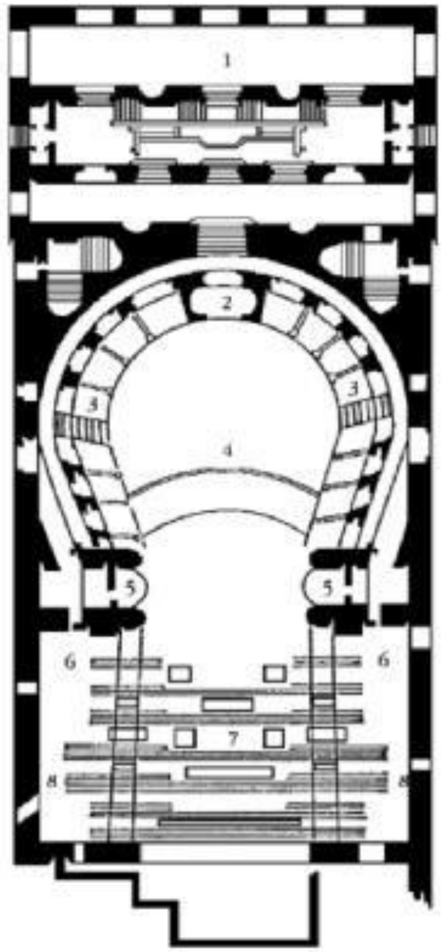

Figure 2. 4 Pianta Teatro San Carlo of Naples. 1) Entrance, 2) Central Stage, 3) Palettes, 4) Plateaus, 5) Palettes of Proscenio, 6) Quinte, 7) Stage, and 8) Backdrops.
Ref; Charles Searson,"Naples opera house reopens after spectacular renovation", *The Gramophone* (London), 2010

2.4 Incoming and Escape Routes

Most theaters in Italy have a main entrance and from the front view there are at least three doors to the atrium where there are various types of services, such as tickets and wardrobes, and access to this part by one or more stone steps, the hall is possible.
Some theaters, depending on the type of program being presented, have a real box, accessed through an independent entry along the gallery. The scene is a side outlet for the departure of actors, dancers and theater workers, and in addition to loading and unloading them and moving the machines and other items, several outputs were used to safely exit and service around the theater hall. However, all the outlets for emergency room evacuations were inadequate, and most of them were locked up by authorities to prevent the unnecessary entry of unnecessary persons, which were therefore unusable during the escape of the fire. The corridors and interior

doors were very small and inefficient when used for escape, and almost no emergency lighting was available.

2.5 Structure of the Italian–Style Theater

This chapter is intended to study Italian theater and vulnerability to fire of different parts.
Between the 18th and 19th centuries, many "Italian style" theaters were made in very different sizes from small to big one.
In the 18th and 19th centuries, the architectural features of most theaters come from the Baroque architecture. In fact, the progress of scenes in this period helped to some extent contribute to the development of theatrical architecture.
Theater architecture in the Baroque period is known to consist of a U-like space and a vast scene.
The skill of Italian architects and designers has made tremendous progress in the Italian theater, and such advances have become a part of the Italian theater in all European countries.
Main features of the architecture are (Fig 2.5, Fig. 2.6):

1. The hall, a horseshoe shaped hall featuring audience seating in the middle surrounded by balconies;
2. The balconies;
3. The scene finds a lot of depth and has an innovative perspective. Actors find more space to display, as it was common in the Renaissance theater;
4. The roofs of the hall and the stage are made up of large trusses;
5. A decorated false ceiling hides the structure of the roof in the hall;
6. The wooden trellis, usually placed on top of the stage.

Figure 2. 5 model that carefully carries out the internal structure of the Italian theater.
Ref; Pietro de Marco Cervino - Giovanni di Dedda La sicurezza al fuoco nei Teatri Storici. Adeguamento delle opere strutturali alla normative antincendio, 2013. Politecnico di Milano.

Further more these places possess valuable architectural and artistic meanings, and the inner theater includes artistic wooden structures, besides inside the interior there are also “stucchi”, graffiti, plaster, painting and also papier-mache.

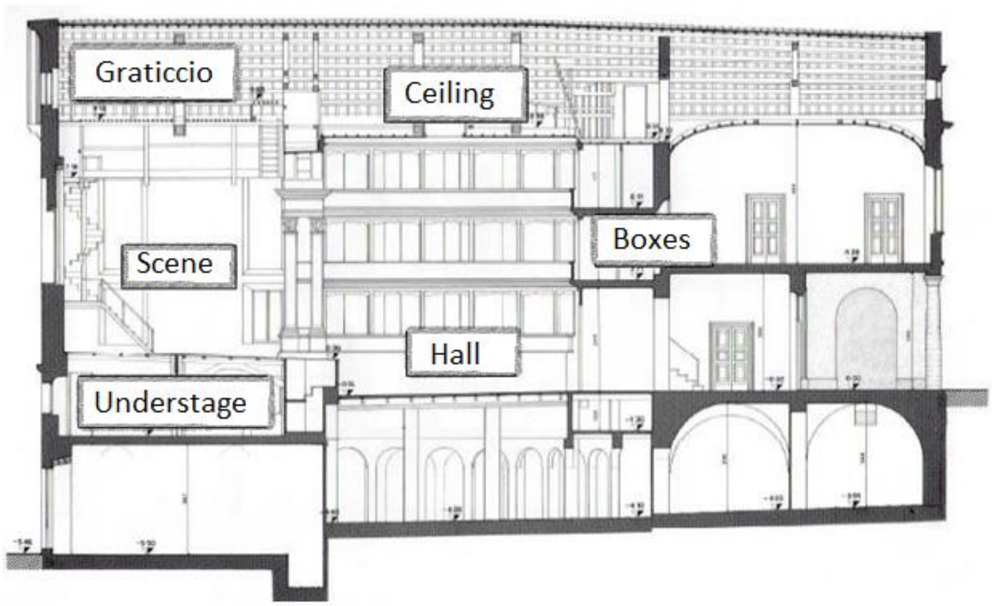

Figure 2. 6 The "places" of Italian theater.
Ref; Mario Panizza, “Edifici per lo spettacolo”, Laterza, Bari, 1996

2.6 The Construction System

Thus section, is an attempt toward the construction of the theater. The structure of the theater building can be divided into three parts

1- An external box in stone or brick masonry

2- Horizontal wooden closure system and ceiling

3- Constructive subsystems in wood that constitute the face of the hall and the stage.

The main spaces of the theater, such as the hall and scene, are composed of the three structures. Below is a section of Italian theater (Fig 2.7).

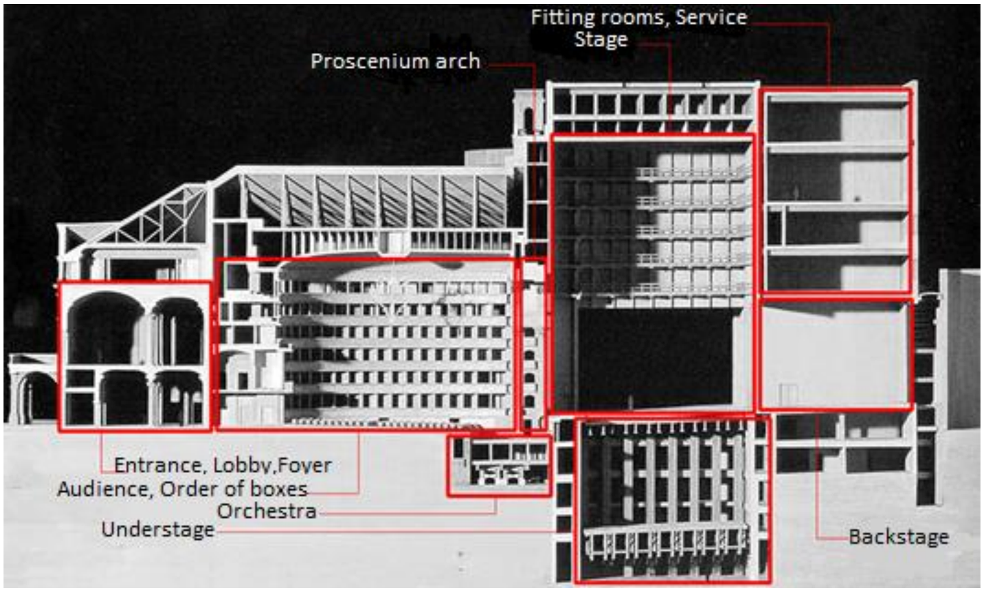

Figure 2. 7 Type section of the Italian Theater.
Ref; available on site http://www.spazioscenico.altervista.org

2.7 The Subsystem of the Italian–Style Theater

As it was stated earlier, the Italian theater consists of the wooden construction sub system, but also more recent steel ones, give it a form and Identity. This give life to the vital places of the theater, hall and stage, to the main theatrical machines and trellis.

The covering structures of the casing are normally made up of wooden trusses carrying purlins. Sometimes you can find minor armors connected or not to the main structures that serve to support the ceiling. Generally, the trusses placed at the stage are visible, the other trusses located at the extrados of the ceiling at the vault of the salon are, instead, hidden from view. The theater hall is the most visible and accessible part to the visitor. The boxes characterized by a complex framed system of pillars (candles) and wooden crosspieces determined the hall horseshoe shape. Wooden and board slabs characterized the horizontals both boxes and of the trampling. The ceiling is characterized by a set of stuccos and frescoes that reinforce the artistic, architectural and historical value of Italian theater (Fig 2.8).

It was built in support or on the system of the boxes or on the perimeter wall and often suspended from the roof trusses, formed by a complex system of wooden ribs.

Figure 2. 8 Scheme of the covering reinforcements and the wooden frames of the hall.
Ref; Pietro de Marco Cervino - Giovanni di Dedda La sicurezza al fuoco nei Teatri Storici. Adeguamento delle opere strutturali alla normative antincendio, 2013. Politecnico di Milano.

The space of the representation is defined as a stage and is vertically delimited by two horizontal planes: the stage, composed of wooden beams and planks, made with wooden crossbars that created a transparent plan allowing a glimpse of the attic. These two subsystems are the means for the use of various theatrical machines. We generally found machines designed for horizontal translation of the stage plans. On the trellis we often find wheels and pulleys intended for suspension and therefore for vertical translation of the scenes. In symbiosis with the architectures previously described, a whole series of accessory realizations can be found, in order to guarantee the connections and the inspect ability of the various parts. Paths in wood suspended or cantilevered from the walls of the area are found both in correspondence of the grid and the ceiling.

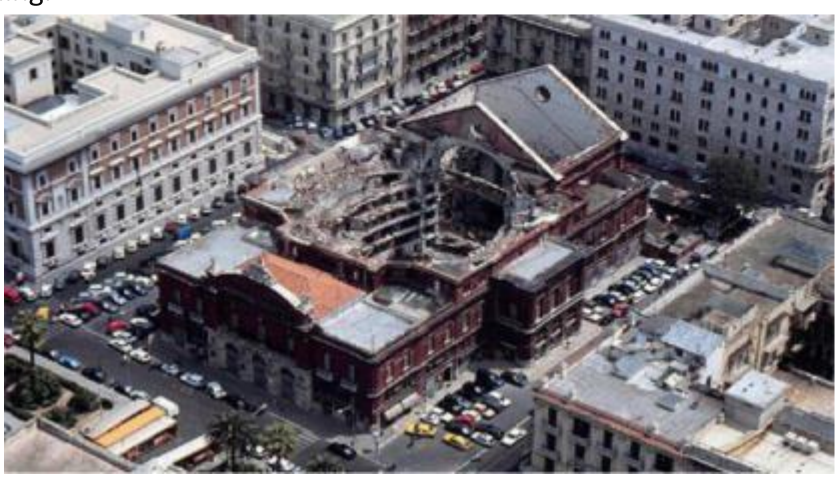

Figure 2. 9 Petruzzelli Theater in Bari after the 1991 fire.
Ref; Mario Panizza, "Edifici per lo spettacolo", Laterza, Bari, 1996

It is easily distinguishable in the image of Petruzzelli theater in Bari after the fire event, the external masonry envelope that surrounds the hall and the stage. Wooden construction subsystems have been destroyed.

The gratings must allow the positioning of the single pulleys or in groups for the sliding of the wire ropes, the bobbins for the hemp ropes, the electric motors and the equipment from time to time necessary for the preparation of the stage effects.
In the following sections, we analyze in detail the roofing systems (truss) and the subsystems of the stage (trellis) and the hall (ceiling).

2.7.1 The Trellis - "cieli forati"

One of the fundamental technical zones for a theater is the grid (Fig 2.10). By trellis we mean that walkable floor located above the stage about two meters from the roof in the smaller theaters, used for the organization of the maneuvers and movements necessary for the scenic effects. This plan is structured in such a way as to allow the positioning and fixing of the suspension cables of the scenes and of the technical equipment suspended on the stage. The gratings must allow the positioning of the single pulleys or in groups for the sliding of the wire ropes of the spools for hemp ropes, electric motors and equipment from time to time necessary for the preparation of the stage effects. The trellis must also allow an easy and fast possibility to move the installed organs and adapt the layout of the scene shots to the show to be set up.
The gravitated floor is made up of a series of wooden beams, placed parallel to the proscenium and spaced from one another to create a worktable with a continuous series of slots through which the ropes can be lowered. movements for stage effects. The slots, called cuts, must be as small as possible to allow the greatest number of cuts and therefore to maneuver, allowing the insertion of the groups of pulleys, while the joists must be sized to ensure the required flow and easy practicality. The material used in the past was only wood, while currently mainly steel beams are used for the supporting structure and joists of wood or steel (or mixed) for the practicable trellis. The supporting beams must be sized to guarantee a finished trellis capacity of about 350 kg/m^2 and lay orthogonally to the proscenium. When positioning these end girders, it is necessary

Figure 2. 10 Garibaldi theatre in Palermo – the trellis on the stage. Ref; Calogero Vinci, Il teatro Garibaldi a Palermo e la costruzione dei teatri storici minori, Palermo 2013, Edizione photograf

to consider the need to allow the descent of the ropes to the winches, to the counterweight shots or simply to the maneuvering balconies.

Figure 2.11 Garibaldi theatre in Palermo – the trellis on the stage
Ref; Calogero Vinci, Il teatro Garibaldi a Palermo e la costruzione dei teatri storici minori, Palermo 2013, Edizione photograf

Figure 2.12 Graticcio trellis of the Pergolesi Theater - Jesi (Ancona).
Ref; Calogero Vinci, Il teatro Garibaldi a Palermo e la costruzione dei teatri storici minori, Palermo 2013, Edizione photograf.

Figure 2.13 Detail of a steel trellis with a system of shots.
Ref; Pietro de Marco Cervino - Giovanni di Dedda La sicurezza al fuoco nei Teatri Storici. Adeguamento delle opere strutturali alla normative antincendio, 2013. Politecnico di Milano

2.7.2 The Truss

The coverage of the Italian theater's hall is characterized by the relationship between the trusses, which constitute the supporting structure, and the ceiling, which in most cases entrusts its loads to the truss itself. The truss (or roofing or trestle) is an architectural element, traditionally made of wood, formed by a vertical truss girder placed vertically and used as a base element for a sloping pitched roof. In the absence of a wall plug, the truss represented the most suitable solution for the construction of roofs with inclined flap. Depending on the light to be covered, the structure may vary in the elements from which it is composed. Just like the walls to which they are substituted, the trusses create non-pushing structures. The distance between the trusses, up to lights of 20 m, is about 3.00/4.50 m. In the pavilion heads, the trusses can constitute the point support for the cantons. In double-pitched roofs that develop with changes in ridge direction and lateral walls, the trusses can be placed diagonally to provide on one side the supporting structure for the displacement line, from the other side for the flood line.

2.7.3 Type of Truss Scheme

The most classic truss consists of the following elements:

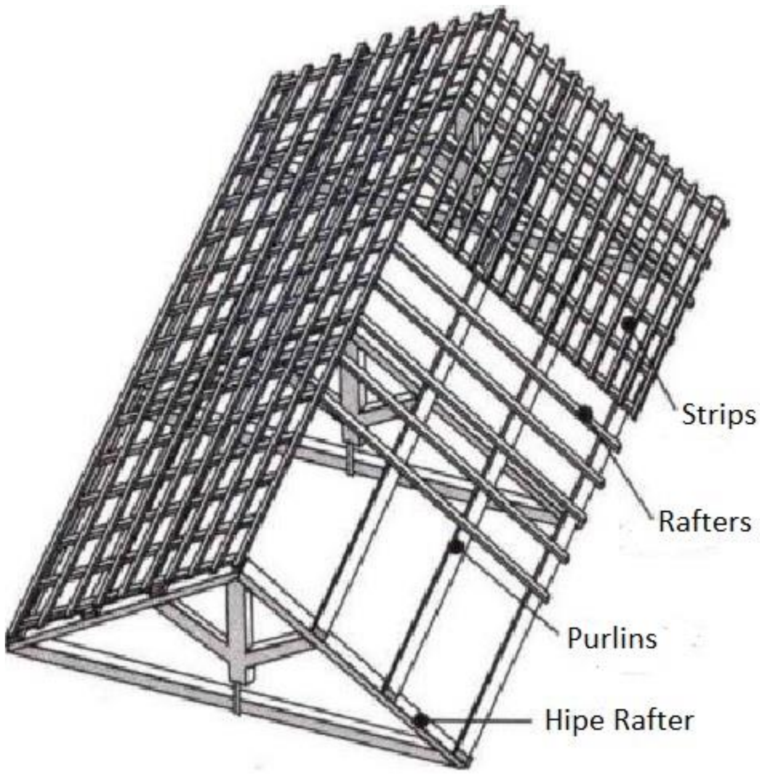

Figure 2. 14 Covering scheme with truss.
Ref; available on site http://www.spazioscenico.altervista.org

- Two struts: these are the inclined beams that go outwards and determine the slope of the roof. Subjects mainly in compression and flexion.
- A lower chain: It is the horizontal element that constitutes the base of the triangle and which supports tensile stresses that would otherwise be burdened, in the form of horizontal force on the point of support of the struts.
- Element of greater length of the truss, it was generally in one piece, but sometimes it was realized by two connected straight elements.
- A monk or little man: it is the vertical element present inside the truss and has the task of stiffening the structure.
- Two hunkers: These are the elements with an inclination opposite to that of the struts which limit the inflection of the struts themselves, unloading on the monk the compression force to which they are subjected.

There are numerous historical buildings in Italy that present light vaults in Camorcanna, made with reeds of reeds and plaster hanging from wooden ribs. At their soffit they often present pictorial cycles and artistic decorations. These times have often different characteristics regarding the materials used and the type of connections between the elements constituting the structural system. They have the advantage of being very light, of quick execution and of having an effective insulating capacity. The construction system arises from the need to suspend a plaster to disguise or embellish the beams of the floors or to embellish the interior volumes.

Figure 2. 15 Covering with truss ,Garibaldi Theatre Palermo.
Ref; Calogero Vinci, Il teatro Garibaldi a Palermo e la costruzione dei teatri storici minori, Palermo 2013, Edizione photograf

Figure 2. 16 Covering with truss – Garibaldi Theatre Palermo.
Ref; Calogero Vinci, Il teatro Garibaldi a Palermo e la costruzione dei teatri storici minori, Palermo 2013, Edizione photograf

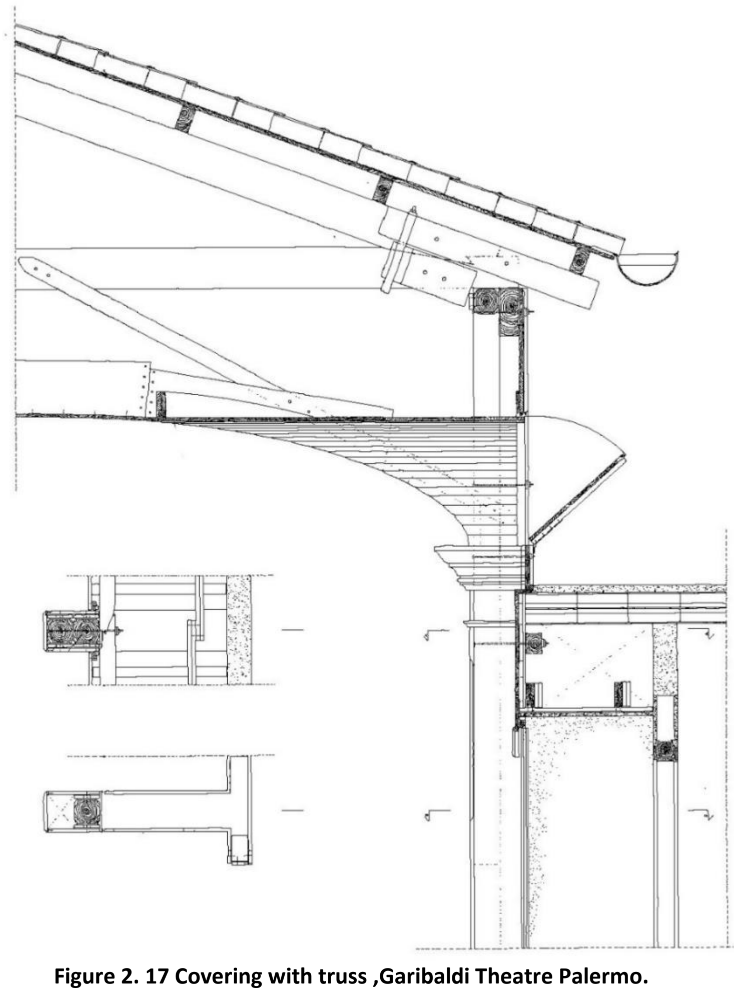

Figure 2. 17 Covering with truss ,Garibaldi Theatre Palermo.
Ref; Calogero Vinci, Il teatro Garibaldi a Palermo e la costruzione dei teatri storici minori, Palermo 2013, Edizione photograf

2.7.4 The Ceiling: The Vault in Camorcanna

In the Italian theaters the vaulted ceiling in Camorcanna is called ceiling and is characterized by a set of stuccos and frescoes that reinforce it architecturally. Already known in Roman times, used to plaster walls and ceilings of bathrooms with mortars mainly of plaster, the system is devised to be a lightweight and economic formwork, to lose, consisting of a corrugated surface on which to apply the mortar; a surface that can also prevent shrinkage cracks or detachment of any loose parts.

The support of the Camorcanna consists of a main wooden structure, with the warping according to the shorter side of the environment to be covered: it is formed by assembling several boards connected by nailing overlapping that take the name of ribs. They then rest directly on the perimeter walls, fixed with wooden wedges and mortars a few centimeters above the level of the finished intrados. The ribs are then braced by smaller boards called Tambocci, which sometimes have a good workmanship with well-squared profiles, other times they are made from irregular boards fixed to a forced joint between one rib and the other and stopped with nails oblique.

Often there is also a further warping, made up of small-sized wooden boards, called "panconcelli", arranged parallel to the ribs between a Tambocci and the other, which serves to increase the engagement surface of the stretched leather. Immediately under the wooden structure created in this way is the mat of reeds on which the plaster is applied. The canes, which can be broken in half or in several parts according to the longitudinal axis, or only crushed, they were intertwined together forming a regular mesh or resting directly on the wooden part, without being crushed, tied by flexible reeds or copper wire between them and, through wide-head nails, to the Tambocci and to the ribs. The mat is ready to be plastered to its intrados, proceeding with the layers of the scratch coat, of the smoothing and smoothing with fine mortar. It could also be plastered to the extrados, to provide protection

The intradosal surface was therefore ready to be painted or decorated with valuable stuccoes. This constructive system, which sees the period of greatest diffusion in the nineteenth century, was present both in churches and in stately buildings with the qualities of lightness and economy, subsequently it lent itself well also to the theatrical ceilings, conforming in such a way as to assume the best curvature for good acoustics.

Figure 2. 18 The ceiling's extrados , Teatro del Popolo , Vittoria (RG).
Ref; Patrizia Lo Sardo, I teatri storici in area siciliana, Phd thesis, University of Palermo

Figure 2. 19 The ceiling's extrados – Teatro Luigi Pirandello , Agrigento.
Ref; Patrizia Lo Sardo, I teatri storici in area siciliana, Phd thesis, University of Palermo

Figure 2. 20 Extrados vault in Camorcanna.
Ref; Enrico Quagliarini, "Costruzioni in legno nei Teatri all'Italiana del 700 e 800", Alinea, 2008

They have many advantages, such as having an insulating capacity, a suspended plaster for interior effects, and a covering and decorating interior.

Figure 2. 21 Example of frescoed intrados.
Ref; Ovidio Guaita, "Teatri storici in Italia", Mondadori Electa, Milano, 1994

2.7.5 Decoration

The interior architecture of the Italian theaters is remarkable for its decoration and arrangement. The most commonly used system for walls, ceilings and pavilions (chambers) is the chalk-covered wood structure that has made the building an important artwork and architecture.
In such way the theater has a stretch structure that is thick.

2.7.6 The Proximity Screen

The proscenium curtain divides the stage of a theater from the auditorium and spectators. However, when we talk about the curtain of a theater, we must distinguish between the velvet curtain and the safety fire curtain.

2.7.7 Velvet Curtain

The velvet curtain is that sliding drape that closes the scenic arch dividing the stage from the hall. It is made of velvet, a very heavy fabric, since one of its functions is to not let the noises and the lights of the stage pass during the changes of scene between one act and another. There are different types of these curtains, in fact, differentiate between the methods of opening and closing; the main ones are the Italian curtain, the German curtain, the Greek curtain, the French curtain.

Figure 2.22 Sipario of the "San Carlo" Theater of Naples.
Ref; Charles Searson,"Naples opera house reopens after spectacular renovation", The Gramophone (London), 2010

2.8 The Introduction of the Fire Barrier in Theaters

With the end of the nineteenth century, the beginning of the twentieth century, and the advent of electricity at the theater, we began to pay more attention to security problems in theater spaces against possible fire risks that had destroyed, from Vienna to Nice, several theaters. of Europe, causing numerous victims. In 1879 the Teatro di Monaco of Bavaria was equipped with a fireproof curtain, and in 1882 there were the first proposals, by several companies, that took care of this sector, in order to provide the Teatro Regio of Turin with this metallic curtain, but this measure against fire risk, in Turin, at the Teatro Regio, was not adopted, while all the main theaters of Italy, unlike the Teatro Regio, became established in the nineteenth and twentieth centuries of the fireproof curtain. On 28 November 1931 a terrible fire destroyed the stage of the Teatro Comunale of Bologna (Fig 2.23), but thanks to the presence of the fire curtain, providentially lowered, prevented the fire from spreading in the hall of the architect Bibiena.

Figure 2. 23 Remains of the stage of the Teatro Comunale of Bologna after the 1931 fire.
Ref; Lynn, Karyl Charna (2005), *Italian Opera Houses and Festivals*, Lanham, Maryland

In the night between 8 and 9 February 1936 a terrible fire broke out on the stage of the Teatro Regio of Turin destroyed the theater, since, despite all the implementation proposals that the administration had received, it was never allowed to be laying of a fire curtain.

2.8.1 Regulatory and Procedural Aspects

The fire safety curtain is a passive fire protection tool and its design and construction are regulated by specific Italian laws.

- Mandatory: "In theaters with capacities exceeding 1000 spectators, the proscenium must be equipped with a metal safety curtain. The installation of the security curtain is not compulsory in the entertainment venues, with a capacity exceeding 1000 spectators, in which only occasional theatrical performances are performed, provided the stage has a surface of less than 150 m^2 ".

- Characteristics: "The safety curtain must form a separation, fireproof, fire resistant REI 60 (The abbreviation REI derives from the French words: Resistance = R = resistance, Entretenir = E = tightness, Isolement = I = isolation), between the hall and the stage. It must normally operate vertically downwards, it must close at a speed of no less than 0.25 m/s and withstand a pressure of at least 45 daN/m^2, without any fluctuations occurring that could compromise its operation. The safety curtain in the lowered position must strike the floor of the stage in correspondence with the underlying fire barrier ".
- The command of the safety curtain: "The safety curtain controls must be in such a position as to allow easy and safe maneuvering, ensuring complete visibility of the curtain during the descent. Two switchboards must be provided, one located on the stage and the other of the scene ".
- The protection of the security curtain: "The safety curtain must be protected from the side of the scene by a manually controlled rain-cooling system. This command must be in the same points as the control panels of the curtain. The flow rate of the cooling water must be not less than 2 l / min per square meter of the curtain and be evenly distributed over the whole area of the curtain ".

The D.M. 19 August 1996 in Italy therefore essentially sets two basic requirements: (1) structural: the fire safety curtain must be able to withstand a pressure of 450 Pa;(2) fire resistance: the fire safety curtain must form a REI 60 separation.

The procedure by which the compliance of the project with the above requirements is verified is instead prescribed through the Letter of the Ministry of the Interior 2 July 2003. First of all, it is established that the design must make direct reference to an experimental test carried out on a sample that is classified at least REI 90 and features similar to those of the fire curtain that is intended to be built. The design of the fire safety curtain is then developed starting from the constructive characteristics of the sample taken as reference and based on the related experimental data, respecting design rules that allow in fact to extend the REI requirement tested on the sample to the fire safety curtain. The compliance of the project with the requirements of the law is approved from time to time by the competent offices of the Ministry of the Interior which then issues a Single Installation Approval for the specific project.

2.8.2 Items to be Protected in the Safety Shield

The safety curtain must be protected by the device on the scene. In similar places where the maneuvers are located, it must be equipped with a manually controlled cooling system, with the cooling water flow rate not lower than 2 liters per minute, and the distance from the curtain must be equal to all distributions of the same area. Fire safety curtain should be able to withstand 450 pounds pressure. And the fire safety shutter must form a detachable REI60. The method by which the project is approved. In designing the fire safety projection, it should begin with a sample manufacturer's specimen taken as a reference and adapt it to the relevant test data and design rules, and then the fire safety shutter as an obstacle to fire spread. Project compliance with legal requirements is approved by the Ministry of Interior competent offices to install fire extinguishers in a specific project.

2.8.3 Construction and Installation Features

Depending on the relationship between the height of the towers of the stage and the predicted surface, different types of fire curtains can be used. Safety barrier only one leaf has a wider application, for example, if the height of the tower of Stage 2 is very much used and serves as a single, vertical door, which, when opened, it goes up completely until it disappears in public.

Figure 2. 24 Single leaf fire safety curtain with single leaf of the Teatro "La Fenice" in Venice. Ref; available on site teatrolafenice.it

Integrated safety and safety curtains and fixed Tympanum is considered in cases where the relationship between the height of the towers of the stage and the predicted surface is slightly less than 2, the Proscenium can be slightly reduced. By installing a fixed buffer, let's find out that it uses a single-leaf curtain. Two-Billion Safety Curtain for the cases where the use of Tympanum is a fixed operating table, we use it in this case to prevent the fire from falling into two vertical sliding doors.

Figure 2. 25 Double leaf fire safety curtain of the "Lorenzo da Ponte" Theater of Vittorio Veneto.
Ref; William Paul Gerhard, "Theatre fires and panics: their causes and prevention", John Wiley & Sons, 2009

Structurally, the fire safety shutter consists of 2 doors that form the actual element of separation. These are installed vertically on two guides installed on both sides of the vertical props that extend throughout the run. The significant weight of the panel (approximately 100 kg/m^2) is almost completely unbalanced by using a counterbalance system. Equipped with a hydraulic connection system that closes the safety shutter in the absence of power.
The fire can be fixed at constant speed by removing excessive energy by gravity. In addition, the motor usually has a notebook that can open the curtain even if it breaks the curtain and thus allows it to be displayed.

In the fire curtain, the upper part of the support must be fixed, and the movable curtains must also be completely closed so that there is a certainty that it will prevent the fire from passing. This can be done continuously with two U-shaped profiles, an anchor on it. The sand-to-wall wall is fixed to the moving section. Two profiles that are connected to one another are involved in the closure of the curtain, and, along with the presence of sand, prevents the passage of smoke and fire. The closure in the lower part is usually made by direct contact between the moving metal structure and the metal abutment element from the threshold level.

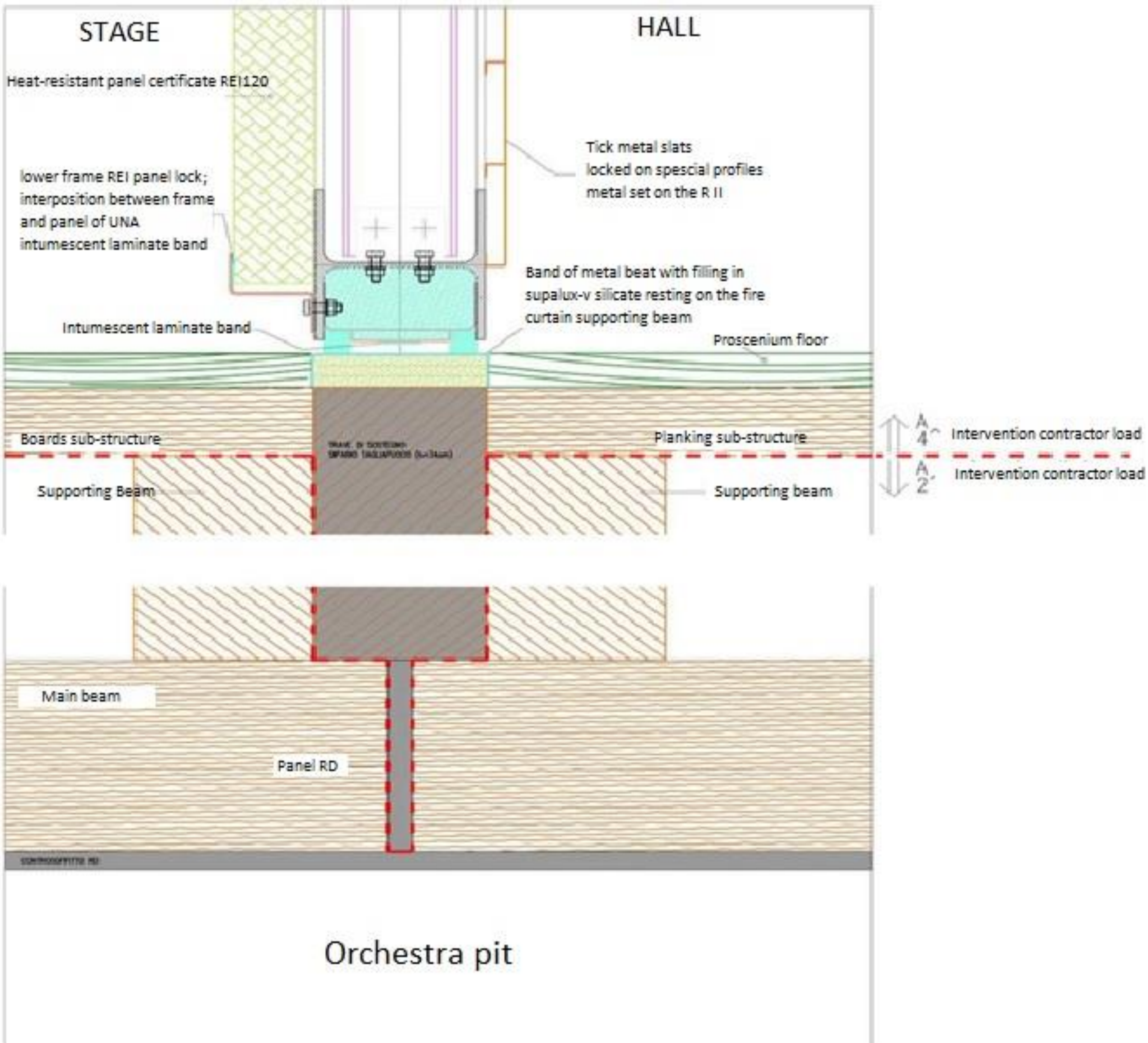

Figure 2. 26 Detail of the fire curtain of the "Amintore Galli" Theater in Rimini.
Ref; La sicurezza al fuoco nei Teatri Storici. Adeguamento delle opere strutturali alla normative antincendio, 2013. Politecnico di Milano.

Figure 2. 27 Lifting / lowering system of the fire curtain.
Ref; William Paul Gerhard, "Theatre fires and panics: their causes and prevention", John Wiley & Sons, 2009

2.9 Conclusion

The corridors and interior doors were very small and inefficient when used for escape, and almost no emergency lighting was lost, therefore the possibility of being safe from the fire was too low. It is clear that fire is a very important hazard to cultural heritage, and it has had high priority in fire safety community. In keeping the safety of people and buildings, the maintenance of the character is highly significant. This dichotomy, between fire safety (for both people; and the building and contents) on the one hand and maintaining character on the other, is at the heart of fire safety issues in heritage buildings.

For some historic buildings, traditional approaches may be applicable; while, most buildings especially those erected many years ago, approach of this kind could lead to both serious technical and financial problems, and to unwanted results about the historical and architectural character of buildings, which is often unacceptable by the conservationists.

Usual fire protection techniques are often not applicable and/or not acceptable for the protection of cultural heritage. There is important lack of specific information on fire safety technology for cultural heritage. Therefore, it is necessity to apply a clear a clear and sophisticated process or to have a modern fire suppressive engineering methodology.

It is highlighted that while in conventional buildings the main goal is the protection of human life, in cultural heritage buildings the safety of the building is at least as vital as the protection of human life. This is because original historic fabric is often unique and "the loss of any authentic fabric in a fire is irretrievable". Furthermore, authorities in charge of the protection of cultural heritage, find no support in prescriptive national fire safety regulations, there is a lack of well-found methods allowing a correct evaluation of the fire risk incurred by cultural heritage and they miss the tools to estimate the efficiency of different fire protection measures. Additionally, to acquire development in fire safety of historical buildings, having a high level of international co-ordination and strengthen the levels of transnational multi-disciplinary co-operation are suggested. In integrating new technologies with traditional disciplines there is a need to develop synergies within related organizations so that loss levels can be reduced and, ideally, halted.

The main goal must be to keep the cultural built heritage in an authentic status for future availability, access and enjoyment by all. Accordingly, the use of limited resources which are available and recognizing that conservation is cultural process are important. And there is an urgent need to integrate, co-ordinate, and assess the associated factors on a pan-European level so that a common state of the art understanding emerges to reduce such level of loss. These will happen through: appropriate statistic information which consist of the analysis of the opinions of experts on the rate of the loss in these buildings. A common state-of-the-art understanding, and appreciation, of available appropriate countermeasures; this should include concerted action to influence future developments in technology.

Promoting findings and benefits of relevant risk assessment methodologies and property management support. Effecting know-how dissemination through publishing proceedings and recommendations.

The other issue is the little research effort taken in this field, in fact preservationist must rely on protection technologies which are used for other conventional buildings which they often need to satisfy perspective regulatory obligations which are difficult or impossible to satisfy for heritage buildings. And in many cases these technologies are not applicable, or they are not efficient in these circumstances. There is also a significant knowledge gap between fire safety community and the preservationists. Because of the difference in the physical makeup of the buildings, the safety suppression varies accordingly. And it can be argued that the current situation is not an ideal one and there is a need for more improvement.

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Chapter Three; Fire Safety Codes

3.1 The fire regulations over the Centuries

The main cause of the closure of historical theaters was fire events. In the period between 1777 and 1903 there were 382 fires in Europe in theaters with the loss of over 8,000 lives. As reported in a study conducted by the National Fire Brigade, entitled "Study on Fire in the Public Spaces in Italy", the significant fires that determine the loss of the historical good are about 11% of the total of damaging events. The high frequency with which the loss of such an inestimable historical and cultural value for the Italian heritage occurs, denounces the alarming vulnerability to the fires of historical theaters. Due to the environmental factors (e.g.: the vulnerability of structures, fire source presence, artistic value of building, building layout) and occupant's density.

The fundamental problems that contribute to raising this threshold are many: the location and the complexity of access to the area where the property is located by the rescue; the presence of escape routes, as well as emergency exits, not suitable for the crowding of the activity; the heterogeneity of the building typologies and of the constructive modalities afferent to different epochs; the use of building materials with no fire reaction characteristics. If on the one hand these elements are considered critical from the fire point of view, on the other they constitute the peculiarities of an historical-artistic asset that is a tangible testimony of material history, whose preservation must be guaranteed to posterity.

For this reason, the difficulties inherent in conservation are multiple and arise when we try to combine the architectural uniqueness with security, trying to harmonize the peremptory needs of fire prevention with the protection of national historical and artistic heritage.

Through the application of deterministic-prescriptive rules, the fire-prevention regulations guarantee the safety of the building as well as the occupants and the material goods contained therein, resulting in complex application and often inadequate for most of the assets to be protected. In order to overcome this dichotomy, in recent years a performance approach has been achieved with the application of fire safety engineering which, while leaving the safeguard and safety objectives unchanged, is able to combine the need for safety and protection.

The problem of fires in the buildings of artistic and historical interest had already been dealt with at the beginning of the last century in various normative bodies: under the law 1089 of 1 June 1939 - "Protection of things of artistic or historical interest", the principle that the integrity and safety of the historical and artistic patrimony had to be preserved, and, more in detail, the regional decree 1564 of 7 December 1942 established that a possible fire should not have caused direct or indirect damage to the monumental part of the building.

Subsequently the D.M. 20/5/92 n. 569 "Regulations concerning fire safety regulations for historical and artistic buildings for museums, galleries, exhibitions and exhibitions" and the D.P.R. 30/6/95 n. 418 "Regulations concerning fire safety regulations for buildings of historical and artistic interest destined to libraries and archives", begin to jointly tackle the problems of security and protection of protected property for the most commonly used destinations in the context of historic buildings, such as museums, libraries and archives. More in detail, provisions regarding detention rooms have been established with the C.M. 15/2/51 n.16 "Safety rules for the construction, operation and supervision in theaters, cinemas and other public entertainment venues in general" then surpassed by the most recent D.M. 19/8/96 "Technical regulation of fire prevention for the design, construction and operation of the premises for detention and public entertainment".

Despite the decree of 1996, still in force, analyze the problems of entertainment venues nothing indicates the historical theaters where the protection of spectators is added to the preservation of the artistic and cultural heritage of the building. This objective was clearly clarified by Legislative Decree 8 March 2006 n. 139, normative text of reassigning the previous legislative provisions concerning the functions and tasks of the National Fire Brigade, which states that it is necessary "to protect human life, the safety of people, to preserve goods and the environment through measures and methods of action that avoid the onset of fires and events connected to it or to limit its consequences ".So even for theaters, fire safety has as its main objective to safeguard human life, primary safety, and also to preserve immovable properties whose intrinsic value is precisely the structure itself, secondary security. In any case, the dictates of the prescriptive decree of 1996 are still difficult to apply, partly overcome due to the design based on the performance approach that allows to identify the prevention and protection measures most suitable for pursuing the objectives set by Legislative Decree 139/06, downstream of an in-depth analysis of the building in question.

3.2 The evolvements of Fire Codes Based on History of Fires

The tragic outcomes of fire have helped people to develop strategies to control, prevent, contain, and make safe situations with fire. For the limitation in the traumatic effect that fire creates, different agencies such as the National Fire Protection Association(NFPA), the International Code Council(ICC), Underwriters’ Laboratories (U.L), and many others have had major impacts to establish the codes and regulations. [1]

3.2.1 Some Samples of Changes in Codes and Regulations According to Fire

The following table provides examples of how to modify the rules, in some cases, and to amend the rules. Fire safety laws have often been experiential and after each incident, the relevant laws have been improved [1]. The fires in historical theaters and the exploration of the causes of such accidents have been in the past and are still very important today to improve fire safety regulations in this area.

<table>
<tr><th>Year</th><th colspan="2">Explanation</th></tr>
<tr><td>64 AD</td><td colspan="2">Creation of wider streets, putting restrictions on the heights of buildings, and homes with fire resistant materials like stone instead of wooden pillars.</td></tr>
<tr><td>1631</td><td colspan="2">The first American Building Code was announced, and the construction of wooden chimneys and thatched roofs were outlawed because they tended to be hazardous and causing fire.</td></tr>
<tr><td rowspan="3">1648</td><td rowspan="3">In America First Fire Wardens were organized to;</td><td>Prevent fire by inspections in America</td></tr>
<tr><td>Have the permission to inspect every home for proper cleaning and constructions of the chimneys.</td></tr>
<tr><td>Based on this law if any fire was started because of the ignorance in cleaning or the chimneys, the Wardens had to be fined.</td></tr>
<tr><td>1661</td><td colspan="2">After the Great Fire of London, interest in developing a hand Pumper form of fire protection apparatus aroused.</td></tr>
<tr><td>1679</td><td colspan="2">The start to the first Paid American Firefighters, later in 2008 according to the statistic of the Bureau of Labor Statistics, there were about 365,600 paid firefighters.</td></tr>
<tr><td>1736</td><td colspan="2">The First Union Fire Company in Philadelphia was established by Benjamin Franklin and 30 men were volunteer for the department of fire.</td></tr>
<tr><td>1871</td><td colspan="2">The year of Great Chicago Fire, for reconstruction of the building, it was required to use fire and building codes for new spacing and construction materials.</td></tr>
<tr><td>1872</td><td colspan="2">Boston attempted to have better building codes and to inspect proper building construction.</td></tr>
<tr><td>1812-1890</td><td colspan="2">First Automatic Sprinklers</td></tr>
<tr><td>1874</td><td colspan="2">The first automatic sprinkler head was invented and was installed on Pratt's automatic sprinkler system by Hennry S. Parmalee.</td></tr>
<tr><td>1881</td><td colspan="2">Franklin Grinnel made an improvement to their inventions and designed a glass sprinkler head which is used today.</td></tr>
<tr><td>1903</td><td colspan="2">After Iroquois Theater Fire, federal and state standards for existing pathways, exist doors, exist signs and markings maximum seating, the use of panic bars were created.</td></tr>
<tr><td>1904</td><td colspan="2">After Baltimore Fire, the National Standard Size for fire hose as 71U2 coupling was formed.</td></tr>
</table>

1904	As a result of Slocum Ship Fire, in the New York Harbor, the standard for inspecting almost 300 ships was brought up. Testing, improving emergency equipment on ships, and destroying any defective equipment were set by Federal and State regulations.	
1911	Fire proofing, sprinkler systems, improved exiting from high-rises, and development of the NFPA 101	
1929	After the explosion of Cleveland Clinic Hospital, it became a law to have safety film for all X- ray films.	
1930	The Ohio State Penitentiary Fire, new fire codes for jails and prisons under NFPA and Life Safety Code (NFPA 101) were adopted which required new and existing improved facilities to be built of inflammable materials to be provided with automatic sprayer and/or fire alarm detection systems.	
1934	Morro Castle Fire lead to establishing stricter safety standards for ships like, emphasis on fire drills, the use of fire resistant materials, automatic fire doors, ship-wide fire alarms, emergency generators, and new training for firefighting.	
1940	Rhythm Club Fire Resulted in the Following Code Changes	Outward swinging doors.
		Fire suppression systems.
		Folding revolving doors.
		Number of exit doors.
		Battery run emergency lighting.
		Exit access size.
		Building materials.
		Confines interior furnishings.
		Enhancing the Life Safety Codes.
1942	The Knights of Columbus Hall Fire was conducive to standards in locking doors and windows.	
1944	As the result of Ringling Brothers Circus Tent Fire, NFPA Standards 102 (Grandstands, Folding and Telescopic Seating, Tents, ad Membrane Structures) was developed and its reflection was apparent in the 2000 International Building Code and 2003 NFPA 5000.	
1946	Winecoff Hotel Fire made changes in the locations of fire exists, fire suppression systems, and fire alarm system.	
1949	St. Anthony Hospital Fire caused several fire code changes in hospitals and health care facilities around the nation.	
1953	In general Motor Plant Fire, the following standards were announced	Limits on roof tar build up
		Separation of risky operations

		Sprinkler supplies in Industrial buildings.
		Fire covering for steel frame trusses
		Automatic fire doors
		Smoke and Heat Venting NFPA 204- Guide.
1953	The fire of Our Lady of the Angel's School caused the following changes to the Lady of the Angels School:	The Our Lady of the Angels school did not have to comply with all the new fire codes and standards while newly built schools were required to do so.
		School fire safety regulations and standards were fixed and endorsed through the nation and over 1000 schools were inspected again for obedience.
		The changes include the requirement of fire alarms, automatic sprinkler systems, outward opening for manual exit doors, window outlet heights, fire resistance rated walls, devoted backup lighting, parting of heating devices, and fire doors at staircases.
1961	Within the Fire of Los Angeles, homes were required to be built with fire resistant shingled roofs.	
1971	Apollo Fire resulted in improving standards in fire safety of space travels and safety for commercial air planes.	
1977	Beverly Hills Supper Club Fire made sprinklers required in nightclubs and public assembly areas over 300 capacities, and banned the use of aluminum electrical wiring. It is worth noting that it was the first time to preserve the fire scene for investigation.	
1980	The fire in MGM grand Hotel and cause the Code Changes	In the casinos of the city, there was the obligation for complete retro fit of sprinklers.
		Announcing the fact that smoke is more devastating for people than the fire to light.
2003		Have sprinklers systems in new clubs with the load of 50 or more occupants

	The Station Nightclub Fire in 2003 came up with the following obligations to:	Ban indoor fireworks
		Disqualified indoor pyrotechnics in less than 1,000-person limited gatherings.
		Sprinklers are mandatory by 7/1/05 in nightclubs with over 300 capacity.
		Sprinklers are mandatory by 7/1/06 in nightclubs with over 150 capacity.
		Removed “grandfather clause” and required old buildings to approach new code agreement.
		Low-level exit sign became obligatory in all nightclubs.
		Allowed fire authorities to examine clubs and close those which violated fire code.

Table 3.1 Changes in fire safety rules based on events over the years, Writer.

3.3 Fire Protection Codes and Regulations in Historical Constructions

The fire safety in historical buildings is a significant concern which its preservation parallels objectives for fire and life safety. This concern about these building has a long history in reference for the consideration to these is the first Technical Committee on Cultural Resources that was held in 1940s. The regulation is the clear reflection of public expectation for safety and neighboring properties. These rules are normally prescriptive. the codes and standards of the modern period trace their origin to 19th when automatic sprinklers were created. As of then, the sprinklers functioned properly as extinguishing devices; however, they were initially mounted in various ways that their reliability was not clear. To address the inconsistencies a group that represented sprinkler and fire insurance interests gathered in Boston. There were a number of meetings that culminated with a meeting in New York city and the 18th and 19th of March. A remarkable outcome of this meeting was the release of sprinkle installation rules entitled: "Report of Committee on Automatic Sprinkler Protection" which later it became known as NFPA13. There were some changes in the committees and meetings which opened up the NFPA that its first organization to join was in 1904 and the National Electrical Contractors Association of the United States, the Associated Factory Mutual Insurance Companies, and the Factory Mutual Laboratories were its active members under the new rules. From the early start to NFPA until its contemporary attempts its mission is to reduce the burden of fire and hazards on the quality of life. The goal is achieved by supporting consensus codes and standards and , research, education for fire and associated safety issues. The NFPA 909 code which was set for cultural resources property was developed during 1940s. The principle aimed at preserving the culturally significant and character defining buildings that are normally irreplaceable and there is a need for their continual operations. The purpose was to be acquired through minimum requirements through a comprehensive protection program. In order to help the safety of people and also keeping the artistic features of historical buildings NFPA 909 and NFPA 914 codes were conducive steps. The codes were applicable in culturally significant buildings, new buildings, the existing buildings. In addition, protecting the original qualities of collection, structural integrity, and emergency responder access were the other objectives of the NFPA 909. The preservation had to be done within minimal removal/ changes to the specific architectural features. It was established as supplements to the existing codes by recognizing the particular nature of cultural resources properties.

3.3.1 NFPA 909 vs NFPA 914

<table>
<tr><th colspan="2">Major objectives of NFPA 909</th><th colspan="2">Major objectives of NFPA 914</th></tr>
<tr><td>Item</td><td>Explanation</td><td>Item</td><td>Explanation</td></tr>
<tr><td rowspan="3">Collection Preservation</td><td>Protect/preserve original qualities of collection</td><td rowspan="3">Life safety</td><td rowspan="3">Egress
structural integrity
operations
security</td></tr>
<tr><td>Structural integrity</td></tr>
<tr><td>Emergency responder access</td></tr>
<tr><td rowspan="2">Building Preservation</td><td>Preserve original qualities/character of building, structure, site, environment</td><td rowspan="4">Historic preservation</td><td>Preserve original atmosphere of building, structure, site, or environment</td></tr>
<tr><td>Minimize removal/alteration of distinctive architectural features</td><td>Lessen removal or adjustment of historic features</td></tr>
<tr><td rowspan="2">Continuity of Operation</td><td rowspan="2">Minimize disruption of operations consistent with property's mission and protection goals</td><td>Characteristic features preserved with sensitivity</td></tr>
<tr><td>Encourage compatible use with minimal alteration</td></tr>
</table>

In comparison to NFPA 909 code is the NFPA 914 which includes all building that are significance on the historical, architectural, or cultural elements.

Moreover, in heritage buildings the distinctive stylistic features or examples of craftsmanship that characterize a building structure, or site, must be treated with sensitivity. This is framework for the application of fire safety science to cultural preservation of the heritage. The process includes, team approach, identifying historic features, identifying fire safety problems, compliance options that may be prescriptive provisions or performance based approach, and compliance audit.

The compensatory features of NFPA 914 included: building materials, fire-retardant actions, noncombustible contents, Fire/smoke barriers, shaft enclosures, fire discontinuing, fire-resistive structure, fire recognition and alarm systems, automatic suppression systems, management operative controls, electrical gear.

The danger of fire is an inevitable event but the risk is more when it come to the populated wooden buildings. fire prevention and a fire suppression part were among the program to have a fire suppression program. The reason in setting the rules are to save lives and property with more concentration on preserving the aesthetics of heritage buildings.

3.3.2 APPROVED DOCUMENT B AND HISTORIC BUILDINGS in the USA

Building regulations for Fire Safety, Approved Document B (ADB), is one of a series of documents that has been approved and issued by the Secretary of State to provide practical guidance regarding the requirements of the Building Regulations for England and Wales. Nevertheless, about life safety, assets protection and artefact repossession, historic buildings have definite challenges to face and hardly 'fit' the strict nature of the information given within ADB. Accordingly, to save the historic buildings a range of fire safety features and to set them against assessment of the hazard and risk specific to the building are important steps. Therefore, the building and occupants need to be managed, and passive and active fire safety systems in the buildings will have to be enhanced physically. The basic strategy for achieving this is the process of fire risk assessment and fire safety management. In the following table, instances of protective measures, their connection to the five sections of Part B and common problems and possible solutions with respect to heritage buildings are given.

3.3.2.1 Means of warning and escape

Common Issues in Historic Buildings	Potential Solutions
Room geometry can render British Standard approvals for use of detectors inappropriate.	*Watchful choice of detectors can significantly improve the chance of noticing a fire before it develops too large. Beam detectors can cover large areas with fairly few

Large windows or decorative ceilings can let a large flow of air over detectors, avoiding them from fast respond. [2]	detectors and reflectors, dropping the disruption to the fabric of the building. *Wireless systems can be used in areas of a historic building where setting up wires is not allowed. The site of the detector is also important to avoid environmental conditions, such as air flow, manipulating the efficacy of the detector.
Installation of systems disruptive to historic fabric of building.	'Hidden' aspirating detectors have been used in historic buildings where the detector head is covered in a wall or ceiling and minimizes visual impact. Aspirating detectors repeatedly sample the air and will make smoke detection more quick. [2]

3.3.2.2 Internal fire spread (linings)

Common Issues in Historic Buildings	Potential Solutions
Variation of linings – exposed brick, timber panelling, wall-hung fabrics.	Relocation of wall-hung fabrics away from crucial circulation zones and escape ways will significantly decrease the risk of fire spread and smoke compromising emptying the building.
Enhancement of timber linings and paneling by surface applied treatments affecting the original fabric of building.	By advancement of the fire performance of timber paneling in main circulation zones and escape routes as identified in the fire risk assessment, the impact on the historic fabric will be diminished.

3.3.2.3 Internal fire spread (structure)

Common Issues in Historic Buildings	Potential Solutions
Installation of fire stopping measures can involve removing ornate panelling and can potentially affect the airflow within a building, creating problems with moisture and damp.	Careful installment of fire stopping measures at serious connections with minimum disturbance to the aesthetics of the paneling. If it is essential to eliminate original or decorative features with consultation from a renovation specialist and a historic building specialist.

Installation of fire suppression systems can be disruptive to the fabric of the building and water resources and tanks can be limited or difficult to site.	Active suppression systems should be cautiously designed according to the location of the sprinkler heads, pipes, water resource, the building to confirm the ability to control a fire. Accessibility of first-aid firefighting gear and inclusive training of staff in its use. The suitable fire extinguishers and blankets, when appropriately used, can block the fire at source and avoid it from becoming serious.
Using sprinkler systems can be destructive to valuable items and archived objects/materials.	Oxygen reduction system will prevent damage to valuable materials. If fitting to the risk, a water-mist suppression system will spread over noticeably less water than a sprinkler system.

3.3.2.4 External fire spread

Common Issues in Historic Buildings	Potential Solutions
Risk of external fire spread mainly related to buildings with flammable facades – limited to working with existing fabric of building, options for promoting fire performance is restricted.	Surface applied treatments for timbers are accessible but paying attention to their preservation is necessary. Because they will need reapplying regularly due to weather conditions. Water-mist suppression systems have been used to covering a building in water mist to prevent fire from immersing it, examples are wooden churches, parts of buildings such as thatched roofs, and historic timber ships.

3.3.2.5 Access to facilities for the fire brigade

Common Issues in Historic Buildings	Potential Solutions
Contact to fire tender vehicles can be inadequate. Historic buildings can be inaccessible from adjacent fire and rescue service.	Liaise with local fire and rescue service concerning access and facilities to develop an agreed 'planned response'. If access to the building is limited, it may require presence by another type of tender vehicle with specialist equipment. Correct site plans with access points and other important information need to be supplied to fire

	and rescue service to maximize effectiveness on site. Develop artefact salvage plans in co-operation with the local fire and rescue service.
Limited water resources (no fire mains).	Use local resources such as lakes or rivers, rather than relying on a potential inadequate mains supply.

3.4 More on Building Regulations and Safety in European countries and Italy

The standards are required for undertaking the designs of: Means of escape, Smoke management, Fire resistance of the construction, Firefighting, Fire safety systems (alarm, suppression, …)

In Italy, the prescriptive approach is the basic of regulations and concern several building use. But within the lack of prescriptive approach or in the case of "derogation" with respect to prescriptive rules, the performance based design, advanced calculation methods can be applied too, based on prescriptive approach. Specific technical rules of firefighting are used by the ministry. In Italy the national Euro Codes within prescriptive approach for the design codes of means of escape and smoke management, firefighting in Italy depending the use of buildings are available. For fire resistance The Decree of the Ministry of the Interior, 16/02/2007 ("Classificazione di resistenza al fuoco di prodotti ed elementi costruttivi di opere da costruzione") is applicable to assess the fire resistance of the building. For the fire safety management systems (alarms, suppression) the rules are also in prescriptive within the national standard. It is possible to apply the international Euro codes to the national standards in Italy. Some Eurocodes (EN1992-1-2; EN1993-1-2; EN1994-1-2; EN1995-1-2) may be applied assuming the suggested values as NDPs.

3.5 Analysis of the Codes and Standards

Standards in Fire protection in historic structures which have significant historical meaning, cultural value, representing rare, unique, and historic qualities have not been discovered. Due to the importance of keeping the historical aspects of the buildings, there is a great emphasis on management systems and use of fire extinguishers. Fire in historical buildings and especially in theaters has been a tremendous problem for fire services. Fire codes that were used were weak or nonexistent. The wood construction of the theater, poor egress, and illuminated with gas lightening were controversial reasons for fire. When fires occur, managing people and providing order into exists become quite overwhelming. Sometimes because of the complicated mechanisms and not having the panic hardware, the exists could not comply with the rush and panicking people in the fire. Moreover, people had problem passing the narrow and confusing stairs. Other reasons for fire in historic buildings were the lack of extinguishers, sprinklers, alarms, telephones, or water connections. Sometimes the fire curtain also was not lowered to protect the audience and the introduction of air into the buildings intensified the fire. In some cases, unannounced inspections were done to ensure that the code were being followed.

In general, the aims of fire code officials involve in:

-Insuring the proper protection of the buildings.

-Easy access of the exists.

-Proper function of the alarm systems and extinguishing systems.

-The efficiency and maintenance of the systems and facilities used in the buildings to ensure the safety of people and property within the buildings.

It is a significant fact that tragic outcome of fires can be avoided provided that both owners of the property and officials of the code enforcement work in parallel.

Educating staff and people globally lead to avoid the catastrophic consequences of fire. As with cultural resource properties and historic buildings, there are unique fire safety engineering problems. There are other codes that do not adequately address conservation issues

But NFPA 909 and NFPA have efficient framework to compensate for the shortcomings of the other standards.

Among the prescribed codes and standards NFPA 914 code is efficient for heritage buildings. It includes all the requirements and keeps the historic character of the old buildings. It goals which are mainly the safety of lives and properties can be applied to prescriptive or performance methods. The NFPA 914 has a clear framework to provide the safety by starting with documenting the historic elements and by prioritizing that historical or cultural significance should some compromise be necessary to reach minimum safety objectives. After identifying the fire risks, the solutions that comply with the hazards are designated without ignoring the historical contents. For NFPA 914 according to the safety goals the solutions can be Performance Based Approach, Prescriptive Approach, or risk indexing while having the least impacts on the historical features. Emphasis on care periodic audit of the work is the other pivotal element of NFPA 914 Code.

To conclude, fire codes have changed significantly in the past 100 years and they are different from region to another. For each historical building, evaluating fire safety and the level of risk must be done and fire safety is not limited to a single safeguard; however, it is depended on several components. For ensuring the reasonable life safety, multiple safeguards are required, in case one component fails. Besides, it is by correcting the deficiencies and standards the major aims which are the safety of lives and property can be achieved.

Therefore, as already mentioned, for existing structures, and especially historic buildings, which are very important in terms of price and value, the performance-based method should be considered for each instance. Passive and active decisions are required to improve fire safety and reduce the risk of fire according to the characteristics of the building and in order to minimize the changes.

3.6 Comparison and Analysis between Performance Based Approach and Prescriptive Solution

In European building performance based fire safety design is the accepted methodology which is a popular replacement of the traditional perspective system. In 1990s the need for more effective and efficient regulatory approach was put forward. This approach is more self-regulated and involves economic instruments in comparison to the prescriptive standards that are satate oriented and requires commands and control regulations. Unlike the performance based approach the prescriptive approach concentrates on verifying specifications of what to be done in the building control. In establishing the performance based approach however promoting the use of new materials and new combinations of materials were required. The shift in technology and failures in the traditional prescriptive methods were controversial reasons for replacements of prescriptive methods with the performance based approach. This method was created in 1990s in New Zealand. These systems are appealing for the need of unique buildings such as historical or cultural significance. The calculation procedure the individual characteristics of building and passive and active fire protection are considered in the calculation procedure. In this method a realistic understanding of the behavior of structures in fire and the overall safety of the building can be verified. [3]

Through the more profound understanding of phenomena and a more precise analysis of structures in fire, an equal to or higher safety level than with prescriptive fire design is obtained. [3] Thus, performance approaches offer the balance between the need to protect unique buildings and their contents and the wish to reserve the important historical or cultural features of the building. The public expectation for the built environment of the country is reflected in building regulations with respect to the least accepted requirements for health, safety, and welfare, and in some cases for environmental, energy, and culture. By describing the acceptability of materials the requirements of materials, products, and systems that have been shown by experience to result in acceptable buildings, building regulations have applied the prescriptive style. Besides, these perspective systems haven shown to be efficient by the evidence of the rare failure occurrence in even minimally code compliant buildings. A particular shortcoming of the perspective systems is that in unique buildings or where the possible solutions are in some way constrained these systems do not work well. These constrains includes, aesthetic objections to the degree of compartmentation required in the regulations, the inability to fulfill egress requirements such as the number of exists or maximum routing distance necessary because of the building size or site restrictions. [4]

While there are some systems that try to quantify equivalency, such as the Fire Safety Evaluation Systems (FSES) published in NFPA 101 A2, such systems must be built for specific occupancy types and must be repeatedly recalibrated as the strict requirements develop. Performance-based regulations are about essential results rather than about detailed solutions and openly define the intent of the code, clearly. Additionally, the process defined in such documents as the SFPE Engineering Guide to Performance-based Fire Protection Analysis and Design of Buildings is built around a agreement of stakeholders, including the designers, owners, builders, and regulatory officials, as to the aims and the appropriateness of the suggested methods to accomplish those goals.

According to a survey done for verifying the kind of regulations in buildings of different countries, it is revealed that most countries allow for the performance based design and the use of advanced calculation methods. But as for Greece, Hungary, Romania and Slovakia the regulations are purely prescriptive and do not allow for the use of advanced calculation methods. And each country provided a list of regulations for fire suppression. While some have guide lines and FAQ's, other countries like Croatia, France, Greece and Italy do not provide this sort of information from the authorities. Moreover, the regulations are applicable to most types of buildings. There are some required national/ international standards like: means of escape, smoke management, fire resistance of the construction, firefighting, fire safety systems (alarms, suppression, …) It is noted that although some countries do not have these regulations; however, they have the national regulation for fire safety or some rules from NFPA. The objective in preserving historical structures is unlike any other buildings, in some cases the goal is to keep the structure itself, or sometimes the content is of the most concern, sometimes both aims are significant. In other cases, the aesthetic, the interior and exterior architectural details, the internal detail of the structure itself which is unique and needs perseverance are of great importance. Consequently, the art of historical preservation must be allowed to find explanations that are consistent with the specific requirements of the building. Such freedom cannot be accomplished with prescriptive approaches established with the typical building observance. These ideas underlie NFPA's Code for Fire Protection of Historic Structures (NFPA 914). This Code4 describes fire safety requirements for the protection of historic structures and for those who operate, use, or visit them. It covers ongoing operations, renovation, and restoration and acknowledges the need to preserve historic character." It includes clear objectives for life safety and historic preservation that are related to either prescriptive or performance solutions. There are eight design fire situations specified for performance approaches that are matching to those included in the Performance-based Design Option of the Life Safety Code (NFPA lOl). The protection of museum and library collections is the subject of another document, NFPA 909, Code for the Protection of Cultural Resources. [4]

It is highlighted that prescriptive approach is an elaborated complex that fe readers identify with, on the contrary PBA is more clear explanation of statutory duties. Based on the report of the Public Inquiry into the Piper Alpha Disaster (1990), in prescriptive approach which enforces detailed obligations compliance with the rules become the primary objective, instead of the main goal which is safety. Which results in less innovation and responsibility and less improvement. Alternative argument was that prescriptive regulation can prevent the implementation of new technologies that deliver larger levels of safety than existing technology. [5] Accordingly, in PBA innovation and reduction regulatory costs are the basis of the regulations and complicated prescriptive approach undermines safety outcomes. In addition, the idea that prescriptive controls compromised the main objectives or rules and they create unnecessary regulatory burden was not universal. It was also noted that the current building regulations could create safety in buildings that fire and structural failure is rare. However, it is obvious that performance based regulation is a competitive option to the prescriptive regulation and has been a part of previous decades of experience and writing. It is argued that the regulations should be on performance basis that is based on the requirements of the product rather than on prescriptive approach which relies on descriptions of the characteristics and designs. It is highlighted that for health, safety, consumer protection, and environmental regulation in particular the Performance Based Approach has become rapidly popular among countries. [6] A main issue with the prescriptive approach is that they are not applicable to buildings that have unique constructions and this lead to continues constrains in aesthetic objections, the inability to meet egress requirements because of building restrictions. However, In Performance Based Approach there are required outcomes and describing the intent of the code without ambiguity.

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Chapter Four; The Fire Risk Management

4.1 Fire risk management

Risk management technique tries to decrease all of damage under the acceptable level with low cost. Usually for preventing accidents use technique and implement insurance plan [1]. Risk management as a complete methodology contains of different evaluation method, all the following stages included this approach.

1. Define goals

2. Risk understanding

3. Determine risk levels

4. Assessment of risk acceptance

5. Define Risk mitigation tools

6. Application of results in practice

In the figure below management risk is shown. The definition of risk management is accepted via International Electronic Commission. There is certain communication between "risk evaluation", risk analysis and risk management. As example, Covello and colleagues [2] considered risk evaluation as part of risk analysis. From following figure, risk analysis is part of risk management process.

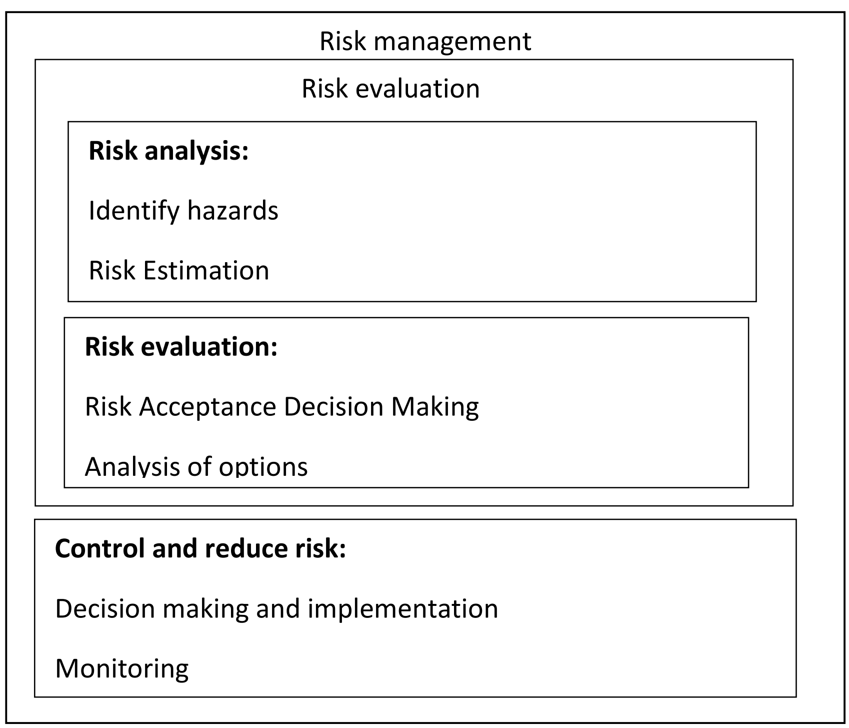

Figure 4.1 The process of risk management (Writer)

This is a process which make decision in case of Identified hazards, exposed population and harmful consequences and applying evaluated design via fire risk evaluation and management of program (maintenance and training) continuously which can lead to achieve acceptable levels of risk. This can consist of management of costs and predictable results which is connected to decision making and also balancing fire and insurance cost. Another aspect of this process is management and control of connection which is consist of any exchange of information between engaged groups of people (designer and fire model analyzer) [3].

4.1.1 Different Stages of fire risk management functionality

To reduce fire damage, organization and government in each country have obvious duty to reduce and manage fire risk. Industry and business organization develop plan to reduce fire risk which is consist of three phases. These three phases are plan before fire occurrence, actions during fire and after fire occurrence. First phase become identification of potential resources of fire which are consist of men error such as careless destruction of matches or cigarettes and inhumane errors such as incomplete wiring and spark in industrial building. The sources of fires in historical theaters should also be investigated, all electricity installation, heating system and etc. must be controlled. In many cases, fire occurs during restoration operations, then all safety precautions should be followed.

Second action in the first phase is identification of combustible materials or object which is connected to prevalence and spread of fire, smoke and toxic gases. The third action in second phase is risk analysis which could be quantitative and qualitative methods. In each building, espescially in historical theaters Exite routes are one of the most important items which should be considered and reviewed because it has a significant role in the safety of people.

These analyses are done using number of occurrence of fire during one year and possible damage in case of fire. By doing all safety actions, the fire occurrence still could be happened. As result emergency action must be considered for safety of people and property which is preventing fire spread to adjacent locations that is second phase of fire risk management. Third phase are actions after occurrence of fire which are quick action to repair damage part and restart routine work and activity. Also in this phase the evaluation of damage for taking insurance action must be done.

4.2 Evaluation of fire risk

4.2.1 Fire hazard in building

Fire risk hazards can be divided into two categories. The first one sources of fire and the other one flammable materials. These two are very basic issues, by controlling these issues, fire can be prevented. And in the next stage, assuming that the fire occurred, we can consider other issues, including escape routes.

Source of fire: distributed material due to spread of smoke, intentional fire, flame or spark caused by work process, the heat caused by fiction, ovens, oil and gas burner equipment, waste incinerator, heaters, matches, lighting equipment, electric current wires and electric devices.

Flammable materials: tints, paint thinner, solvents, glues, liquid gas, available gas in gas transmission lines, wall levels, fabrics, furniture, reactive chemicals, plastics and foams. Building structural components such as channel and chimney, open holes for transmission of pipe and cable. Also wooden components in the wall must be considered as flammable sources.

4.2.2 Fire risk

Risk is property or action which two events or more can happen. The special event which can happen in unknown way and at least one of these events are unwanted. Risk has two aspects. The probability of unpleasant consequence occurrence and the second one, uncertainty, time and magnitude of occurrence [3].

Fire risk is function of many parameters such fire occurrences probability, magnitude and load of fire specification which is amount of flammable materials in area of fire respect to thermal value of them, level of financial and social loss and probability of indirect loss such as the closure of factory. Fire risk can be identified respect to size of building, building type, building geometry and building application [4]. Fire risk evaluation is a systematic process for description and quantifying risk which is related to materials, processes, actions and dangerous event. Risk analysis is consisting of three phases. The first is identification of hazards, the second risk evaluation and third phase risk assessment [3].

4.2.3 Evaluation objectives of fire risk

General purpose of fire risk, making decision background for choosing from two choices which are acceptance of current situation and its risk or make decision to upgrade current situation. The other purpose of risk evaluation is differentiation and separation between important risks and other risks which are not so important. The list of minor goals of risk evaluation are reported as below. The existence of each goal is not proof of absence of the other one and usually choosing the method for safety analysis define each goal [5].

-Estimate the risk size

-Improvement of system by using comparison between risk level and defined criteria

-Make decision to increase status of safety level

-Attract the attention of officials

When the goal is to reduce risk size, two aspects must be considered [6]

-reduce risk up to acceptable level of performance

-reduce risk up to level which is successful

According to these two principle, the risk will be reduced until it will be practical. Lay down the rules and security actions to reduce risks, must be designed in the affordable and also and create acceptance level of risk.

Fire risk evaluation provide technical principles for making decision. One of the useful result of risk analysis, determine the equipment for preventing and protecting fire hazards. The goal of deployment of these equipment is to reduce probability of occurrence of events and identification of necessary action against these events at the time of occurrences. Risk analysis which is applied for fire hazards is a process for estimation of damage caused by fire which combines potential damage in different scenario. Each fire scenario has its unique probability of occurrence [2].

4.2.4 Fire risk assessment methods

There is still no perfect method which can define fire risk assessment, but legitimate and planned program can be used. Fire risk assessment can be applied in different phases [7].

1. Define risks associated with uses of building

2. Define fire risk

3. Fire safety assessment

4. Presenting solution

5. Recorded Findings

Risk analysis can be divided in sevral separated categories which is related to available documents. These methods are reported in below.

1. Qualitative methods

2. Quantitative methods

3. Semi-quantitative methods

4. Scoring methods

4.2.4.1 Qualitative methods

Qualitative methods are used for dangerous events, events are not sorted according to degree of danger. For chemical industries has been created Hazard and Operability Study (HAZOP) and What if Method and check lists. Qualitative methods could be used as screening method in preliminary risk analysis [8].

Qualitative risk assessment method for deployment needs accreditation, but accreditation is difficult and validation rarely happen. The output of such methods not comparable with costs. Main problem and issues of such methods different users lead to different result and it means results are under the influence of functionality of users. Advantage of method are speed and low cost and deployment are easy.

4.2.4.2 Quantitative methods

Quantitative methods of risk analysis being focused into combination of frequency of occurrence and results. In the process of quantitative methods analysis, usually many scenarios with different chain of accidents must be combined. Each scenario has been created by primitive event and for the building chain of accidents may be result of primitive event. For quantitative analysis of fire risk to be used Fault Tree Analysis (FTA). This method of risk assessment is considered behavior of persons and reliability of security systems [9]. The strongest and most extensive part of risk assessment is assessment of quantitative risk. In this type of evaluation, there is a difference between definitive and probable analysis. Definitive analysis is explained the danger and do not pay attention to frequency of events. Probable approach define low risk based on frequency and events. This method is used for risk assessment in the building and Event Tree Analysis (ETA) is extensively used. Possible approach of risk assessment in international standard is accepted for fire safety engineering as process for detecting a fire scenario. Quantitative methods for risk analysis, attain information based on three questions.

1. What can be done wrong?

2. How often does this happen?

3. What is the result of this happening?

Quantitative methods when done completely, it takes a lot of time and money. So this method is not recommended for historical theaters. If these costs are not met, the work has not been done properly and some scenarios and fire probabilities are not considered. This undermines the accuracy of calculations. With the exception of NFPA551, all published fire risk assessment standards emphasize quantitative risk assessment methods [10].

4.2.4.3 Semi-quantitative methods

Semi-quantitative risk assessment methods are used to identify the hazards associated with unwanted events. These methods normally include risk-based methods, scoring methods, numerical classification methods, and so on. Risks are classified according to a rating system. Both frequency and event are considered, the different strategy of designing protective systems is compared by comparing the scores obtained [8]. Semi-quantitative methods are not yet widely used in building design projects. In industrial risk management, this category of risk-based approach is widely used. Methods have been developed to rank and prioritize protective equipment. These methods are also widely used in the inspection of fire protection equipment.

In many situations, when the safety of a fire in a system should be evaluated, there is not enough time and capital to carry out a quantitative evaluation. So there is a need for the use of semi-quantitative assessment tools. Over the years, many efforts have been made to develop risk assessment methods, such as M. GRETENER and various NFPA methods. The M. GRETENER system is based on statistics and information from the Swedish insurance company. Basically, it was first used for industrial applications. NFPA methods are available for different types of buildings. But basically for American buildings [9]. In accordance with the specifications of historical theaters, it is better to use this method and get better results. In Chapter 6, FRAME (semi-quantitative) method has been used to evaluate two case examples

4.2.4.4 Scoring methods

Fire safety scoring methods are designed to determine the overall effect of several factors. In this type of safety assessment, a number or index is presented, which is the index, the sum or result of the points assigned to all the characteristics of a system. This safety assessment system has a very wide use in fire evaluation, also in theaters. The fire propagation characteristics and the overall action reducing effect are expressed as a whole and provide a simple and rapid assessment of the fire safety situation. Safety rating scoring methods are a useful and powerful tool that can provide valuable information about fire risk. This methodology is used in many projects, including risk assessment and fire risk, to reduce the cost of fire safety and to select more appropriate control options, and also use scientific and technical information. These methods are based on an important link between complex scientific principles, including empirical and theoretical models. This methodology is used with different titles, including risk rating method, index system and numerical grading. Initially in the 19th century, these methods began to work as insurance plans. But in the last few decades, their main concept has been seen in many forms. Scoring methods based on empirical and scientific judgments consider a value for a variable, and this amount is allocated to the variable in a combination of computational actions. Finally, a specific value or index is obtained and this value can be compared with the results of other evaluations or with standard values. Fire safety assessment scoring methods are now widely used due to their high ability and relatively easy to use. The assessment of fire safety involves examining a large number of different factors, which is very difficult to assess all of them in a coherent and uniform manner. It is very difficult to analyze these complex systems. But it's not impossible. Risk assessment is a costly and complex process. Scoring is a cost-effective, valid and useful tool for evaluating fire safety [11]. The safety assessment system has been developed for a variety of forms and a range of goals. In order to evaluate fire safety, the rating system is divided into four categories. The first is the M. GRETENER method, which is based on a multivariate model. The second category is the Dow's Fire and Explosion Index, a special industrial method. The next category is the fire safety evaluation system (FSES) and similar models that are part of complementary methods, and do not provide a separate amount or weight of the features of a system. And the final category are methods with theoretical basis in multi-factor decision making models [12]. The M. GRETENER method is developed by an insurance company and is, in fact, an appropriate option for protecting capital. This method is widely used and used in describing risk. The main drawback of scoring methods is that these methods include old information and new techniques are considered less. The effect of the performer's mindset and other things, such as the news of buildings, on the scoring methods is inevitable.

4.3 Comparison of fire risk assessment methods

In Figure 4.2, the main methods of risk assessment are compared in terms of cost and accuracy. As you can see, quality methods require fewer costs to run and easier. But they do not provide accurate results in return. Although the implementation of qualitative methods of risk assessment is possible at a high speed and in the short term, it also does not require a high level of expertise. Instead, the results obtained by these methods are not very precise. Although few methods are very good, but the cost and complexity of their implementation are high and require more time and expertise. According to the figure, when choosing a method, it is necessary to choose a method which, while providing accurate and reliable results of risk assessment, can also be easily implemented and implemented. In fact, when choosing a risk assessment method, the method should be chosen in such a way as to be as close as possible to the ideal point of the chart. An ideal method for risk assessment is a method that generates the most accurate results with the least cost and manpower and in the shortest possible time.

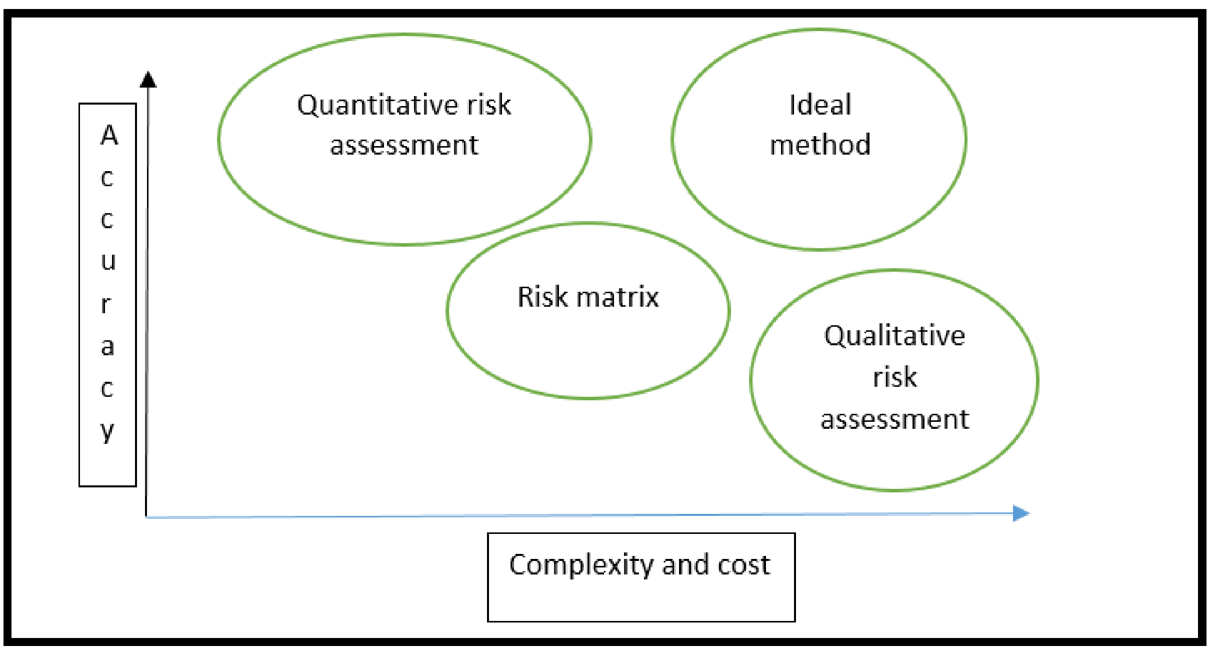

Figure 4.2 Compares risk assessment in terms of complexity or cost with accuracy

It is difficult to assess the risk matrix because of the lack of access to complete and sufficient information. Some of the risk assessment problems include the following:

1. Restrictions on available information

2. Evaluation of the matrix is unstable

3. It is not easy to evaluate the risk-control and control relationship in the matrix

4. Risk change with changing conditions

4.4 Fire Risk Assessment Method for Engineering (FRAME)

4.4.1 Introduction of the method

Fire Risk Assessment Method for Engineering is based on M. GRETENER approach [12]. In this way, past problems have been corrected and, unlike the methodology that calculates the risk of fire only for consumers and their contents, the other two aspects of risk, namely, for individuals and the risk of work interruption, are calculated separately. Fire risk engineering assessment is a risk assessment method that evaluates fire risk calculations separately for three different aspects. These three aspects include the risk to the building and its contents R, the risk to individuals in R1, the risk for the activities performed in the building, which is R2. In this method, different relationships are used to assess the risk of fire. By performing the complex and prolonged calculations described below, the risk level for all three aspects is separately calculated by the general relationship below.

$$R = \frac{P}{A \times D} \quad (4.1)$$

P: Potential Risk

A: Acceptable Risk Level

D: Protection level

To calculate each of these three parameters, quantities and other parameters must be calculated and refined. In this way, the result of calculations, namely, the risk of fire R, is obtained as a single number. Given that safety is relative, this number will always be greater than zero. In the case of this risk, there are two modes: in the first case, the value of R is smaller or equal to one. This means that protection measures and acceptable risk levels are at or above the potential risk. In this case, the risk level is acceptable and in other words, the system is in a satisfactory level in terms of fire safety. It is clear that no matter how much this number moves to zero, the conditions will be better and more favorable. In the second case, if the value of R is greater than 1, then in the present case, the potential risk is higher than the product of multiplication of the protection level and acceptable level. And the safety measures taken are not enough. In this case, the risk is not acceptable. In other words, the site is not safe in terms of safety. The more the risk number is obtained from the number one, the conditions are worse in terms of fire safety.

4.4.2 FRAME accreditation

The basis of FRAME is the experimental relations and extensive expertise of individuals. Testing this method with actual fire tests is not possible. But its credibility can be tested in real-world case studies in the following ways.

A. For a series of buildings, the results of which are obtained by expert individuals, the values calculated in FRAME also show the same results.

B. For a series of fires detailed in the specialized press, the calculated values in the FRAME also show the same weaknesses found in real fires.

C. The influential factors used in FRAME are comparable to those found in international fire laws.

4.4.3 Uses FRAME

4.4.3.1 Achieving the appropriate plans and concepts for fire protection:

The first FRAME help is the user's guide to a balanced concept and design for fire protection. Experienced experts understand the weaknesses that are identified during the calculation, and by searching among these findings, identify the points where improvements can be made and, by performing new calculations, provide a suitable protection plan.

4.4.3.2 Check existing conditions:

FRAME can be used to check the status and use any effort to improve the design. The calculated calculations balance the strengths and weaknesses and indicate how much the current situation is far from the proper condition. FRAME can be used to prove that the fire protection program, which only meets the legal requirements for safety, cannot provide sufficient protection for its building and its activities.

4.4.3.3 Rough estimate:

Experiences have shown that there is a relationship between the calculated risk and the expected damage from a real fire. Therefore, FRAME can be used to define the expected normal loss. In some cases, the damage is higher than the expected loss. Therefore, should be investigated for deliberate fire. In fact, when the difference between what is expected under normal circumstances and the actual damage is high, there are some very possible external factors.

4.4.4 Basic principles of FRAME

1. In buildings that are adequately protected, there is a balance between risk and protection. If the risk and protection are expressed numerically, we can say that the value is equal to each other. The ratio of risk to protection is less than or equal to one. This larger ratio represents a shortage of protection in comparison to risk, and a smaller amount indicates better status.

2. Possible intensity and frequency can be expressed as a result of several influential factors. These factors are two categories. The first group of influential factors expresses the numerical values for the worst case. These values are referred to as potential risk. Which reflect intensity. The second group is a numerical value that measures the acceptability of a fire. The main factor is the possibility of a fire, but the amount of content or discharges and economic importance are also used to determine how the fire risk is tolerable. These issues affect the levels of acceptance.

3. The fire protection level can also be expressed as a combination of values for different protective techniques. These values represent the following elements.

- The most commonly used extinguishing agent

- Design of escape routes

- Fireproof the building

- Fire extinguishers

- Discovery and fire detection methods

- Automatic fire extinguishing systems

- Special and general firefighting groups

- Physical separation of risks

- Escape and Rescue Organization

4. Risk assessment is conducted in a building separately for assets, residents and indoor activities. Thus, three separate calculations are required. This is because the worst consequences of fire for buildings, individuals and activities are different. There is also a difference in the effectiveness of protection.

- The worst consequence of the building and its contents is complete destruction

- For residents, the onset of each fire is a threat and is therefore considered as the worst consequence

- For drone activities that damage anything, it is considered as the worst consequence even without complete destruction.

According to previous statements, the destruction of the entire building is considered to be the worst consequence. All factors affecting the size of the fire are taken into account in the calculation of potential risk. Similarly, all tools used in fire suppression apply to the acceptable level calculation. The level of acceptance depends on the sources of fire, the value of the building and its contents, and the delay in the control of fire, which necessitates the evacuation of the inhabitants.

For starters, starting a fire is initially a threat and the worst consequence. All factors that contribute to the development of fire are considered to be potentially risky. The level of acceptance depends on the sources of fire, the discharge time, and all the factors that cause the fire to escalate faster than the rescue and escape from the risk. The level of protection is calculated with respect to all elements that reduce the discharge rate and reduce the fire spread.

For activities, a fire that puts everything in danger is considered as the worst case even without complete damage. Therefore, the potential risk includes the same factors as for the building other than the load of fire. The acceptable level depends on the sources of fire, the amount of profit and credit, and the degree of dependence of the activities to the location of the fire.

Protection level on protective equipment and equipment that helps to start work again after a fire.

5. A separate calculation of risk and protection should be made for each part. Each fire unit should be used as the base unit for calculations. In buildings with more than one fire section, each part should be reviewed separately.

4.4.5 Balance between risk and protection

The first major idea of FRAME is that there is a balance between risk and protection in buildings that are adequately protected. When both quantities are expressed as a number, we can say that both values should be equal in equilibrium. Although the risk ratio to protection is equal to one. A greater than one indicates a low level of protection measures, and a smaller amount represents better conditions. One can say that there is a balance between risk and protection that the cost of the damage is equal to the cost of the safeguards. Damage caused by fire does not only include damage caused to materials and equipment. It will also cover all costs associated with the incident. Such as economic costs due to people's work and unemployment, cultural costs caused by the loss of unique goods and equipment, moral costs of death and loss of life, the costs of bearing fire consequences, costs Environmental damages, litigation costs, prosecution, loss of product market loss, loss of social value. All of these costs will require a lot of human capital and personnel that will be determined only during the fire and after the fire.

The cost of protection is not limited to additional insurance costs or Firefighting equipment. But also includes the items that follow. The cost of training people, the cost of maintaining systems, checking and testing equipment, designing emergency plans, selecting equipment and equipment, and the cost of financing public fire services, hospitals, police and the costs of water supply. The balance between the risk of fire and protection that is expected in FRAME is consistent with what is found in urban residential buildings made of non-combustible materials.

In these places, it can be expected that the fire is detected in the early stages of the expansion. Firefighters quickly come to restrict incident hazards for part of the building that has been fired. Residents can leave the building before the arrival of the firefighters and return to the place shortly after temporary maintenance and repairs.

The second major idea of FRAME is that the intensity and frequency of risk can be expressed as a result of the effect factor. The first group determines the effect factor of a numerical quantity for the worst case possible, and this number indicates the severity of the effect. Potential risk is called. The second group defines values of numerical values that indicate the amount of fire acceptance. The main factor is the risk of fire. But the contents of the building, the discharge conditions, and economic significance are considered to determine the risk of fire. This value determines the acceptable risk.

The third idea is that the level of fire protection can be expressed as a sum of the combination of different protection methods. These items express the quantity and quality of protection available for a given position. The numerical value is the protection level of the protection.

There may be several parts or sections inside a building. For this reason, the FRAME method considers a single-sectoral unit as the unit of evaluation in the calculation. For Multi-storey building, each floor should be considered separately. For buildings with more than one section, each segment should be considered separately for risk assessment [13].

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Chapter Five; Fire Risk Assessment with FRAME

5.1 The importance of the subject and the objectives of the project

There are three main methods for designing fire safety design, all of which are acceptable by law and vary in detail. These three methods include the following [1].

Standard method: Use of the guide is the proposed template by the rules and regulations.

Fire safety design method: Calculation of indicators below the safety levels. For example, evaluate the risk of escape time.

Risk-based design: design based on risk analysis and quantitative risk assessment.

Studies have been done on the comparison of different design methods and results have been achieved. Regarding design according to the rules and regulations, it can be said that except for cases where good engineering studies have been carried out, fire safety laws in the building are not primarily based on valid scientific data [2]. Therefore, buildings designed and built in accordance with the rules of construction and, in the event of strict implementation of the rules, reflect a level of safety that is only acceptable for consensus [1][2]. In general, it can be said that construction laws only provide at least a level of different aspects of fire safety and, in certain cases, do not have the desired benefit for the building [4]. The correct use of design solutions means the use of a fire safety engineering design approach, and this is only possible based on risk assessment methods [5]. At present, performance-based fire protection design is proposed for large and complex building fire safety. However, in the design of performance-based protection, it is difficult to decide on different design solutions. The overall goal of performance-based design is to minimize risk for individuals and assets. Therefore, in order to make a rational decision among different design solutions, the concept of risk should be considered in the decision-making process [6]. Using fire risk and cost analysis, different fire safety measures are comparable in a small number of conditions. Therefore, a solution that provides an optimal level of fire safety can be found. These methods can be used to design new buildings or to assess the status of existing buildings. Fire risk assessment provides an effective tool for assessing various preventive measures that are used to prevent the occurrence of fire or the evaluation of fire detection and fire extinguishing devices [7].

In this study, we will study the risk of fire in two case studies of the Italian historical theater using the FRAME risk assessment method, which is the most important factor affecting fire safety, and determine the level of risk. . In addition, given the important role of effective rules and regulations for risk reduction in buildings, using the concept of risk assessment, the effectiveness of national fire safety laws and regulations will be evaluated in historical theaters.

Because it is important to pay attention to the efficiency and cost-effectiveness of the measures in the field of safety and the provision of protective measures. In part of the study, using the

FRAME method, we will provide a template for optimizing the selection and enforcement of safeguards. By providing this template, it is possible to prevent actions that increase the level of fire safety in the building, and to select and execute measures according to the characteristics of the building, which will cause the highest reduction in the level of fire risk.

In this study, we use the FRAME Fire risk assessment method, which is a quantitative method for evaluating the risk of fire, to evaluate fire risk. FRAME is the most comprehensive, transparent, and most practical computational method for assessing the risk of fire in the building.

This method is a tool for helping fire engineers to define a suitable and cost effective concept for a new or existing building. In buildings where there is a requirement to ensure safe escape or rescue for residents, FRAME helps protect the building, its contents and its activities. This method can be easily used to assess fire risks in existing situations and to understand whether different designs are functional or not. A systematic assessment of the most influential factors will be given, and the final result will be a set of detailed descriptions of the positive and negative aspects associated with fire risk. Other advantages of this method are accuracy, ability to run in short time and low cost of implementation [8].

5.2 Research objectives

5.2.1 Overall goals

Fire risk assessment using the FRAME method in two Italian historic theaters and optimization of the proposed fire control design pattern.

5.2.2 Proprietary goals

- Determine the potential risk, protection and risk acceptance level of property, individuals and activities separately in each unit

- Determine the level of risk separately for individuals, property and activities in each unit studied

- Determine the efficiency of existing facilities and facilities according to the calculated level of risk

- Identify sensitive and vulnerable areas with estimated risk levels

- Provide appropriate control solutions based on the level of risk and cost

5.2.2 Practical purposes

- Provide a fire safety design pattern commensurate with the location of the assessment
- Provide research background with the approach of providing a fire prevention design modeling software.

5.3 Hypothesis and research questions

1. Is the risk of fire in the tested units acceptable?

2. Are existing fire safety safeguards effective enough to create acceptable risk?

3. Do national fire safety rules for historic theaters have the necessary effectiveness to reduce fire risk to an acceptable level?

4. Is there a suitable model for optimizing the design of fire safety design using the potential risk level available by various protective measures and using the FRAME method?

5. What does the level of fire safety provide for the prediction and full implementation of protective measures in the building?

6. Is the fire insurance tariff set for the building appropriate for potential damage and risk level?

5.4 Definitions of the main concepts

Risk: A physical condition or condition with potential damage, such as damage to life, body organs or capital

Danger: The potential for unwanted release due to appropriate scenario and frequency and its consequences.

Risk Quality Assessment: A limited assessment to identify hazards that includes a detailed description of hazards or a checklist.

Quantitative risk assessment: Risk assessment with a clear estimate of the probability of occurrence and consequence of a series of scenarios.

Semi-quantitative assessment: Risk assessment, limited to information ranked.

Risk assessment: Determining whether the calculated risk is within acceptable limits?

Fire risk assessment: A well-defined process for estimating and evaluating fire risk, which identifies the appropriate fire scenarios and their probabilities and their outcomes.

The overall goal of fire safety: is the favorable results of the functioning of the immune system, expressed in terms of qualitative terms.

Particular objective of fire safety: A fire building requirement, system, or occupants that is required to achieve the overall safety goal. Objectives are part of overall goals. Generally, minor goals are a series of operations that are more likely to address general objectives.

Fire safety design based on efficiency: an engineering approach for designing fire protection based on general and partial fire safety objectives, the probable and definite analysis of fire scenarios, quantitative assessment of different design based on the general and specific objectives of fire safety using the engineering tools.

ALARP: A threshold for accepting risk-based risk reduction to a level of decline that is technically feasible. It is also cost effective.

Building specification: Description except for buildings such as layout, access and exit paths, type of building and materials, contents and joinery, building structures, fire safety systems and their characteristics, which are typically based on the design characteristics in a suitable form and sufficient for use with a fire scenario to estimate the scenario's outcomes for the desired building.

5.5 Studies on the development of the FRAME method

In the early sixties, a Swiss engineer, Gritner, presented a method for assessing the risk of fire in buildings. In 1975, a design engineer named Smith employed the aforementioned method for design purposes and worked on it completely, and saw defects that could be improved.

The main drawback of the Gritner method was the use of tables for multiple parameters. Initially, he did not have full tables and after several tests he concluded that the tables did not have the proper function as an engineering method. In some cases, the evaluation process was very long and provided different results for assessing a situation by different people. So Smith began to correct the method. Many tables were replaced by formulas to calculate the parameters, and the factors that caused differences in the various studies were reviewed. Using formulas instead of tables allows you to do the job with a programmable calculator, making things much easier.

In the late seventies, Sarat and Cluzel in France offered a different type of Gritner approach for safety. Their method was called ERIC. Their work contributed greatly to the development and presentation of the second part of the FRAME. In 1980, the second model of the Gritner model was published by a Swiss organization. In this way, attention was paid to two aspects of fire risk for assets and individuals.

In 1983, Smith was seen as a third aspect of fire damage that was a work-related or economic break-up caused by fire. Therefore, he presented the third part of the FRAME method in the sections on asset safety and individuals. This was the first model of the FRAME method, which gave three aspects of fire safety. FRAME is the developed method that the Swiss engineer proposed for the first time. This method is similar to the German DIN 18230 and the Australian TRBV100, the insurance evaluation system, and the traditional ERIC approach in France.

In the year after using the FRAME method, only a small amount of changes was necessary to improve the FRAME against the knowledge of 2000. Over the past years, it has become clear that FRAME can be used as a proven method in the design of a fire suppression system implemented.

In the early version of FRAME, at the level of time required to evacuate, there was a lack of compliance with legal requirements. The 1985 FRAME version did not specify the requirements for multiple outputs, and only indirectly focused on the discharge time from the output paths. The discharge time was also considered insignificant for many very busy places, so that the effect of population density was not adequately evaluated. In addition, during the 1990s, the legal requirements for rescue routes, after a fire detection, take up to 300 seconds to reach a safe area. Moreover, it should be taken into account that if people were not informed at an early stage of fire, it would be too late to discharge the site in order to be safe from fire. This problem could be aggravated in homes for the elderly, in hotels and other similar residential areas. All these points made the FRAME version 2000 a new formula for calculating the drain time factor.

Gritner's approach was first introduced to assess fire risk. Some reports of fires that had low financial losses but high mortality rates required a similar approach to fire safety. The inferiority or interruption of the third aspect is the risk of fire. Follows the same argument for financial and financial safety in FRAME.

FRAME is the most comprehensive, transparent and practical computational method for assessing the risk of fire in buildings. This method is a tool for helping fire protection engineering to provide a meaningful and cost-effective concept for new or existing buildings. In buildings where there is a requirement to ensure safe escape or rescue for residents. FRAME helps protect the building, its contents and its actions. This method can be easily used to assess fire risks in existing situations and to understand whether different designs are functional or not.

As mentioned, FRAME calculates the risk of fire in buildings for the assets and contents of the building as well as for individuals and indoor activities. A systematic assessment of the most influential factors is presented. The final result will be a set of detailed descriptions of the positive and negative aspects associated with fire risk. It should be recalled that this method is not suitable for risk assessment in open air facilities [9].

5.6 Fire risk assessment studies using FRAME

According to studies conducted in Iran's domestic research centers, there was no case of fire risk assessment using the FRAME method. Over the past twenty years, dozens of fire risk assessment has been carried out using FRAME in the world. These studies have been conducted to examine the fire safety of buildings with different uses as well as the evaluation of the effectiveness of fire protection systems. Studies in various industries have been carried out such as the wood industry, knitting industry, electronics, dye industry and food industry. Also, in non-industrial buildings, various studies have been carried out using FRAME. Part of these studies have been conducted on fires that actually happened. After the incident, the FRAME calculations and the risk of the incident site were estimated for the location before the fire occurred, using the information reported in authoritative journals such as the NFPA journal and the ANPI and Fire prevention, which provide accurate information about the incidents. None of these studies reveals a discrepancy between the level of risk calculated and the actual events occurring. These studies, on the other hand, are also used to validate the FRAME method. The main reason for doing these calculations for events is that if the calculations are confirmed by reality, can this method provide sufficient warning about the high risk before the occurrence of fire and whether sufficient protection is assumed to be is there or not?

Only a small number of reports show that protective measures have been taken. Most of the reports presented in these documents have been disastrous. The unfortunate results have been predicted by the FRAME evaluation method, and FRAME calculations are consistent with the results of the fire [10].

FRAME computation results				Information on fire			
Risk of activity R2	Risk of people R1	Risk Capital R	Damage to millions of dollars	Human casualties		Year of occurrence	Fire
				Injured	Death		
8.35	4.67	7.93	6 to 8	0	97	1986	DuPont plaza Hotel
1.30	2.01	2.55	200 to 600	77	12	1996	Düsseldorf airport
2.79	2.04	2.7	15	6	0	1997	American Pennsylvania Theater Hall
1.38	3.5	2.48	Great destruction	12	16	2003	Hartford Hospital

Table 5.1 Evaluation results using the FRAME method in real fire reports

5.7 Studies on fire safety design in buildings

So far, many studies have been carried out to create risk assessment and fire risk models for people in buildings. Many of these models are based on expected risks for individuals and fire costs. Also, these models have been used to create more effective safety rules. This model takes into account the risks, the growth and spread of fire, the spread of smoke, evacuation of people and other things in order to anticipate the expected risks for individuals.

To support the creation of effective fire safety laws in Canada, the National Research Association of Canada has developed a computerized risk assessment and fire risk assessment model. This model can evaluate the expected fire risk for people with the cost of protection and fire damage in a building. This is the FIRECAM model, and so far, there have been many studies on it [11]. In 2006, Noureddine Benicho used the FIRECAM model in a 40-storey building to choose the most effective and cost effective fire safety options for that building [12]. In another study, this model was used in 8-story building in Canada to illustrate the performance of this model in demonstrating the effectiveness of various fire safety design options [13].

In 2008, Cho et al conducted a study in which they provided a framework for deciding two different methods of fire safety based on risk assessment. In this study, Error tree analysis method was used to evaluate the risk of fire. Factors like evacuation of people, growth and development of fire are considered. In this study, different possible fire contingency scenarios with the effect of fire protection systems and employees' control functions were analyzed. The exact assessment of the probability and outcome of different fire scenarios is difficult to do, but it can be detected based on the statistics of the upper and lower extremes. Hence, in this study, a decision theory, along with risk assessment, has been used to decide on different fire safety design approaches. In this study, two types of fire safety design for a commercial building were also investigated in order to determine how different types of decisions would be made [6].

In 1998, R. Jonsson and J. Lundin conducted a study on comparing the design of fire safety design in high-rise buildings. In this study, a number of different fire safety design methods have been compared to determine which solution is at the lowest risk with regard to cost. One of the most important results of this research was to determine the right choice of design solutions based on risk assessment methods [5].

In 1997, Bovercet concluded that the failure to use safety engineering techniques could lead to unsafe buildings. He clearly demonstrated the utility of a risk-based design approach as a complementary method for designing fire safety engineering. The Department of Fire Safety Engineering at Lund University has conducted extensive research on fire and risk. One of these research projects was Fire Safety Design Based on Calculation, with the aim of creating an accident tree model and analyzing the risk of fire in the building. This model has two applications: one can check the performance of the building in an acceptable risk, and the other to take protective measures at the lowest cost to achieve acceptable risk [14].

In 1992, G. V. Hadjisophocleous and D. Yung carried out an investigation into the risk assessment and protection costs in the apartment. The researchers presented a model for demonstrating the dynamic interaction between human behavior and the development of fire in high-rise apartments. The effects of smoke and fire spread on the relationships between two effective parameters are presented. The expected risk for the ERL's life and the expected cost of FCE fire.

These parameters are used to determine the cost-effectiveness of protective measures in apartments. This model can be used as a tool to evaluate whether different safety designs provide equality? And are designs affordable? For example, this model was used in a 28-storey apartment to evaluate the cost-effectiveness of 9 different types of design of a warning system and sprinkler systems [2].

In 1989 at the University of Sydney, Australia, a research project was conducted by a team of engineers and researchers. Has led to a widespread development of fire safety in Australia. In that project, it became clear that fire safety and protection activities that were carried out in accordance with current legal requirements in Australia constitute an important part of construction costs. The results of the research showed that by developing systematic design methods for designing a fire protection and fire protection system based on risk assessment and fire engineering design techniques, achieving a satisfactory and acceptable level of fire safety can be greatly enhanced in save costs [17].

5.8 Early steps to assess risk using the FRAME method

5.8.1 Building division into study units

As mentioned in the risk management steps, the first part of the risk assessment process is to evaluate the system and obtain the information required by the system for carrying out the risk assessment process. In order to assess the risk of fire by the FRAME method in a complex structure building consisting of different units and departments with different uses. First, the study units should be identified for evaluation. In the sense that, considering the structural and user characteristics of different parts of the building, the fire risk engineering assessment activities should be carried out separately for different sectors. In the division of the building into the study units, the following points should be considered and, depending on the cases, the units should be identified [9].

1. Unit position examined in terms of altitude from the ground: Each floor or half floor of the building should be separately evaluated. Units with different levels of surface cannot be considered as a fire section in terms of accuracy.

2. Infiltration into the outside environment: To the extent possible, the classification and selection of the study unit should be such that the possibility of fire penetration into neighboring units is as low as possible. The partitioning is in such a way that, as far as possible, the external walls of the selected unit, as well as the means of communication to the adjacent section, have sufficient fire resistance and prevent fire penetration.

3. Use of the building and the type of activity carried out in the unit: To the extent possible and with the consideration of the previous cases, the evaluation unit should be chosen in such a way that all of them have the same usage.

4. Characteristics of people in the units studied: The different sections of the building that people have in terms of mobility, as well as in terms of perception and feeling are different, should be examined separately.

In this study, two case studies of the historical theater in the city of Florence, Italy, were evaluated only one compartment. This compartment includes parts of the auditorium, stage and boxes. Considering the cases mentioned in this study, they were considered as one compartment in the FRAME method.

5.8.2 Provide checklist for collecting information

In the assessment of fire risk engineering, much information is needed from the site to be evaluated. Finally, these data and information are combined to calculate the risk level for each unit. Due to the large number of information needed to assess fire risk, a checklist was developed to accelerate work, categorize and systematize information and parameters collected. This checklist is provided with all the information required in the FRAME Executive Order. The ordering of questions is also in accordance with the progress of the risk assessment process from the beginning to the end of the work and reaching the level of risk. The checklist contains 55 questions. The first six questions relate to general information about a construction site that is evaluated in whole or in part. In the following checklist, questions are needed to evaluate the risk of fire risk engineering.

5.8.3 Data collection

In the risk assessment methodology, the first step is to carry out a risk assessment, a comprehensive understanding of the building or units to be evaluated, and to collect the information required for the next steps. Data collection was carried out in presence of study units using checklists. At this stage, according to the type of information needed to assess the risk through observation, interviews with individuals and authorities concerned, or reference to the documents, the information was collected. In general, this information includes structural data of buildings, electrical systems, firefighting systems and water, electricity and gas installations, number of personnel employed in different sectors and their type of activity, and other items that are listed in the checklist.

5.8.4 Preparing the computational package in Excel

The FRAME bundle in Excel was provided by correspondence at http://www.framemethod.net. During this study, using this package, two historical theaters were studied in Florence.

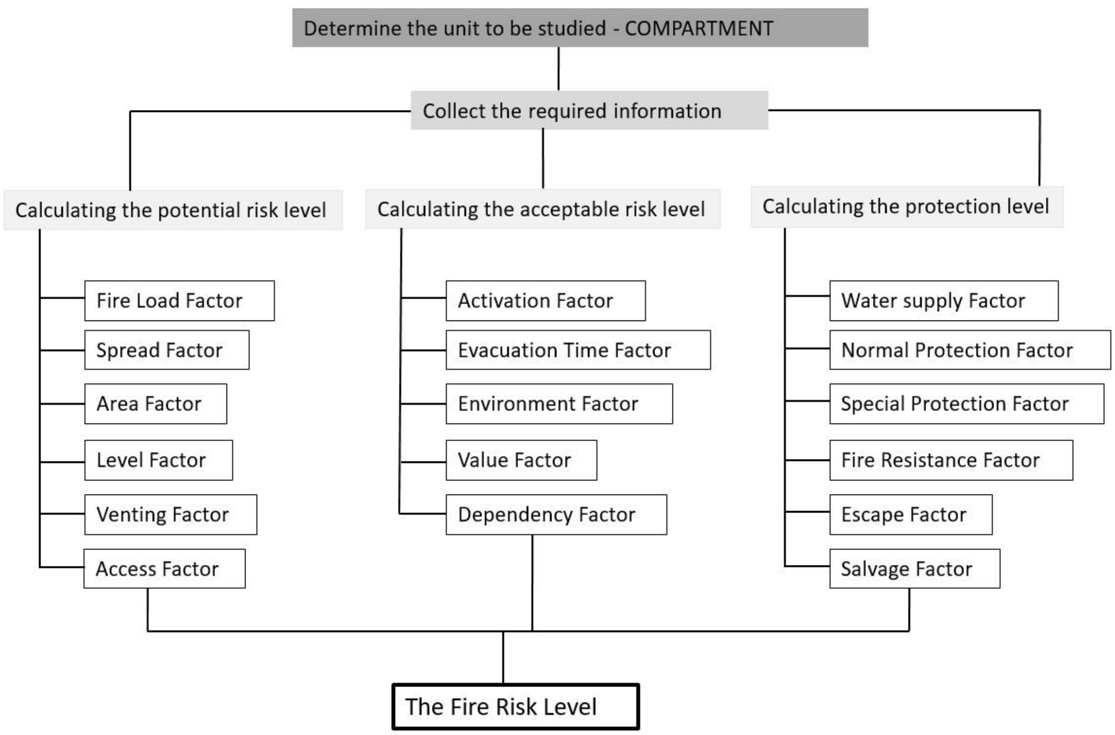

Figure 5. 1 Risk assessment steps in the FRAME method (writer)

5.9 Calculate the potential risk in each unit

In the design of the fire risk assessment, for the calculation of the risk level, the three main parameters of potential risk P, acceptance level and protection level D are required. The first part of this relationship is potential risk, which will be further explained in the calculation. The potential risk for building and its contents P, potential P1 risk for individuals, as well as P2, is the potential risk for activities through the following relationships and with regard to the factors listed below.

$P = q \times i \times g \times e \times v \times z$ **(5.1)**

$P1 = q \times i \times e \times v \times z$ **(5.2)**

$P2 = g \times i \times e \times v \times z$ **(5.3)**

q: Fire load factor

i: Fire spread factor

g: Area factor

e: Level factor

v: Venting factor

z: Access factor

All of these values are non-unit quantities.

5.9.1 Fire load factor calculation

The fire load factor determines how much the combustion per unit area, i.e. square meter, exists. There are a lot of burning materials in the building, some of which generate a lot of heat, and some have a low combustion capacity. To estimate all of these materials at a level, it is assumed that each of these materials burns up to full ash and the energy produced is measured to the extent that it covers the whole area of the fire. This energy represents a firefight expressed in mega joule units per square meter. The fire load of the building includes the fire of the building itself, such as the structure, the wooden parts and the insulation materials and the fire caused by the contents of the building, such as stored goods, machinery and temporary walls. In total, the fire is the result of two fire types.

- **Immobile fire Qi** load caused by building components.

- **Mobile fire load Qm** that is specified by the type of user and caused by the equipment.

In theory, in order to obtain a fire, a list of all combustible materials present in the site, together with the specific heat value, must be provided. Calculates the total thermal load that is released from them and divides the resulting amount into the total surface area of the space. The distinction between building fire and its contents will help us estimate the fire load of the building. Regarding the type of building, in terms of structural components, it is possible to estimate the amount of combustible materials in the building and therefore immobile fire loads reasonably. The tables below show typical value for immobile and mobile fire load of the building according to the type of building.

Typical values for Qi	MJ/m2
A. Totally noncombustible construction (e.g. concrete / steel only)	0
B. Non-combustible construction, with max. 10% allowance for combustible	100

construction elements as windows, roof covering, etc.	
C1. Wooden structure with noncombustible covering	300
C2. Fire resistive construction with wooden floors	300
D. Only the structural elements are non-combustible	1000
E. Combustible construction	1500

Table 5.2 Typical values for immobile fire load Qi

Typical values for Qm	MJ/m2	Range
a. Low fire hazard (LH or light hazard) occupancies	200	
a1. Offices	400	80 - 550
a2. Dwellings	500	330 – 780
a3. Schools	200	215 – 340
a4. Hospitals	250	100 – 330
a5. Hotels	250	310 - 330

Table 5.3 Typical values for mobile fire load Qm

After extracting the mobile and immobile loads of fire from the above tables, the fire load factor is calculated by the following interface.

$q = \frac{2}{3} \times \log(Qi + Qm) - 0.55$ (**5.4**)

q= Fire load factor

Qi= immobile fire Mega Jules per square meter

Qm= mobile fire Mega Jules per square meter

5.9.2 Fire spread factor calculation

The fire spread factor determines how easily the fire can expand inside the building. This quantity is calculated according to the average dimensions of the contents of the building, the flame expansion class, and the temperature of the material and equipment degradation. Each of these parameters is calculated according to the following steps.

5.9.2.1 Average dimension (m)

Essentially, smaller objects burn more easily. In fact, smaller objects have a larger surface area than mass. A piece of hardwood, a much less surface than a sawdust. Therefore, in order to determine how much flammable surface in a combustible substance, there must be a ratio between total volume and total surface of the object. This ratio is expressed as the average dimensions of the building's contents. For a dimension of up to one meter, this factor is small and larger for smaller objects.

The average building contents are then displayed with m and reflects the total ratio between the volume and the surface of the contents of the building. In order to calculate the value of m, it is necessary to estimate the size (length, width, height, or thickness) of the existing objects and obtain the mean dimensions through it. The value of m is expressed on the meter scale.

The size of the average dimension can be obtained according to the following scale.

1. the most commonly used value for m is 0.3 meters, and this is the size of most of the objects that exist alongside us every day.

2. For goods stored in pallets, the average dimension is 1 meter.

3. For small industrial production, where smaller objects are produced or assembled. The average dimension is 0.1 meters.

4. For industrial production, in the form of thin and small sheets and also in dust collecting areas, the average dimension is 0.01 meters.

5. For the location of grains, particles and bodies of very small dimensions, the dimensions are 0.001.

5.9.2.2 Flame Propagation class (M)

Some materials help to expose the fire much more quickly and do not burn any other material at all. Many experiments have been carried out to determine the flame spread in various materials. Make a category like that in the table below. In this category for places with a combination of different materials, the average of two values is also acceptable. The fire spread class is represented by the letter M, and the quantity is unaltered.

Classification	M value
A1 per EN13501-1 or Incombustible	0
A2 per EN13501-1or Nearly incombustible	0.5
B per EN13501 or EN12845 Cat. I : Difficult to ignite (self-extinguishing)	1
C per EN13501-1 : Slow burning materials	2
D per EN13501 or EN12845 Cat. II: Combustible surfaces	3
E per EN13501-1 or EN12845 Cat. III Flammable surfaces	4
F. EN12845 Cat. IV : Highly flammable surfaces	5

Table 5.4 Flame Propagation class (M) [9]

Note: For non-uniform environments such as inventories, a class average of 2.5 can be considered.

5.9.2.3 Destruction Temperature (T)

Basically, although some of the materials are not combustible, fire can have an adverse effect on them. For most materials, you can determine the temperature at which the temperature of the material's degradation begins. This degradation temperature is used as the third parameter in calculating the fire spread factor.

Inflammable liquids	20 °C (70°F)
Human beings, plastics, electronics	100 °C (212 °F)
Textiles, wood, paper, food	200 °C (+/- 400°F)
Average content of residential buildings	250 °C (482 °F)
Machinery, household appliances	300 °C (572°F)
Metals	400 °C (752°F)
Noncombustible construction materials	500 °C (932°F)

Table 5.5 Recommended Values for T, the destruction temperature [9]

The fire spread factor can now be calculated by these three variables from the following equation.

$i = \left(1 - \frac{T}{1000}\right) - (0.11logm) + \frac{M}{10}$ **(5.5)**

i: Spread fire factor (Without unit)

T: Destruction Temperature (Centigrade)

m: Average Dimension (meter)

M: Flame Propagation class (Without unit)

5.9.3 Area Factor

The level factor determines the horizontal effect of the fire, which can be extended to the entire building if it does not obstruct it effectively or fire cannot be fired. A surface barrier, such as a wall, is considered to have sufficient resistance to fire effects. These barriers should meet the following requirements:

- All wall structures, doors must also comply with ISO843 for at least two hours fire.

- The wall should be so constructed that fire cannot spread around its sides and its edges.

- The wall should be constructed so that if the building collapses in the fire area, it will not be destroyed.

The surface factor is obtained using the theoretical length parameters of the evaluated section L, the width of the equivalent of the evaluated section b. The theoretical length is equal to the maximum distance from the center of the section to the two sides and the unit is the meter. The width of the equivalent section of the evaluation is equal to the division of the area of the section into its theoretical length.

$g = \frac{5\times(\sqrt[3]{(b^2\times L)})}{200}$ (**5.6**)

g: Area Factor (Without unit)

b: Equivalent Width (meter)

L: Theoretical length (meter)

5.9.4 Level Factor

The height factor determines the vertical fire effect. The effect of fire upwards, including smoke and heat, downstream, includes heat, water risk and building collapse. To check the fire effect that is far from the access level. Appropriate work is needed. It is rational that floor numbers are considered as a numerical criterion for the assessment of the risk of fire in areas beyond reach.

The height factor e is calculated by considering the floor number E and using the following formula.

$e = \left[\frac{|E|+3}{|E|+2}\right]^{(0.7\times|E|)}$ (**5.7**)

e: Level factor (without unit)

E: Floor number

In this formula, | E | It means absolute value. To specify E, the number of all classes is indicated as follows. For the main access level, E is equal to zero. For classes above the level of access, the value of E is 1, 2, 3, and the last. For classes below the level of access, the value of E is -1, -2, and -3, and to the last. For a ramp-based building, there may be more than one level of access to the surface. In these cases, more than one level can be zero. But underground will still have a negative value and classes with a positive amount for E will be.

This formula can also have decimal numbers, for example, when a half-floor is between classes, an additional amount can be considered with the main floor number. That excess amount of a decimal will be summed up with the original value of that level.

The formula shows the reverse effect by increasing the distance of the desired level from the access level. That is, with a large increase in the distance from the desired level, the amount of access is reduced to a factor of height. The height factor for the access level is equal to one. The figure for the fifth floor is 1.6, on the first floor to 1.75 and for the 200th floor, a building is equal to 2.

5.9.5 Venting Factor

The ventilation factor indicates the effects of smoke and heat inside the building. Each fire generates a large amount of gases that remain under the ceiling of the building as a layer of smoke. This smoke can put the building and its contents in jeopardy and a major threat to the residents of the building and firefighters. It is obvious that any building can quickly be filled with smoke unless the smoke is released somehow from that space. The fire itself will help smoke out. Due to the gases generated by fire, the pressure inside the room goes up and causes the glass to break, the burning of plastic and combustible walls, and smoke is released. Some buildings are also equipped with static and dynamic ventilation systems. All of this creates a "level of release" of smoke. This level includes the aerodynamic level of all open spaces that smoke can escape. The venting factor compares the ventilation capacity with the power of the source of smoke production. The venting factor is calculated using the following formula:

$v = 0.84 + (0.1 \times logQm) - \sqrt{K \times \sqrt{h}}$ **(5.8)**

v**:** Venting factor (without unit)

Qm: Mobile fire load (MJ/m2)

h: Floor to ceiling (m)

K: Ventilation ratio (without unit)

For spaces with sloping floors or slopes, the height between the floor and floor ceiling is used for height. The higher the height makes the thickness of the smoke layer rise without falling to the bottom of the space. For buildings with a dropped ceiling, if the dropped ceiling has sufficient fire resistance, the height is considered to be below the dropped ceiling. Otherwise, the height to the main ceiling should be considered. The third factor K is the smoke ventilation ratio. This value reflects the ratio of the size of the open hole to the entire surface of the floor of the space where smoke can be removed.

Calculate the K value according to the following steps.

1. The size of all windows and glass and plastic skylights on the ceiling and one third of the outer walls are obtained per square meter.

2. If there is an aerodynamic surface value, the static ventilation of the smoke is added to the above amount.

3. For each 10,000 cubic meters per hour of mechanical ventilation, one square meter is added to the higher values.

4. Divide the amount obtained from the previous steps into the total surface area and obtain the K or Ventilation ratio.

Noticeable points in calculations related to K:

- In the case of open space on the walls, it can be said that the holes that are located in the lower third of the walls will affect the fresh air entering the building, the middle third of the wall is a neutral zone, and open holes in one Third on the top, causing smoke to come out.

Double-glazed and reinforced glass and other similar hard materials that may be used, due to the fact that they do not break easily from the fire, should not be calculated in the measurement of the levels.

- The basin ventilation factor is zero.

5.9.6 Access Factor

The access factor can be used to provide external assistance to the fire area and is calculated using the formula given below.

$z = 1 + 0.05 \times INT\left[\frac{b}{20\times Z} + \frac{H^{+}}{25}\ or\ \frac{H^{-}}{3}\right]$ **(5.9)**

z: Access Factor (without unit)

INT: Rounds the inside of the bracket to a minimum

Z: The number of individual paths that allow access to space.

b: Equivalent Width (meter)

H^+: Vertical distance of access level to the floor of the desired space (m)

H^-: The vertical distance of access to the floor of the basement (m)

First, the space around the building is checked. Is there a free access for firefighters from all sides of the building? For the construction of a map, the north direction is placed on the main entrance side and the south, east, and west directions are considered for free access. The number of hot spots available for free access is considered as the access path, and is equal to one of the values 1, 2, 3 and 4. In the next step, the equivalent width is considered as the distance the firefighters must go through to reach the building.

The last step is to check that the direction of the firefighters is up or down. When it is forced to move upwards, $H^+$is considered to be the value of the vertical distance of the access level to the floor of the desired space. When the direction is downward, $H^-$is considered to be the vertical distance of the access surface to the floor. Because firefighting in the underground is much more difficult than the upper levels of the earth, the formula is predicted to be greater for underground floors.

5.10 Determine acceptance level for each unit

The acceptance level determines the fact that people can live in that location, despite a certain level of fire hazard in a location. The formula for acceptance is as follows:

Risk Acceptance Level for Building and Content A.

$A = 1.6 - a - t - c$ **(5.10)**

Risk Acceptance Level for residents A1.

$A_1 = 1.6 - a - t - r$ **(5.11)**

Risk Acceptance Level for activity A2.

$A_2 = 1.6 - a - c - d$ **(5.12)**

a: Activation Factor

t: Evacuation Time Factor

r: Environment Factor

c: Value Factor

d: Dependency Factor

Note: All quantities above are dimensionless quantities.

In these formulas, a maximum value of 1.6 is considered for the acceptance level, which is adjusted by various factors. Activation Factor as correction for frequency, value factor c as correction for financial loss, Evacuation Factor and Environment Factor as a correction for the severity of the damage and factor dependence, as corrective for the severity of the work interruption. All the factors used are 1.6. Start level 1.6 is derived from a comparison of the potential low risk with available public protection levels. This value expresses the possibility of fire caused by natural factors such as lighting, human error, and deficiencies in normal working systems [9].

5.10.1 Activation Factor a

A traditional way to show fire hazard is to refer to the fire triangle. This triangle states that fire requires three factors: oxygen, fuel, and an ignition source. Usually, oxygen and fuel are readily available. Therefore, the presence or absence of an ignition source must be checked. In search of a source of ignition, 5 groups are considered as follows.

The most important group of flammable sources is the context of people's behavior and activities. Two groups of main and secondary activities can be identified. The main activities are those that are performed in a typical and conventional building. Activities include industrial work, material storage, commerce, homework, education, and so on. Sub activities are those that add a different risk. The warehouse of materials can be considered as a subsidiary business. Welding, cooking, or using a flammable liquid for painting can all be part of a minor activity if it is out of normal condition.

5.10.1.1 Main activity

Many laws and regulations already provide some classifications for major activities that are classified as hazardous. Many of them pay attention to the presence of combustible materials and flammable sources, and some categories are used to design Sprinkler system. However, in general, one of the following types of activities is done in each location:

1. A combination of low fire load and low flammable sources

2. Combination of low fire load and average number of flammable sources, such as non-flammable industries.

3. Combination of moderate fire load and average number of flammable sources, such as a large number of industries

4. Combination of high fire load and average number of flammable materials, such as wood and paper industry

5. A combination of high fire load and a small number of flammable sources, such as storage

6. Combination of high fire loads and a large number of flammable sources (unlikely mode)

This category of main activities expresses the value of a1 as the first part of the activation factor. The values for the types of activities listed above are given in the table below.

Fire source : Main activities	a1
A1. Low fire load and a low number of ignition sources (residential, Offices, etc.)	0
A2. Low fire load and a moderate number of ignition sources (Industry of noncombustible products)	0
B. Moderate fire load and a moderate number of ignition sources (Most industries, large stores, retail shops)	0.2
C. High fire load and a moderate number of ignition sources : Industry of combustible products such as paper, wood, petrochemicals	0.4
D. High fire load and a low number of ignition sources (warehouses and similar storage)	0

Table 5.6 main activity list to define a1 [9]

5.10.1.2 Subsidiary activities

Sub-activities that are important in risk calculations and include items such as spark, hot surfaces, frictional heat, or high flammability. These activities are considered as additional risks for where they are not normally performed. For example, welding in a repair shop is not considered as a subsidiary activity, but a sub-activity is considered in a carpet shop. Subcategory categorization defines the value of a2 as the second part of the activation factor. The amount of points given for the types of sub-activities is presented in the table below.

Fire source : secondary activities	a2
F. Secondary welding operations	0.1
G. Additional woodworking or use of plastics	0.1
H. Painting or coating with flammable products	
H1. In a separated, well ventilated room	0.05
H2. In a separated space without additional ventilation	0.1
H3. without separation	0.2
I. Special hazards (e.g. non controllable smokers)	0.1

Table 5.7 the secondary activity list [9]

5.10.1.3 Thermal systems

The third most famous firefighting group is fire. In this section, both types of heat from the work process and heat of the building heating system are considered. Steam and hot water systems have no special hazards unless the heat exchanger is located inside the space and is not in a separate space. Fuel is very important and materials such as coal and oil are less dangerous than gas and waste. Systems that use flammable liquids are more dangerous than water-based ones. Air circulation systems are also very dangerous because they accumulate dust and oil and transfer smoke and burning particles from place to place. The electrical thermal systems are usually dependent on working with a thermoset, which, in case of failure, will be a thermal system as a source of fire. The most dangerous thermal systems are those that are very hot with open flames or radiation levels. The effect of the heating system is applied by the amount of a2 and is the third part to calculate the activation factor.

Fire source : Process and room heating systems	a3
No heating present	0
Heat transfer through water, steam, or solids	0
Heat transfer through pulsed air or through oil	0.05
Heat generator in a separate room	0
Heat generator in the compartment itself	0.1
Energy source: electricity, coal, fuel oil	0
Energy source: gas	0.1
Energy source: wood or waste materials	0.15

Table 5.8 Typical values for calculating a3 [9]

Note: Points in steps 1, 2 and 3 in the table should be combined.

5.10.1.4 Electrical Installations

The fourth group of flammable sources is electrical systems. In many cases where the source of fire is unknown, electricity is the main cause of the fire. Indeed, electricity is a high energy source that can trigger fire. An electrical system that is built according to regulations and regularly inspected by a skilled person will not be considered a fire source. A system that is not being inspected can be dangerous due to depreciation, abnormal use and changes in it. A system that is not in accordance with the rules is a fire hazard indicator. The classification of electrical systems determines the amount of a4 as the fourth factor of activity.

Fire source : Electrical Installations	a4
Electrical installation in compliance with the rules and regularly checked	0
In compliance with the rules without regular checks	0.1
Not according the rules	0.2

Table 5.9 The classification of the electrical system will define a4 [9]

5.10.1.5 Dust, gases and flammable liquids

The last group of fire sources is the use of liquids, gases, and the production of flammable dust. These products are considered to be sources of fire because they can cause fire due to an energy such as a spark or hot surface. For hazardous areas, one category can be used, and in this regard four types of region can be categorized.

- Use or store flammable goods in such a way that the explosive mixture is continuously in the air.

- Use or storage of flammable material in a form that is explosive in explosive atmospheres under normal operating conditions.

- Use or storage of flammable material in a form that has an explosive mixture in unusual conditions.

- The use or storage of flammable goods is accidental and limited in such a way that the presence of explosive mixtures in the air is unlikely.

According to this classification, for a given space, a5 is specified and used in the calculation of factor a.

Fire Source : Flammable gases, liquids and dusts	a5
Permanent explosion risk ATEX zone 0;	0.3
Explosion risk under normal operating conditions	0.2
ATEX zone 1 NEC : Class I Div.1 Occasional explosion risk ATEX : zone 2; NEC : Class I Div.2	0.1
Dust explosion hazard ATEX zone 20/21/22 ; NEC : Class II	0.2
Production of combustible dusts without extraction	0.1

Table 5.10 The classification of hazardous areas [9]

The sum of the values a1 to a5 gives the activation factor.

$a = \sum_{i=1}^{5} a_i$ **(5.13)**

In calculating the activity factor, it is necessary to pay attention to the following points.

- High-risk activities may create an additional activity factor.

- Subsidiary activities are considered only when they create an additional source of fire as compared to the main activity.

Sub-operations that are effective in computing are those that cause sparks, hot surfaces, frictional heat and highly flammable products.

- Thermal conductors and electric radiators are considered as heat generators. Also, heaters and similar devices are from this category.

5.10.2 Evacuation Time Factor t

One of the most important points in the safety of people in a building is the time needed to evacuate people from the area of the fire. For this purpose, in the assessment of fire risk for individuals and building, the evacuation time factor is calculated and considered. The following equation is used to calculate the discharge time factor.

$t = \frac{p \times x[(b+L)+\left(\frac{X}{x}\right)+(1.25 \times H^{+})+(2 \times H^{-})] \times (b+L)}{800 \times k \times [1.4 \times x \times (b+L)-(0.44 \times X)]}$ **(5.14)**

X: Number of inhabitants

L: Theoretical length (m)

b: Equivalent Width (m)

H^{+}: The floor space of the unit to the ground level for the upper floors (m)

H^{-}: The floor space of the unit to the ground level for the lower floors of the earth (m)

p: Mobility factor (without unit)

x: Number of output units

k: Number of separate exit directions

Note: Two exit directions are considered to be distinct if they are at least 90 degrees apart.

The mobility factor is a correction for people who are slowly evacuating. This factor corrects space discharge time for people with low mobility. Depending on the type and conditions of individuals in units, the amount of mobility factor is extracted from the table below.

The mobility factor	
A. Mobile and independent persons (adults, workers)	1
B. Mobile persons needing guidance (pupils, visitors)	2
C. Persons with limited mobility (patients, elderly, inmates)	8
D. There is no clear evacuation plan	+2
E. There is a danger for panic	+2
F. People with limited perception capacities, such as patients, elderly, disabled persons, sleeping guests in hotels, etc.	+2

Table 5.11 Resident mobility factor [9]

Note: Where the first group values are applicable, the second group values are accumulated. Also, for places where there is a lot of people and there is not enough light during evacuation, it should be possible to create anxiety in people.

The minimum useful width of an outlet should be 0.6 meters. Unless otherwise specifically prescribed by law or in specific situations.

To determine the value of x for each output, consider the narrowest mode for its width, and measure it in centimeters, and then reduce the 20 centimeters of this size and the result is divided by 60 centimeters. The sum of the output is equal to the number of output units on the exit path. The sum of all calculated divisions for exit paths will determine the total number of output units for the desired space. The important thing is that large outputs that are normally closed should only be considered as an output unit, not the whole width.

K is the number of directions or output paths that a person can choose to leave space. If two paths are considered together as separate paths, individuals will have to travel 90 degrees or more to go from one exit path to another. So, for a space, a maximum of 4 is possible for separate exit.

To determine k the largest output is considered as the main output. Each exit direction must have at least half the width of the original output to be considered as a distinct standpoint. For example, when the original output size is equal to 3 output units, each additional direction must have a width of at least two output units.

5.10.3 Value Factor c

The value factor indicates that the loss of the building and its contents will result in a significant amount of financial loss. To obtain a content Factor, two sub-factors are needed to determine the amount of losses.

$c = c_1 + c_2$ **(5.15)**

C_1 evaluates the probability and possibility of replacing the building and its contents after the occurrence of fire. The value of c1 will be 0, 0.1 or 0.2 as the building and its content are considered as easily, difficultly, or impossibly to replace.

Usually replacing historic sites, museums and factories built for a special purpose is impossible. Replacing equipment that has long been needed to provide them, and machines with a very special design are very difficult.

The value of c2 specifies the financial value of the property and commodities. Excessive values of the value of the goods and the contents of the building are insurable. But both the society and the insurance industry will suffer in major fires. Therefore, the level of acceptance decreases according to the monetary value of the existing property.

The value of c2 will be calculated by the following formula.

$c_2 = \frac{1}{4}\log(\frac{v_r}{7\times10^6})$ **(5.16)**

v_r: The financial value of the building and the contents (Euro)

c_2: Building Finance Value Factor (without unit)

5.10.4 Environment fire factor r

From the study of large fires, it is known that the main danger to residents of a building is the high rate of fire spreading. The combustible components of the structure, the decoration of the walls at the special surfaces and the carpet of the floor, which are highly combustible materials, are the reasons for the rapid expansion of fire, even in buildings with a low fire.

In the FRAME method, the Environment factor determines the fire speed. The Environment factor is obtained using the immobile fire factor, the fire spread class, using the formula given below.

$r = 0.1\log(Q_i + 1) + \frac{M}{10}$ **(5.17)**

r: Environment fire factor (without unit)

Q_i: Immobile fire load factor (MJ/m2)

M: Flame propagation class (without unit)

5.10.5 The dependency factor d

The dependency factor examines the effect of fire on the activities performed inside the building. A fire in a factory warehouse can cause widespread financial damage, but the plant still has the ability to produce, and the process of production is not damaged, the process does not suffer a lot of damage, and so many potential fire outcomes are delimited. By contrast, if a small production line is in production, a small fire can disrupt the whole production of the plant.

The fact that the best way to determine the effect of fire on activity is the difference between the value of inputs into the production line and the output value of the line. This amount is value added and includes investment costs, manpower, research, and so on. The dependency factor is the ratio between the values added of the total sales of the product in the item under review in one year. To determine the value of the factor dependency, the following table can be used, which, based on the type of work, specifies the dependency factor [9].

Typical values for the dependency factor d	
High technology industry and services	0.7 to 0.9
Industry of consumer products (automobile, household electronics)	0.45 to 0.7
General industry (machine construction, semi-finished products)	0.25 to 0.45
Commercial companies, warehouses	0.05 to 0.15
Administrations	0.8
Average for most businesses	0.3

Table 5.12 the values for d [9]

Note: If the factor is not known, d can be assumed to be 0.3

5.11 Determine the level of protection

The level of fire protection can be expressed as a sum of the combination of different protection techniques. These items express the quantity and quality of protection available for a given position. The numerical value of the protection is the level of protection. The formulas used to calculate the level of protection for buildings and contents, individuals and activities are as follows.

D: Level of protection for building and contents

$D = W \times N \times S \times F$ **(5.18)**

D_1: Protection level for residents

$D_1 = N \times U$ **(5.19)**

D_2: Protection level for activities

$D_2 = W \times N \times S \times Y$ **(5.20)**

W: Water supply Factor

N: Normal Protection

S: Special Protection Factor

F: Fire Resistance Factor

U: Escape Factor

Y: Salvage Factor

All of these factors are without unit quantities.

5.11.1 Water supply factor

Water is the most common and commonly used agent for firefighting. The water's ability to fight fire is unique.

- Chemically, the substance is inactive until it is oxidized.

- Due to its specific heat, it has a high thermal absorption capacity.

- Although it is liquid, it is easy to store and transfer.

- A good thermal transfer agent

- Normally available and inexpensive

In order to prevent fire, there is a need for continuous supply of water for firefighters, and adequate water must be available to control the fire. The water must be transferred to the fire zone by the plumbing system, under the pressure to reach the central area of the fire. Unfortunately, in many parts of the world, existing water reserves are not in accordance with the rules, and it is often reported in real fire reports that firefighters' performance is impaired due to water shortages. For each defect in the components of the water supply system, the numerical FRAME method is expressed as the negative rating of the system. In fact, the water supply factor shows the difference between the quality of water supply in the present and the normal conditions.

The first part in the water supply factor is the type of water resources. They are divided into three categories. The first batch is for mixed use with other applications, and the source itself is filled in. The second category is for mixed use with other applications but is filled by the user and there is no water source in the third category. These three categories get 0, 4, and 10, respectively.

The second component in the water supply factor is the water supply capacity. To determine the water requirement, this rule can be used, which requires about 0.25 cubic meters of water to survive for a real load equal to one Mega joule per m2 of floor surface. The amount of water needed is related to the fire load of the building and its contents. If the resource's capacity is sufficient, the value is 0. Up to 10%, 20%, 30% and more than 30%, these values will be equal to 1, 2, 3, and 4, respectively [9].

The third component in water supply is the water distribution system. The water distribution system is usually designed for average consumption. Maximum consumption during fire extinguishing results in a lot of pressure drop in smaller plumbing systems. The network capacity is determined by the diameter of the pipes and the speed of 2 m/s for the flow of water. If the distribution system is appropriate, weighs 0, if the distribution system is low, weighs 2, and in the absence of the distribution system, the weight distribution 6 is considered for this segment.

The fourth component in the water supply factor is the fireplug. Having a water distribution network alone is not enough and, in addition, there is a need for a sufficient number of fireplug. The status of the fireplug around the building marks the fourth most important factor in water supply. A 70 mm hose connection for every 50-meter distance will have a score of 0. A hose connection for a distance of 50 to 100 meters, a score of 1 and less than a hose connection for every 100 meters, will have a score of 3.

The last factor in the water supply system is the system pressure .Can the firefighter reach the highest point of the building with the available pressure, or need a pump to increase the pressure? A bar, a static pressure of 10 meters, is the vertical pressure of the water. The highest building point is available, if the static pressure is 3.5 bar above the highest point of the building. If there is less pressure, FRAME considers the amount of fines. That will be equal to 3.

All of these scores for the different characteristics of the water system are aggregated and the amount of the supply factor is calculated using the following exponential relation.

$w = \sum w_i$ **(5.21)**

$W = 0.95^w$ **(5.22)**

w: Total fines allocated to different parts of the water supply system

W: Water supply factor

5.11.2 Normal protection factor

Under normal or standard protection conditions, the FRAME method considers the following elements that are generally available or are installed at low cost.

- A fire hazard system that provides fire detection capabilities and informs firefighters and building users.

- A sufficient number of handheld extinguishers and small water hoses

- Basic training for all residents of the building on how to use silencers

- Action of public fire department within 10 minutes after notification

As with the water supply factor, a negative rating is considered for sectors with abnormal conservation conditions and the normal protection factor is calculated.

5.11.2.1 Alarm system

A system of alert should include the presence of organized people in order to check the building for the possibility of fire. There should also be a manual setup system to inform firefighters and alert residents in order to properly dispose of the site and start fire suppression.

Once the fire has been detected, the alarm system must have equipment to inform the firefighters of the fire and alert the residents. One way to do this is to install a manually-installed siren system and connect to the central alarms in the care room. In this case, it is the responsibility of the high-risk system to alert firefighters to alert residents and people in charge of evacuation. This can be done using a phone, a personal phone system, an alarm or a siren.

The operator may be replaced by an automatic system at the central station to send the message to firefighters and residents, or to alert the phone. Of course, there must be enough phone numbers in the building and there should be a dedicated number for alerting.

Normal protection system can be an organization that includes the presence of people for fire detection, the existence of a manual notification system for the fire department and alarm system to alert the residents. Any defect in this organization causes a negative rating in normal protection.

A non-organized building, but equipped with smoke sensors, has a negative rating because of the lack of people. However, the presence of sensors in the calculation of special protection is considered as a positive rating. In the table below, the points for different modes are provided with a protective service for the building, which is extracted according to the type of defect in the relevant score system.

Discovery and warning	n1
A. A guard service with organized human presence, manually operated alert system, notification to the fire brigade and alarm to the occupants.	0
B. without organized human presence	2
C. without manually operated alerting system	2
D. without guaranteed notification to the fire brigade	2
E. without alarm to the occupants	2

Table 5.13 The status of the building security system [9]

5.11.2.2 Extinguishers and hose stations

The second part of the normal protection is the presence of a sufficient number of handheld fire extinguishers and small hose stations for the residents to intervene with fire. The type, number and distribution of these firefighting equipment are specified by local laws and standards that vary from country to country. Due to the limited capacity of manual fire extinguishers, normal protection requires both manual capsules and water hose stations. For places with insufficient number of fire extinguishing caps and absence of water hose station, a negative rating is considered. The score for the various conditions for the firefighting equipment is obtained from the table below as the second component of the calculation of the normal protection factor.

Manual fire fighting	n2
F. Extinguishers adequate	0
G. Inadequate number or lack of extinguishers	2
H. Hose stations adequate	0
I. Inadequate number of hose stations	2
K. No hose stations available	4

Table 5.14 Hand fire-fighting equipment [9]

5.11.2.3 The intervention of the public fire brigade

The main source of firefighting is the public fire department. At the start of the fire, it does not matter how many firefighters can reach the fire, but they must arrive too soon. Firefighters arrive within 10 minutes of the occurrence of fire as normal conditions. Local conditions, such as traffic, make the officers more time consuming to reach the place of fire, and such cases are considered as a negative rating for normal protection. In urban environments, taking into account the distance between the nearest fire station and the speed of 30 km / h, a reliable estimate can be made of the time it takes for firefighters to arrive. The table below shows the scores related to the time of the intervention of the public fire service.

Fire brigade intervention	n3
M. First fire brigade intervention in less than 10 min	0
N. Between 10 and 15 minutes	2
O. Between 15 and 30 minutes	5
P. More than 30 minutes	10

Table 5.15 Fire department intervention during fire [9]

5.11.2.4 Occupants Training

In the discussion of fire safety and the performance of the inhabitants of a building in the time of fire, the training and awareness of the present people is very important about how to deal with fire. A small fire in the early stages can easily be controlled. But due to lack of awareness of people about firefighting methods, they become larger events. Minimum education for residents is essential for how to use fire extinguishing capsules and water hoses. Unfortunately, the use of extinguishers is not standard training. The last part of the calculation of the normal protection factor is the awareness of how people use fire suppression systems. Scores for different modes are obtained from the table below.

Education	n4
Q. All occupants know how to use extinguishers and hose stations	0
R. Only a limited number of persons trained	2
S. No basic training	4

Table 5.16 Score related to occupants training [9]

All these points n_i are combined and using the exponential relationship, the amount of the normal protection factor is obtained.

$n = \sum n_i$ **(5.23)**

$N = 0.95^n$ **(5.24)**

n: Total amount assigned to different parts of the system of normal protection

N: Normal protection factor

5.11.3 Special Protection Factor

The FRAME method for special protection conditions considers elements that are not available under normal conditions and will definitely improve the fire extinguishing system's ability and reliability. These elements that usually require more investment are:

- An automatic fire detection system that reduces the onset of firefighting.

- Improved water supply: More water storage with double tanks and ensuring their availability

- Automatic fire protection system, specially sprinkler system

- Fully equipped fire department

5.11.3.1 Automatic fire detection

There are several types of automatic fire detection systems. In fact, ensuring the correct intervention at the time of the fire justifies the use of the automatic fire detection system. If there is no guarantee of connection with the fire department, then the system is considered unused. It is necessary to have a full-time operator or an automatic transmission system for communication with the fire department. Positive points are only for systems that are related to the fire department. When the system is faster and more reliable, the scores are higher. Sprinkler systems equipped with a fire alarm with flow switches or similar devices are considered as heat detection systems. Smoke and flame detection sensors are considered as fast detectors. An electrical review of the automated system and individual examination of a small fire area are considered as positive points. The following table lists the types of automatic fire detection systems that are used as the first component in the calculation of the normal protection factor.

Automatic detection	s1
By sprinklers	4
By thermal (heat) detectors	5
By smoke or flame detectors	8
With electronic supervision of the system	2
With individual identification of small fire zones	2
Smoke alarm units	2

Table 5.17 Score related to automatic fire detection [9]

5.11.3.2 Improved water supplies

Water supply is very important for firefighting operations. Because the fire occurs unexpectedly. It should be ensured that the water supply system is ready at a time. Natural water resources such as rivers and lakes and any source that can supply water for a period of 4 hours or more can be considered as a system strength point. Water resources that are solely for use in firefighting and those that are controlled and monitored by the user are reliable. It could also be said about the sources that have the pump. For the sprinkler system, a high reliability level is obtained when there is a pump system and a dual source of water. The points for improving the water supply system are derived from the table below.

Water supplies	s2
Inexhaustible water supplies (4 times adequate)	3
For firefighting only	2
Under control of building user (independent)	2
Highly reliable : One water storage with a double flow/pressure source	5
Duplicated highly reliable: two storages, each with a flow/pressure source	12

Table 5.18 Water supply scores [9]

5.11.3.3 Sprinkler systems and other automatic protection

The most expensive and, at the same time, the most effective way of protecting the building is that there is an automatic fire fighting system called a sprinkler. A sprinkler system is designed for predetermined risk. The disadvantage of the sprinkler system is the impossibility of changing the system lifetime. Any spray system that does not match the underlying space is considered as a slow heat detection system, not as a fire extinguishing system. Otherwise, as much as the system meets the space occupancy, it will have strong points and this reliability of the sprinkler system will be more reliable by connecting to a secure water supply system.

Sometimes, all parts are protected by other automated systems, which are used with regard to the type of risk of co2 or foam. These systems are very expensive and generally designed for a single time. The existence of this type of system is also considered as a strong point. In the table below, the scores for the sprinkler system are shown in different conditions, which are used to calculate the normal conservation factor.

Automatic protection	s3
Sprinklers with one (public) water supply	11
Sprinklers with one independent water supply	14
Sprinklers with two independent water supplies	20
Other automatic extinguishing systems (CO_2, foam)	11

Table 5.19 Automatic fire alarm system status [9]

5.11.3.4 The responding fire station

Large cities have professional firefighters with complete equipment at several stations. Smaller cities will have less skillful agents and volunteers will be required. There may be only two or three people permanently at the fire station who inform volunteers when needed. In most cases, there is a direct relationship between the number of officers and the equipment at the station. So, for the type of fire department that can control the fire in the early stages, positive points are considered. In the table below, these scores are presented for different modes.

Responding Fire station	s4
1. Full time station 24h/24 7d/7	8
2. Variable professional crewed station (day time crewed, night time retained)	6
3. Retained station (part time professionals)	4
4. Volunteer station	2
1. Part time industrial fire brigade (working hours)	6
2. Full time industrial fire brigade 24h/24	14

Table 5.20 Kinds of firefighting organizations [9]

Note: Temporary firefighting facilities have personnel only in their working hours, and permanent private organizations have personnel throughout the office hours.

The special protection factor is obtained by aggregating the data provided for all elements and putting the resulting amount in an expository formula.

$s = \sum s_i$ **(5.25)**

$S = 1.05^s$ **(5.26)**

s: Score points assigned to different parts of the special protection system

S: Special Protection Factor

5.11.4 The fire resistance factor

Factor of fire resistance shows the resistance of building components to the negative effects of fire. The collapse of a building in fire is in most cases a major cause of the catastrophe. Fire retardation is almost impossible in a building that does not have adequate fire resistance, and some firefighters who have done this have lost their lives for their work. To calculate the fire resistance factor, it operates in two steps. The first step is to calculate the average fire resistance power.

5.11.4.1 The average fire resistance

In order to determine the fire resistance factor, the main components of the building, such as the type of structure, external walls, floor, ceiling and inner walls, should be considered. The fire resistance is checked for each building component. It balances their importance and calculates the average fire resistance. The power of building elements that have been determined in tests performed on ISO r834 will be reported in the reports and will be used in the following formulas.

$f = \frac{1}{2}f_s + \frac{1}{4}f_f + \frac{1}{8}f_d + \frac{1}{8}f_w$ **(5.27)**

f_s: is the average fire resistance (REI) of the structural and separating elements (minute)

f_f: is the average fire resistance of the outside walls (E = flame tightness) (minute)

f_d: is the average fire resistance of the ceiling or the roof (RE) (minute)

f_w: is the average fire resistance of interior walls (EI) (minute)

Hints:

1. The resistance of building elements to fire is expressed in terms of minutes. These values are determined by experiments based on ISO 834. This quantity represents the time of resistance of building elements to fire effects.

2. To avoid creating unrealistic values for the fire resistance factor, power values over 120 minutes shall not be used.

3. The strength of the external walls, roof, or roof and internal walls should not be greater than the strength of the structure.

4. For the structure of element composition, the weakest element of power must be specified.

5. For buildings with a sprinkler system to protect the structure or roof, the duration of water supply is considered as resistive power, provided that it is not longer than 60 minutes.

6. If the level of windows in external walls is less than 5% of the wall surface, its power can be ignored. Otherwise, the resistance is considered to be zero.

7. The strength of the roof and roof is essentially equal to its underlying power.

8. The internal walls of the building divide the building into the smaller sections in the fire zone. No part shall be larger than 25% of the total space, and no part shall be larger than 1000 square meters. Otherwise, the power of the internal walls is zero.

9. Fire resistance is a passive protection and its role in the protective system should not be overlooked.

10. It is not permissible to consider the fire resistance values for external walls, ceilings, and internal walls more than structural strength.

11. In buildings without separate internal parts. Resistance is zero for internal walls.

5.11.4.2 Resistance of building components
Structural Resistance:

The most important parts of the structure in the building are the columns, beams and load bearing

walls. According to the type of structure and fire prevention measures applied to the columns and beams, the resistance of the structure to the fire is determined. The strength of all types of structures according to the type of structure is as follows.

- Unprotected steel structure for 15 minutes’ resistance

- Wooden structures 0 to 60 minutes’ resistance

- Concrete structures 60 to 120 minutes of resistance

If the building is protected by overhead sprinklers, it accepts that the roof will not collapse as long as the protective system works. Therefore, if there is a proper water supply system, water supply can be considered as a fire resistance capability. Though it is unreasonable to be over 60 minutes.

In a shelf, with unprotected steel columns, no resistance can be considered for these columns unless there is a sprinkler system in place. In two cases, the fire power may be equivalent to the water supply time. A When the warehouse is protected by an in-cabin sprinklers system. B When additional sprinklers are installed to protect the columns.

Exterior walls and ceilings:

The second part of the average power is the resistance of the outer walls. The resistance of the outer walls (in relation to the desired section) will help the officers in two ways. First, it reduces the possibility of fire in adjacent buildings, and secondly, it protects other sections and firefighters from the heat of the fire. The structural and non-structural elements of the walls should be considered and the strength of the weakest component should be considered.

Important aspects of the exterior are windows. If it is less than 5% of the window's exterior, its resistance will be ignored. But for office and residential areas, the law is that the fire resistance of the glass is zero.

The third part of fire power is roof or roof strength. The load bearing elements of the building, coatings, insulators and the weakest parts in the floor are considered to determine the overall strength of the resistance. For a ceiling with flammable insulators in the lower part, the resistance value for zero must be considered. A limited surface of the ceiling of up to 5% can be opened, and this is considered to improve the smoke and heat discharge.

Interior walls:

The final part for calculating the average resistance of a structure is the resistance of the wall of the internal wall. According to calculations, temporary walls should divide the entire space into parts. So that none of these areas is larger than 25% of the total space or its area is not more than 1,000 square. For a space of less than 1000 square meters that is not divided, the resistance value for the internal wall is zero. The most commonplace where resistance to internal walls is true, non-industrial buildings, such as offices and homes. The following table shows the strength of the building's walls based on the type of materials. These values are indicated by tests performed according to the ISO R 834 standard.

Unprotected steel structures	15 minutes
Masonry and concrete structures	60 minutes
With extra fire proofing	90 to 120 minutes
Light timber structure	0
Heavy timber construction on masonry walls	60 to 90 minutes

Table 5.21 Resistance of building components, based on the type of materials

After calculating the average strength of building components resistance, in the second stage, using the following formula and a correction for the specific protection factor, the fire resistance factor is calculated.

$$F = \left[1 + \left(\frac{f}{100}\right) - \left(\frac{f^{2.5}}{10^6}\right)\right] \times [1 - 0.025(S - 1)] \quad \textbf{(5.28)}$$

F: Fire resistance factor (without unit)

f: Average fire resistance (minutes)

S: Special Protection Factor (without unit)

Fireproofing is an inactive form of protection and allows officers to work without the risk of collapsing buildings. For a space where no anti-fires have been performed and solely based on special protection, the fire resistance factor is equal to 1, which in fact means insufficient resistance to fire.

5.11.5 Escape Factor

It specifies the ways by which special measures can be taken to escape from the area of fire. These measures are mainly two types: one that increases the discharge rate, and the other that slow down the spread of fire. In the first group, there are actions such as automatic fire detection, increasing the capacity of the evacuation routes. The second group of actions includes smoke ventilation and fire prevention, which reduce the risk of fire.

5.11.5.1 Automatic fire detection

Automatic fire detection reveals the possibility of rapid fire detection. If there is no guarantee of association with the fire department, any diagnostic system will be unused. The privilege that will be considered for automatic recognition in this regard (due to the connection with the fire department) will be like special protection, and it is logical that the advantage of rapid detection in both cases is the same. Increasing the number of outlet capacities is the second way to increase exit speed. The best way to increase exit capacity is to prepare multiple output doors, which is because people can get out of more than one way. For various firefighting systems, the FRAME method for calculating the risk level takes into account the various scores used to calculate the risk factor. These rates are presented in the following table according to the type of protection system.

Automatic detection and alarm	u1
By sprinklers	4
By thermal (heat) detectors	5
By smoke or flame detectors	8
by smoke alarm units	2
With electronic supervision of the system	2
With individual identification of small fire zones	2
Partial detection in areas of high risk	2
Not more than 300 persons to be warned	2

Evacuation alarm with spoken messages by voice communication system	6

Table 5.22 Automatic fire detection system status [9]

5.11.5.2 Vertical evacuation paths

For one-story buildings, one can say that people are safe when they are out of the unit. For multi-stories buildings, this is usually not the case. Evacuation staircases should have direct paths and outlets that lead to them. There are three types of stairwells that can ensure people reach the ground at a low level. These three types of external staircases, internal stairways and separate internal staircases are included.

- External staircases provide the best protection when taken in the context of the weather conditions.

- The built-in staircases are separated by walls and fireproof doors from the rest of the building, and emergency lighting and smoke evacuation systems are foreseen for them.

- Separate internal staircases with fire walls are separated from the rest of the space, but do not have some other features such as fireproof doors and smoke and emergency lighting systems.

To calculate the escape factor, the rating for the various types of vertical exit paths is presented in the table below.

	u2
No stairs used for exit	0
1. Open inside stairs	0
2. Single enclosed inside stair	1
3. More than one enclosed inside stair	2
4. At least one enclosed and smoke protected inside stair	3
5. More than one enclosed and smoke protected inside stair	4
6. Inside stair(s) and 1 outside stair	6
7. Inside stair(s) and more than 1 outside stair	8
8. Inside stair and outside toboggan or ladders for 1st / 2nd floor	2

Table 5.23 various combination of vertical exit paths [9]

In the small buildings used for kindergartens, for the first and second floors above the ground floor, the use of the ramp downwards is accepted as a staircase. One of the most effective measures to increase evacuation speed is the design of an evacuation plan, which means removing people's doubts as to how they leave the building. The existence of a complete and specific plan for evacuation and the presence of a direction on the discharge routes are considered as additional points.

5.11.5.3 Compartmentation

Compartmentation reduces the number of people to be evacuated and also creates an obstacle to the spread of fire. Some buildings are divided into smaller sections due to the legal requirements or type of building used by the interior walls. Like hospitals, schools and hotels that have many interior parts. When the interior space of the building is divided by internal walls with a resistance of 30 and 60 minutes, to areas smaller than 1000 square meters, a positive rating is considered.

	u3
Separation of space into parts with a surface less than 1000 square meters by separating surfaces, with a resistance of 30 minutes	2
Separation of space into parts with a surface less than 1000 square meters by separating surfaces, with a resistance of 30 minutes	4

Table 5.24 Compartmentation values [9]

5.11.5.4 Automatic fire protection and firefighting

It is clear that the best way to reduce the risk of fire is to shut it off. Automatic firefighting systems, therefore, provide effective protection to individuals. In some cases, the risk of fire in a small area, for example the kitchen of a restaurant, is concentrated in the space. In this case, the installation of a regional automatic protection system or a partial sprinkler system for the area would be useful to reduce the possibility of fire spreading to other areas. Therefore, local protection and sprinkler systems are considered a positive factor. For types of conditions, the automatic fire-fighting system is considered to be concessions in order to be able to calculate the escape factor. In the table below, these rates are given for different systems.

Automatic protection	u4
Sprinklers only in areas with increased fire risk	5
Sprinklers full protection	10
Other automatic extinguishing systems	4

Table 5.25 Automatic fire alarm system status [9]

5.11.5.5 Responding fire station

The last part in calculating the release factor is the quality of the intervention of the firefighters, and for the safety of individuals, the issue of strength and skill of persons in the early stages of fire will be in the first place. The type of fire department, the quality of its operation, as well as the equipment in the fire centers, are important and effective factors in combating fire. The privileges awarded to the fire department's characteristics as the last component to calculate the escape factor are obtained from the table below.

Responding fire station	u5
1. Full time station 24h/24 7d/7	8
2. Professional crewed station (day time crewed, night time retained) Private fire	6

brigade	
3. Retained station (part time professionals)	4
4. Volunteer crewed station	2
5. industrial fire brigade (part-time or full-time)	4

Table 5.26 The situation of the fire department in the place [9]

All scores obtained from the above 5 steps are combined and the result is given in the following formula and the escape factor is calculated as the special protection factor.

$u = \sum u_i$ **(5.29)**

$U = 1.05^u$ **(5.30)**

u: Total points for various protective measures

U: Escape factor (without unit)

5.11.6 Salvage Factor

The property salvage factor is calculated using elements that reduce the growth of fire in critical areas, as well as elements that limit the effects of fire. The calculation is done in a way similar to the method of calculating the specific protection factor and the escape factor. Elements that are generally effective in reducing the harmful effects of fire include the protection of vulnerable areas, plans for incident situations, and the division of activities between several different situations.

5.11.6.1 Protecting vulnerable areas

One way to reduce the damage caused by fire is to protect most of the vulnerable areas of the building. Compartmentation is one of these methods. So that it is possible to install regional protection systems, sprinklers or any other automatic protection system in a sensitive area. For those who are vulnerable, extra protection is provided. Scores related to different protection conditions are provided in the table below, which is used to calculate this factor.

Physical protection	y1
Sub compartmentation in fire areas of max.1000 m2 EI30 separated	2
Sub compartmentation in fire areas of max.1000 m2 EI60 separated	4
Partial automatic detection in critical areas	3
Partially sprinklers (in critical areas)	5
Other automatic extinguishing system in critical areas	4

Table 5.27 Protection status of sensitive areas [9]

5.11.6.2 Disaster planning

One of the most important ways to deal with the consequences of fire is to prepare for the incident. The question is, how should the work be started again after the fire? In this regard, the FRAME method takes into account the factors that prepare the conditions.

Is all information, such as financial and economic information, models and patterns, computer programs, customer lists and vendors available and kept in an area safe to be available after a fire? Does the factory or department have access to spare parts and machinery to make repairs shortly after the fire? Is it possible for the organization to repair itself alone or with the minimum help from sellers and machinery manufacturers? Has it been agreed with other organizations to provide space or equipment for deployment and activities elsewhere and for an interim period? The remaining solution to reduce fire damage is the existence of multiple production centers. In the FRAME method, to calculate the property recovery factor, for the different conditions, the points are considered, which are presented in the table below.

Organization	y2
Safeguarded financial and economic data	2
Easy access to spare parts and replacements	4
Repairs possible with minimal help	2
Relocation agreements	3
Multiple production capacity	3

Table 5.28 Organize for post-accident situations [9]

The scores obtained from the previous two steps are aggregated and the amount of the Salvage Factor is obtained using the formula below.

$y = \sum y_i$ **(5.31)**

$Y = 1.05^5$ **(5.32)**

5.12 Estimates of the risk level of different units

After the potential risks, the level of acceptance and the level of protection for the different units have been calculated according to the previous steps, at this stage, using the following relationships, the risk level for our activities, occupants and building and content is estimated separately.

- Level of fire risk for building and content:

$R = \frac{P}{A \times D}$ **(5.33)**

- Level of risk for occupants:

$R_1 = \frac{P_1}{A_1 \times D_1}$ **(5.34)**

- Level of risk for activities:

$R_2 = \frac{P_2}{A_2 \times D_2}$ **(5.35)**

5.13 Estimated Expected Damage

An important aspect of calculating FRAME is the relationship between the amount of risk involved and the amount of damage that can be caused by fire. Using this method, it is possible to determine the expected normal damage. The scale provided in the table below is used to estimate the amount of damage caused by fire.

Value of R	% of compartment destroyed
Up to 1.0	10 % or less
1.0 to 1.3	10 to 20 %
1.3 to 1.5	20 to 30 %
1.5 to 1.7	30 to 50 %
1.7 to 1.9	50 to 80 %
More than 1.9	80 to 100 %

Table 5.29 Expected loss rate based on existing risk level [9]

Using the above table, the expected damage rate is calculated for all units where the risk of fire is calculated. Since the FRAME method is initially designed to evaluate the insurance, it is an important application to estimate the damage in examining the tariffs for fire insurance. If the fire insurance tariff is differentiated for each section, the expected damage level can be calculated with the amount of insurance cost paid.

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Chapter Six; Experimental, Case Studies

In this chapter, two examples of Italian historical theaters were selected and evaluated by comprehensive frame software to determine the level of fire risk in these buildings. If there is a need to improve the current situation with regard to frame data, solutions will be developed to increase their safety level.
The selection of these case studies has several reasons, including architectural issues and building authenticity but one of the most important reasons for selecting the Niccolini theater and the Pergola theater was having a safety plan.
In this research, we have tried to examine cases that have been thoroughly investigated in terms of fire safety measures and have extinguishing , warning/alarm system, emergency exit routs and guide signs.
As a result, if the frame evaluation, despite these measures and the existing status of the level of safety is inappropriate or low, then other active and passive solutions can be presented.

6.1 Case Study N.1: The Niccolini Theater

The Niccolini Theater of Florence is located in Via Ricasoli, a few steps from the Duomo. The picture below shows the position of the Niccolini Theater.

Figure 6.1 3D Google Map Photo of the Niccolini Theater

General information of this historical building is given in the table;

District	San Giovanni
Location	Via Ricasoli 3- 5, Florence, Italy
Building Name	Niccolini theater
Construction	1648
Capacity	About 500 seats
Other denominations	Palazzo Ughi, theater of the Cocomero, theater of via del Cocomero
Property	Ughi, Accademia degli Infuocati, Ghezzi, Pagliai.
Architects, Engineers	Saller Alessandro, Giovannozzi Innocenzo, Ruggieri Giuseppe, Mannaioni Giulio, Sgrilli Luigi, Poccianti Pasquale, Antonio Carcopino, Buonaiuti Telemaco, Lotti Emilio, Fantappiè Enrico Dante, Benaim André.
Painters, Sculptors, Decorators	No data detected.
Famous men	Niccolini Giovanni Battista.

Table 6.1 The information of Niccolini theater

6.1.1 History of The Niccolini Theater

Until the early twentieth century theater was called "Theater of Cocomero", it has a long history as the ancient name of the street where it is located.

In 1648 Don Lorenzo de 'Medici was one of the founders of the Academy dramatic, the first example of school and stable company of dramatic theater in the city, With the protection of Cardinal Giovan Carlo de 'Medici he began to use the theater of Cocomero, which had recently been built by Nicholas of Ughi and in which were represented tragedies and classic comedies, noble entertainment of aristocrats and the same grand ducal family.

Figure 6.2 Plan of the Niccolini theater
Ref; Available on official site of the Niccolini theater

The theater in via the cocomero so also took the name of "Infocati theater", and in 1861 acquired the name "Niccolini theater" in honor of Giovanni Battista Niccolini, great Pisan dramatist who died in that year.

The theater was active until the end of the eighties, when the prose was moved to the Pergola theater. Today also at the Teatro Verdi, the Municipal Theater and the Goldoni theater they are represented by prose but not continuously.

In 2007 they started the retrofitting and renovation of the theater, purchased by the publisher Mauro Pagliai, with reopening expected in late 2015 (Fig 6.3, Fig 6.4).

Figure 6.3 Restoration of Niccolini Theater
Ref; Available on official site of the Niccolini theater

Figure 6.4 Restoration of Niccolini Theater view from boxes
Ref; Available on official site of the Niccolini theater

The long process of restructuring directed by the architect André Benaim has brought the structure - 406 seats and 4 rows of boxes - to their original splendor, starting from the facade and roof renovation before moving in, renovating of all plants and installing latest safety technologies. Particularly they have been recovered, on the ground floor, the rooms used in the past to commercial funds, and was then recreated the foyer of 1914, now used for ticketing, cafe and bookshop. The state of degradation in which the property is located has required a heavy intervention, also structural, which has involved every portion of the building, from the cellar to the roof, and lasted for almost two years. In January of 2016 the 2,500 square meters with seven gates on Via Ricasoli are so back available to citizens and tourists.

6.1.2 Determine the compartment to be studied

As in the FRAME, one calculation is for one compartment, firstly the compartment must be specified.
In the historical Italian theater, the parts which are more at the risk of fire are; auditorium, stage and boxes. Therefore, in this study we have tried to examine these areas as the weakest parts of

the building against fire. First, it must be reviewed that these parts can be considered as a compartment or should be separately calculated and checked.
As mentioned, in general, the following should be considered in order to determine the compartment;
- Elevation position of the compartment from the ground.
- The possibility of fire penetration to outside.
- Type of activity.
- The characteristics of existing people.
The altitude of compartment is important in order to accessibility of the firefighters to the compartment's fire, in our case all three parts; audience hall, boxes and stage have equal access for the fire bridge's equipment.
Since these parts are connected to each other, the spread of fire and fire behavior are similar in them, so the fire penetration to outside of the compartment will also be defined for the whole of the three parts.
Type of activity and the feature of people are the same in different parts.
Therefore, these three parts can be selected as a compartment for studying and performing FRAME calculations.

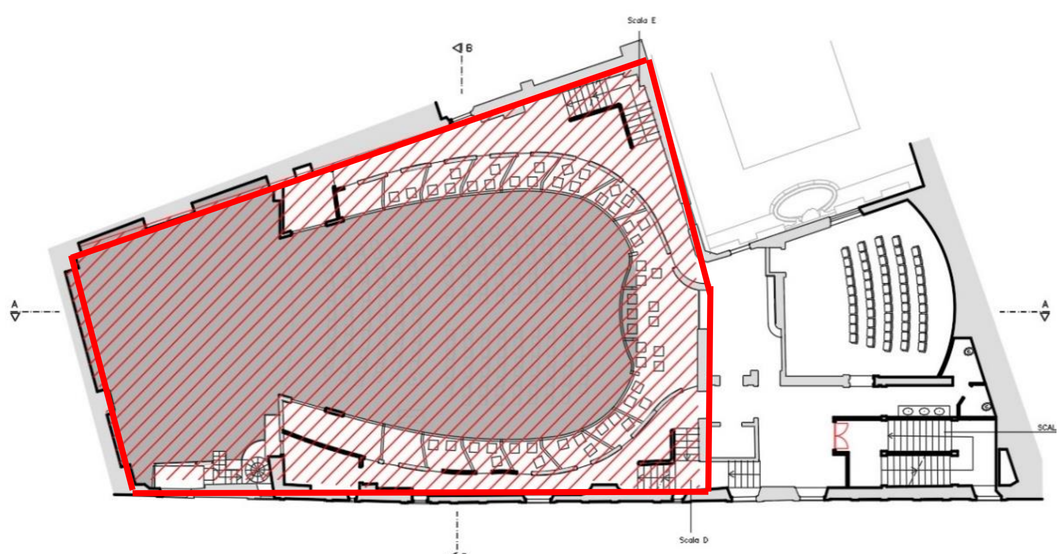

Figure 6.5 Plan of the Compartment (Defined with the Red Line)
Ref; Authorities of the Niccolini Theatre

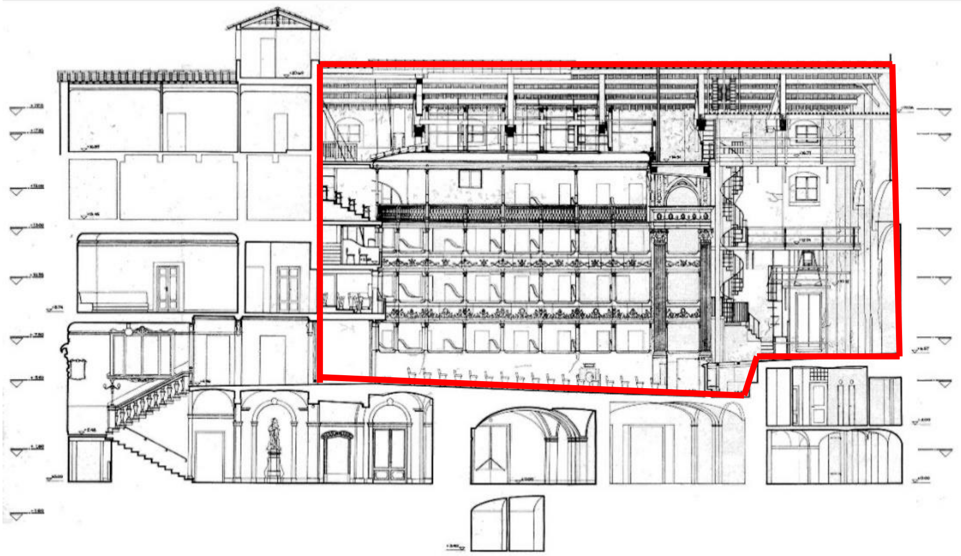

Figure 6. 6 Elevation of the compartment (define with the red line)
Ref; Authorities of the Niccolini Theatre

6.1.3 Collecting the required information

To perform FRAME software calculations, comprehensive information is needed in all areas such as: plans and measures, the characteristic of the building, exit way, stairs, structures and materials, electricity installation, heating system, the fire protection system, emergency plan and etc.

Much of the information needed, was collected from the authorities of the Niccolini theater such as the emergency plan.

The correspondence with the Florence Fire Station was also provided the other relevant information.

Construction; The building has the common structure of historical theaters, 2500 m² in a horseshoe-shape, with 4 levels of boxes, very thick stone and masonry walls, wooden floors, some with tiles, slate roof on massive oak structure. No effective compartmentation because of two monumental stairs joining the four levels.

The entrance/exit doors on one side only at the Niccolini street, the building is accessible on three sides for firefighters.

The building is equipped with extinguishers, hose reels, a fire alarm system and fire detection and sprinkler in stage. Notification to the fire brigade is by the staff and also automatically.

6.1.4 Input Data and Calculating; P, A, D and R for Property, Occupants and Activities

The next table gives an overview of the calculation of the Niccolini theater with FRAME. The FRAME computing sheets for the Niccolini theater are fully documented in Appendix A.

Item	Explanation	(sub) factor	Value	Result
Fire load immobile		Qi	1000	q=1.65
Fire load mobile		Qm	500	
Temperature rise		T	200	

Average dimension		m	0.33	i=1.15
Reaction to fire		M	3.0	
Length		l	30	g=0.56
Width		b	15.53	
Level		E	3	e=1.22
Height of room		h	2.8	V=1.07
Ventilation		K		
Access direction		Z	3	Z=1.00
Height difference		H	13.45	
Potential Risks		P=1.40	P_1=2.49	P_2=0.85
Activation factor	Main: public Heating: ok Electrical: ok Explosion: no Secondary: no Painting,spraying,glues, etc.: ok	a		a=0.4
Occupants		X	430	
Exits		x	9.4	
Exit directions		k	2.62	
Evacuation time factor		t		t=0.42
Content factor	20.00 million euro - Unique	c		c=0.29
environment factor		r		r=0.6
dependency factor		d		d=0.3
Acceptable Risks		A=0.48	A_1=0.18	A_2=0.61
Water supplies	Available capacity as %60 of required	w	4	W=0.81
Normal protection	Only a limited number of persons trained	n	2	N=0.90
Special Protection	-by smoke or flame detectors -Sprinklers with one (public) water supply -WITH compartment protection by foam, water mist, powder, CO2, or inert gas -Full time station 24 h/24 7 days/7	s	47	S=9.91
Fire resistance	Structure:15 Walls: 60 Ceiling:15 Partitions:0	f	24.38	F=0.96 F_0=1.15
Escape protection		u	50	U=11.47
Salvage		y	13	Y=1.89
Protection Level		D=7.02	D_1=10.35	D_2=13.73
Calculated Risks		R=0.41	R_1=1.36	R_2=0.10

Table 6.2 FRAME Results Calculation for existing situation, Niccolini Theatre

6.1.5 Analysis of the results of the calculations performed

As mentioned before, in the theaters does not matter the risk of activity, and we look at the risk of building and the risk of occupants.

6.1.5.1 The Property

In the studied compartment, these results obtained by FRAME;

- The potential risk (property); P=1.40

- Acceptable risk (property); A=0.48

- Protection level (property); D=7.02

- Risk Level for building and its content; R=0.41

In this section it can be concluded that the obtained results are evaluated qualitatively and in the next step, the weakness and power points are classified according to the results and FRAME formula.

P; the Potential Risk is the expression of the severity component of a fire risk evaluation. The potential risk will thus be calculated with those elements that can contribute to a worst case scenario.

Therefore, when the potential risk is greater, the building will be more exposed to fire risk. In the Niccolini theater, this value is larger than one. In the following, we will examine the factors affecting potential risk for property.

The Potential Risk P for property, is defined as the product of the fire load factor q, the spread factor i, the area factor g, the level factor e, the venting factor v, and the access factor z.
P = q * i * v * g * e * z

The first 3 factors in the formula reflect the fire scenario: duration (factor q), development (factor i) and flashover conditions (factor v). The other 3 factors reflect the impact of the building configuration on controllability of the fire by the fire brigade: compartment characteristics (factor g), level (factor e) and access possibilities (factor z). The combination of fire scenario and the controllability define the severity of the fire risk.

Consequently, g, e and z factors that are related to building characteristics cannot be effective in reducing potential risk in this case, since this building is an existing and historic building, should prevent building change as possible.

P = q * i * v * g * e * z		
Factor	Formula	Sub Factor
q	$\frac{2}{3} \times \log(Qi + Qm) - 0.55$	Qi: immobile fire load
		Qm: mobile fire load
i	$\left(1 - \frac{T}{1000}\right) - (0.11 logm) + \frac{M}{10}$	T: Destruction Temperature
		m: Average Dimension

		M: Flame Propagation class
v	$0.84 + (0.1 \times logQm) - \sqrt{K \times \sqrt{h}}$	Qm: Mobile fire load
		h: Floor to ceiling
		K: Ventilation ratio
g	$\frac{5 \times (\sqrt[3]{(b^2 \times L)})}{200}$	b: Equivalent Width
		L: Theoretical length
e	$\left[\frac{\lvert E\rvert + 3}{\lvert E\rvert + 2}\right]^{(0.7 \times \lvert E\rvert)}$	E: Floor number
z	$1 + 0.05 \times \mathrm{INT}\left[\frac{\mathrm{b}}{20 \times \mathrm{Z}} + \frac{\mathrm{H}^+}{25} \text{ or } \frac{\mathrm{H}^-}{3}\right]$	b: Equivalent Width
		Z: The number of individual paths that allow access to space
		H^+: Vertical distance of access level to the floor of the desired space

Table 6. 3 The potential risk (property) formula, factors and sub factors due to the capability to change

(blue)	Factors reflect the impact of the building configuration
(orange)	Factors reflect the fire scenario
(green)	Sub Factors that can be changed
(yellow)	Sub factors that cannot be changed (respect of historical buildings)

A; The acceptable risk A is a measure for the exposure: The more exposure (to property, people, activities) the lower the acceptable risk is. The Acceptable Risk Levels reflect the fact that people can live with the threat of fire up to a certain level.
The Acceptable Risk Level A is defined as the maximum value 1.6 minus the activation factor a, the evacuation time factor t, and the value factor c.
A = 1.6 - a - t – c

The Acceptable Risk Level A (for the building and its content) is calculated from the maximum level 1.6, the number of fire sources (activation factor a), the priority given for the human safety (evacuation factor t) and the severity of the loss (value factor c). In order to improve the risk of fire, it should increase the acceptable risk, the value factor c is high in historical theatre because of the uniqueness of the building. Then the activation factor and evacuation time factor should be reduced in our case.

Risk reduction measures to improve the Acceptable Risk Level are separation of fire sources and improving the evacuation method. Compartmentation improves the evacuation as it shortens the evacuation path, but it is also possible to add exits (increases factor x), to install emergency lighting to reduce the risk of panic, and to provide a clearly conceived evacuation scheme. This will reduce the evacuation time and factor t.
Locating hazardous activities such as heating, painting, welding or woodwork in a separate room with a fire door is just common sense and is reflected in the FRAME calculation by lower values for the activation factor a.

A = 1.6 - a - t – c		
Factor	Formula/Explanation	Sub Factor

a	$a = \sum_{i=1}^{5} a_i$	Main activities
		Process and room
		heating systems
		Electrical Installations
		Explosion risks (NOK)
		Dust hazard (NOK)
		Secondary activities
t	$\frac{p \times x[(b+L) + \left(\frac{X}{x}\right) + (1.25 \times H^{+}) + (2 \times H^{-})] \times (b+L)}{800 \times k \times [1.4 \times x \times (b+L) - (0.44 \times X)]}$	X: Number of occupants
		L: Theoretical length (m)
		b: Equivalent Width (m)
		H^{+}: The floor space of the unit to the ground level for the upper floors (m)
		H^{-}: The floor space of the unit to the ground level for the lower floors of the earth (m)
		p: Mobility factor (without unit)
		x: Number of output units
		k: Number of separate exit directions
c	$c_1 + c_2$	c_1= the probability of replacing the building
		$c_2 = \frac{1}{4}\log(\frac{v_r}{7 \times 10^6})$ v_r: The financial value of the building and the contents (Euro) c_2: Building Finance Value Factor (without unit)

Table 6. 4The acceptable risk (property) formula, factors and sub factors due to the capability to change

(green)	Sub Factors that can be changed
(yellow)	Sub factors that cannot be changed (respect of historical buildings)/ hardly can be changed

D; The protection level is the probability component of the fire risk evaluation. The worst-case scenario will only occur when the protection fails. So the higher the protection level is, the lower the probability of a worst-case fire will be.

The Protection Level is calculated with those elements that speed up the evacuation or slow down the growth of the fire.

The Protection Level D is defined as the product of the water supply factor W, the normal protection factor N, the special protection factor S and the fire resistance factor F.

D = W * N * S * F

D = W * N * S * F			
Factor	Formula/Explanation	Sub Factors	
W	$w = \sum w_i$ $W = 0.95^w$	W1; Water storage type	
		W2; Water storage capacity	
		W3; Distribution network	
		W4; Hydrant hose connections	
		W5; Static pressure	
N	$n = \sum n_i$ $N = 0.95^n$	N1; Discovery	warning
			Call to fire brigade
			Occupants alarm
		N2; Extinguishers	
		N3; Fire hose stations	
		N4; Fire brigade arrival	
		N5; Occupants' training	
S	$s = \sum s_i$ $S = 1.05^s$	S1; Automatic fire detection	
		S2; Improved water supply	
		S3; Reserved for firefighting only/Not	
		S4; Control of water supply	
		S5; Pressure / Flow energy source	
		S6; Sprinkler protection	
		S7; Other automatic	
		S8; Responding fire station	
		S9; Industrial fire brigade	
F	$f = \frac{1}{2} f_s + \frac{1}{4} f_f + \frac{1}{8} f_d + \frac{1}{8} f_w$	Fs; Structural /compartments Ff; Outside walls	
		Fd; Ceiling or roof	
		Fw; Interior walls	

Table6.5 The protection level (property) formula, factors and sub factors due to the capability to change

(green)	Sub Factors that can be improved
(yellow)	Sub factors that cannot be improved (respect of historical buildings)/ hardly can be improved

The scenario for defining the risk for the building and its content is that of total destruction. The Protection level includes considers all elements that can reduce the probability of such total destruction: An adequate water supply to fight the fire (factor W), standard or "normal" fire protection measures (factor N), special provisions or special protection (factor S) and the fire resistance of the building elements (factor F).

The elements that increase the probability of fire damage will be calculated with "penalty" points. That is the case when the water supplies or standard protection features are deficient, which will result in values of factors W and N below 1, and in values for the Fire Risk which will increase: The numbers reflect the idea that those compartments which have not a basic protection are the worse risks.

On the other hand, special provisions for extra protection and for fireproofing are giving bonuses as they increase the level of protection for the building and its content. The factors S and F are normally higher than 1 and this reflects an improvement in the degree of protection.

R; The Fire Risk R is defined as the quotient of the Potential Risk P by the Acceptable Risk Level A and the Protection Level D
$R = P / (A * D)$

In the Niccolini theatre, the risk level is 0.41, this value express that the theatre with this situation and this protection level (7.02). In terms of fire safety have a good level. In any case, fire safety can always be increased. If the risk of fire is closer to zero, we will see a better fire situation.

6.1.5.2 The Occupants

Following results are calculated by FRAME for occupants;

- The potential risk (people); 2.49
- Acceptable risk (people); 0.18
- Protection level (people); 10.35
- Risk Level for occupants; 1.36

The FRAME results indicate that there is already a higher risk of fire for people than property; $P1=2.49 > P=1.40$

$A1=0.18 < A=0.48$

$D1=10.35 > D=7.02$ It is only the level of protection of occupants that is more than the level of protection of the building and consequently this has a positive impact on reducing the risk of fire.

$R1=1.36 > R=0.41$

This suggests that some of the sub factors that do not affect the fire risk of the property have a significant impact on the fire safety for occupants or vice versa. Then in this section we will highlight and focus on these factors more.

P1; The Potential Risk P1 is defined as the product of the fire load factor q, the spread factor i, the level factor e, the venting factor v, and the access factor z.
The scenario for assessing the risk R1 for the occupants has been defined as any beginning fire. The formula for the Potential Risk for the occupants, P1, reads thus as follows:

$P1 = q * i * e * v * z$

P1 is calculated by using five of the previously defined factors, which reflect best a developing fire, which is the likely scenario during the evacuation period of the occupants. Therefore, the area factor g is deleted from the formula, but the others are maintained: The presence of fuel is considered in the fire-load factor q; the speed of the developing fires in the spread factor i; the threat of smoke is evaluated by the venting factor v.
It should be noted that in FRAME the g-factor does not intervene in the risk assessment for the occupants. As any developing fire is considered as "worst case for people", the size of the

compartment is not considered as relevant for severity and/or probability of the risk to persons. However, the size and shape of the compartment is considered in the calculation of A1, but this is a measure for the "exposure" and is dealt with separately.

The complexity of evacuation in a high-rise building also in the historical construction as Niccolini theatre with four floor of boxes, compared to a ground level situation, the human reactions in such conditions, and difficulties encountered to bring adequate help are reflected in the formula by the level factor e, and the access factor z.

A1; The Acceptable Risk Level A1 is defined as the maximum value 1.6 minus the activation factor a, the evacuation time factor t, and the environment factor r.

A1 = 1.6 - a - t - r

change the environment factor r to lower value, reducing considerably the acceptable risk A1. Usually people are considered to be safe, when they have left building on fire: the most evident measurement for the exposure is the evacuation time. But experience learns that the fire propagation in a building is not a uniform phenomenon and that rapid fire spread is the major reason for fire victims. This means that to evaluate correctly the exposure of people, evacuation time and fire propagation shall be jointly considered. In FRAME this results in the formula:
A1 = {1.6 – a} - (t + r)

The most significant factor for fire spread is the presence of ignitable surfaces, mostly building finishing and packaging materials. This is the reason why FRAME uses an r-factor, calculated with the immobile fire load Qi (building materials) and the combustibility factor M (for the surface conditions).

$$r = 0.1\log(Q_i + 1) + \frac{M}{10}$$

r: Environment fire factor (without unit)

Q_i: Immobile fire load factor (MJ/m2)

M: Flame propagation class (without unit)

Factor	Formula	Sub Factors
r	$0.1\log(Q_i + 1) + \frac{M}{10}$	Q_i: Immobile fire load factor
		M: Flame propagation class (without unit)

(green)	Sub Factors that can be improved
(yellow)	Sub factors that cannot be improved (respect of historical buildings)/ hardly can be improved

Table6.6 The environment Factor formula, factors and sub factors due to the capability to change

The evacuation time could be calculated for the existing conditions of the compartment and its occupants. The t-factor, considering the whole path from the most remote corner of the compartment to the outside of the building, the capacity of the occupants to move, and the compression effect when too much people use the same path such as the Niccolini theater.

Multiple deaths in a fire are likely to occur where long evacuation times come together with rapid fire spread. The combined values of high t- and r-factors will result in a value of A <1, which means an increase in risk of fire.
Then in our case to improve fire risk, long evacuation times or rapid fire spread shall be modified.

D1; The Protection Level D1 is defined as the product of the normal protection factor N and the escape factor U.
D1 = N * U

For assessing the Risk R1 for the occupants defined before as any starting fire. As such, a fire can be extinguished with rather small amounts of water, thus the Water supply factor W is not considered to calculate D1.

The normal protection, fire alarm, manual firefighting and fast fire intervention are certainly of importance for reducing the growth of the fire. Therefore, the value of N is used for calculating D1.

<table>
<tr><td colspan="4">D1 = N * U</td></tr>
<tr><td>Factor</td><td>Formula/Explanation</td><td colspan="2">Sub Factors</td></tr>
<tr><td rowspan="7">N</td><td rowspan="7">$n = \sum n_i$
$N = 0.95^n$</td><td rowspan="3">N1; Discovery</td><td>warning</td></tr>
<tr><td>Call to fire brigade</td></tr>
<tr><td>Occupants alarm</td></tr>
<tr><td colspan="2">N2; Extinguishers</td></tr>
<tr><td colspan="2">N3; Fire hose stations</td></tr>
<tr><td colspan="2">N4; Fire brigade arrival</td></tr>
<tr><td colspan="2">N5; Occupants' training</td></tr>
<tr><td rowspan="9">U</td><td rowspan="9">$u = \sum u_i$
$U = 1.05^u$</td><td colspan="2">U1; Automatic fire detection</td></tr>
<tr><td colspan="2">U2; Sub compartments</td></tr>
<tr><td rowspan="2">U3; Exit path protection</td><td>Horizontal exits</td></tr>
<tr><td>Signage and illumination</td></tr>
<tr><td colspan="2">U4; Sprinklers</td></tr>
<tr><td colspan="2">U5; Other automatic system</td></tr>
<tr><td colspan="2">U6; Smoke vents actuation</td></tr>
<tr><td colspan="2">U7; Responding fire station</td></tr>
<tr><td colspan="2">U8; Industrial fire brigade</td></tr>
</table>

Table6.7 The protection level (occupants) formula, factors and sub factors due to the capability to change

(green)	Sub Factors that can be improved
(yellow)	Sub factors that cannot be improved (respect of historical buildings)/ hardly can be improved

The escape factor U replaces the special protection factor S and the fire resistance factor in the formula for the risk calculation for the occupants. The reason for this is that both special protection and fireproofing have influence on the safety of the people, but not in the same way as for the building and its occupants.

R1; The Fire Risk R1 is defined as the quotient of the Potential Risk P1 by the Acceptable Risk Level A1 and the Protection Level D1

$R1 = P1/ (A1 * D1)$

The scenario for assessing the risk R1 for the occupants has been defined as any beginning fire.

6.1.6 Expected loss rate based on risk level

Using the calculated risk levels related to buildings and contents, the potential damage caused in case of fire can be estimated. In the FRAME according to the risk level of the building and Tables (chapter 5, table 5.29), the expected damage Buildings in percentage is predictable.

In Niccolini theater, the value of R is 0.41 less than 1, then according to the FRAME table 10% damage or less is expected.

6.1.7 Suggested solutions to improve risk level

In general, according to the reviews and the results of the FRAME software, the Niccolini historical theater has a good level of fire safety, currently. The main reason for this is the protective measures that have been implemented.

Only; the amount of risk for individuals is a bit more than one (R1=1.36) that with the proposed solutions that will be discussed below Risk of people will be acceptable. We introduce the proposed changes in the frame and get the optimal output with minimal changes.

6.1.7.1 Active Solution

For improving the risk level for occupants, the value of P1 should be decreased and A1, D1 should be increased, the following table indicates which sub factors can be changed with the active solutions.

R1 = P1/ (A1 * D1)												
Factors to be reduced	Sub factors to be reduced					Factors to be increased		Sub factors to be increased				
P1	q	i	e	v	z	A1	D1	a	t	r	N	U

Table6.8 Identify the factors that can be improved by active solutions to reduce the risk of individuals

	Sub factors that can be improved with Active solution

In the following table can be found some suggested solutions for improving the fire safety in Niccolini theatre, it should be noted that priorities take into account the cost and operationally and efficiency of the proposed solutions.

Factors	Proposed Solutions/Explanation	Prioritize by number
q ; Fire load factor	Change the contents of the building Especially seats of the auditorium and boxes in order to reducing the mobile fire load	6
i ; Spread Factor	Replacing seats and curtain of stage with more fire resistance instead of existing seats and curtain in order to improve the value of m: Average Dimension and M: Flame Propagation class	6
v ; Venting Factor	mechanical (smoke) ventilation systems installation and reducing mobile fire load in order to better Ventilation ratio.	5
a ; Activation factor	Banning, working with glue and paint (flammable materials) and welding, etc. to prepare the scene before the show without separation and follow the safety tips. Secondary activities	4
t ; Time evacuation factor	Reducing the number of audiences in order to improve time evacuation	2
N ; Normal protection factor	Normal protection is well implemented	1
U ; Escape factor	The auditorium and the box are also equipped with sprinklers	3

Table6.9 the proposed solutions with prioritize, the Niccolini theatre

In FRAME software, insert 402 total number of persons instead of 430 and in escape factor, U, and defined that whole compartment protected by sprinklers, then the following results are obtained;

R= 0.39, R1= 0.94, R2= 0.10

6.1.7.2 Passive Solution

As mentioned before, the Niccolini theatre has a comprehensive fire safety plan with a relatively good level which is why the safety results are acceptable. Since the historic building is a cultural heritage Therefore, priority is the active solution to prevent a change in the building.

In this study, it was found that by presenting a complete and appropriate safety plan, the concerns about the safety of the fire can be eliminated and there is no need for changes in the structure and architecture and materials of the building.

6.2 Case Study N.2: The Pergola Theater

The Teatro della Pergola is a historic opera house in Florence, Italy. It is located in the center of the city on the Via della Pergola, from which the theatre takes its name. Below is a picture(Fig

Figure 6.7 3D Google Map Photo of the Pergola theater

6.7) of the location of this building as well as a table of general information.

District	Historical Center City
Location	Via Della Pergola 12/32, Florence, Italy
Building Name	Pergola theater
Construction	1656
Capacity	About 1000 seats
Property	Academic Real Estate Cardinal Gian Carlo de' Medici The Grand Dukes of Tuscany
Architects, Engineers	Ferdinando Tacca Luca Ristorini Baccani
Painters, Sculptors, Decorators	No data detected.
Famous men	Cardinal Gian Carlo de' Medici

Table 6.10 The information of Pergola theater

6.2.1 History of The Pergola Theater

It was built in 1656 under the patronage of Cardinal Gian Carlo de' Medici to designs by the architect Ferdinando Tacca, son of the sculptor Pietro Tacca. It has two auditoria, the Sala Grande, with 1,500 seats, and the Saloncino, a former ballroom located upstairs which has been used as a recital hall since 1804 and which seats 400.

Figure 6.8 The Pergola Theatre, view from stage
Ref; Available on official site of the Pergola Theatre

Figure 6.9 The Pergola Theatre, view from auditorium to stage
Ref; Available on official site of the Pergola Theatre

The Pergola has exceeded 350 years since the inauguration with the comic opera Il podestà di Colognole by Giovanni Andrea Moniglia, which began a long series of shows. It was the Academic Real Estate, a group of nobles dedicated to the cultivation of the arts, who identified the ideal site where to build a building capable of replacing the Teatro del Cocomero (The Niccolini Theater), judged too small for academic activities.

On a project by Ferdinando Tacca, a unique room was built, probably inspired by the way in which the spectacles that occurred in the courtyards of Renaissance palaces. Thus the boxes were built, a peculiar feature of the Italian theater that was born with the Pergola: small separate spaces that allow each family to admire the show from a privileged position.

Currently there are only two owned boxes: one remained for the Real Estate, and another one reserved for the theater director. the inimitable acoustics enhances the voice qualities of the greatest actors, and is largely due to horseshoe-shaped plan.

Work on completing the interior was finished in 1661, in time for the celebration of the wedding of the future grand duke Cosimo III de' Medici. Theatre used by the Grand Dukes of Tuscany, it was only after 1718 that it was opened to the public.

In 1801, on the first floor, the Saloncino, designed by the architect Luca Ristorini, was opened, a large room with stuccos dedicated to music and dance (completely restored in 2000, today it is the second hall of the theater. The same Ristorini had some years before, in 1789, completed the works for the renovation of the great hall, with the construction of the royal box and the increase in the number of boxes.

These expansions are the prelude to one of the most fruitful periods in the history of the Pergola, the one marked between 1823 and 1855 by the management of Alessandro Lanari.

The architect Baccani presides over important modernization works, which give the building the Atrium of the Columns with its characteristic decorations.

The theater is lit by gas lamps, and Florence enjoys the rank of capital of Italy. The Buildings sell a share of the Academy to the King Vittorio Emanuele II, of which the sovereign enters to make full part. Financial problems begin for academics, partially solved thanks to the intervention of the Municipality of Florence. When the electric light arrives in 1898, it throws its rays on a theater in crisis.

Figure 6.10 Exterior of the Teatro della Pergola
Ref; Available on official site of the Pergola Theatre

Figure 6.11 The Stage of Pergola theatre
Ref; Available on official site of the Pergola Theatre

Figure 6. 12 The seats of Pergola theatre
Ref; Available on official site of the Pergola Theatre

The Pergola's present appearance dates from an 1855-57 remodeling; it has the traditional horseshoe-shaped auditorium with three rings of boxes and topped with a gallery. It seats 1,000. It was declared a national monument in 1925 and has been restored at least twice since.

6.2.2 Collecting the required data

As mentioned, for using FRAME method a comprehensive information is needed from the structure, walls, ceiling and partition's material to electrical installation and heating systems and fire safety/emergency plan.

Most of this information was taken by my professors from the theater authorities, it is worth noting that this comprehensive information, especially Fire Safety/Emergency Plan, is not publicly available and it is difficult to access.

The other data that most of them are related to the protection level calculation was provided with correspondence with Florence's fire station.

6.2.3 Determine the compartment to be studied

In the Pergola theatre similar the Niccolini theatre, the three sections; the auditorium, stage and boxes are considered as a compartment for reviewing.

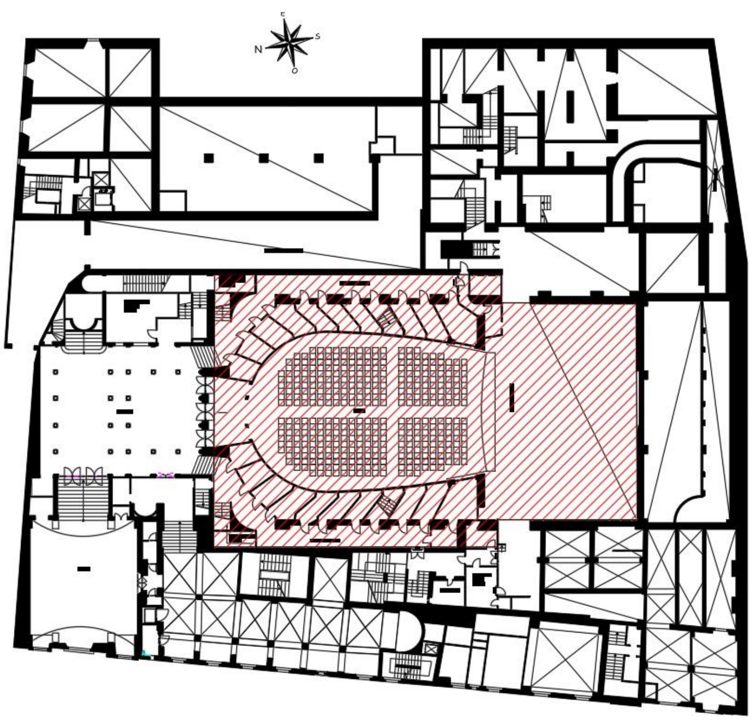

Figure 6.8 Plan of the Compartment (Defined with the Red Line)
Ref; Authorities of the Pergola Theatre

6.2.4 Input data and Calculating; P, A, D and R for Property, Occupants and Activities

The following table is an overview of the calculation of the Pergola theater with FRAME. The FRAME computing sheets for the Pergola theater are documented in Appendix B.

Item	Explanation	(sub) factor	Value	Result
Fire load immobile		Qi	1000	q=1.65
Fire load mobile		Qm	500	
Temperature rise		T	200	i=1.17
Average dimension		m	0.22	
Reaction to fire		M	3.0	
Length		l	40	g=0.56
Width		b	24.50	
Level		E	3	e=1.22
Height of room		h	2.7	V=1.07
Ventilation		K		
Access direction		Z	3	Z=1.00
Height difference		H	12.40	
Potential Risks		P=0.69	P_1=0.81	P_2=0.42
Activation factor	Main: public Heating: ok Electrical: ok Explosion: no Secondary: no Painting,spraying,glues, etc.: ok	a		a=0.4
Occupants		X	700	
Exits		x	13.81	
Exit directions		k	16.9	
Evacuation time factor		t	290(S)	t=0.42
Content factor	30.00 million euro - Unique	c		c=0.29
environment factor		r		r=0.6
dependency factor		d		d=0.3
Acceptable Risks		A=0.66	A_1=0.2	A_2=0.76
Water supplies	Available capacity as %80 of required	w	2	W=0.9
Normal protection	Only a limited number of persons trained	n	2	N=0.90
Special Protection	-by smoke or flame detectors -Sprinklers with two independent water supplies -WITH compartment protection by foam, water mist, powder, CO2, or inert gas -Full time station 24 h/24 7 days/7	s	56	S=15.37
Fire resistance	Structure:15 Walls: 60 Ceiling:15 Partitions:0	f	24.38	F=0.80 F_0=1.15
Escape protection	Whole compartment protected by sprinklers	u	60	U=18.68
Salvage		y	12	Y=1.80

Protection Level		D=9.95	D_1=16.82	D_2=22.48
Calculated Risks		R=0.10	R_1=0.25	R_2=0.02

Table 6.11 FRAME Results Calculation for existing situation, Pergola Theatre

6.2.5 Analysis of the results of the calculations performed

6.2.5.1 The Property

By the FRAME calculating, the following results are obtained for the building and its contents;

- Risk level, R=0.10

- Potential risk, P=0.69

- Acceptable risk, A=0.66

- Protection level, D=9.95

These results indicate that the theater is at a good level of fire safety and the safety measures implemented are sufficient.

6.2.5.2 The Occupants

The results below for the occupants show that the fire safety for the people in this historical theater is as well as fire safety for the property, one of the main reasons of this good level of protection is the sufficient water supply and also using of sprinkler in whole of the compartment.

- Risk level, R_1=0.25

- Potential risk, P_1=0.81

- Acceptable risk, A_1=0.2

- Protection level, D_1=16.82

6.2.6 Expected loss rate based on risk level

Since the risk of fire can never be zero, but this can be greatly reduced and close to zero. In this theater, the fire risk is close to zero.

As a result, the damage rate is less than 10% according to the FRAME table.

6.3 Comparing the two case studies in terms of fire safety

Both theaters are at a very good level in terms of fire safety, But the Pergola theatre has a slightly higher safety level and less risk of fire.

The main reason for this difference is the use of sprinklers in entire of compartment in Pergola theatre and also the exit ways with considering the number of audience in terms of number of exit, minimal width, distinct paths have better condition than Niccolini theater.

Below is a list of factors that have brought fire risks closer to zero in these historic buildings. Almost all of them were active and protective measures or preventive activities.

- Water supply factor
- Normal protection Factor
- Special protection factor
- Escape protection factor
- Salvage factor

6.4 Propose possible solutions

6.4.1 Proposal to provide a fire optimization model (MATLAB) in accordance with the features of the building under study

According to the FRAME method calculates the risk of fire for three different aspects separately.

Using the results of this method in the designing of fire safety provides this possibility that in designing and implementing fire safety plans in different buildings with different uses, only the results of that type of risk are considered, which is related to the use of the space under study; for example, in designing a fire safety system in a storehouse , as the main purpose of the protection of the storehouse and the contents of the storehouse, the only activities to be taken are to reduce the risk of building and its contents, thus preventing additional and ineffective activities .

In the building of the historical theater and the buildings which are historical heritage, the protection of the building is very important such as the protection of people. But activities in historical theaters due to the possibility of displacing the performance will impose low losses and cost in the fire events to these buildings. And this study in the area of activities (R2, P2, A2, D2) does not matter much.

In order to achieve acceptable fire safety design patterns, which, based on the level of fire risk, determine the level of protective measures; in the MATLAB software can be provided a software package; this software package determine the level of protection measures to reach the desired level of risk, with high speed and accuracy.

The general function of the software works in this way; the software takes information of the studied area and then, depending on the level of risk specified in the application input, will determine the level of protection activities required to reach the selected risk level.

According to the FRAME method, for each type of risk, the risk change function can be obtained from the score for various protection sub factors (w, n, s, u, y) as follows.

$$R = \frac{B \times 0.95^{-(w+n)} \times 10.5^{-s}}{1.572 - 0.039(1.05^{s} - 1)}$$

In these equations, for the risk of building and content, people and activities, the constant values of B, B1, B2, which is equal to the result of the division of potential risk on the level of acceptance, according to the conditions of each section of the study in the first part of the software, it is calculated with proper speed and accuracy; it is placed in equations as a constant value.

$$R_1 = B_1 \times 0.95^{-n} \times 1.05^{-u}$$

$$R_2 = B_2 \times 0.95^{-(w+n)} \times 1.05^{-(s+y)}$$

In fact, after calculating the coefficients B, B1, B2, for each section of the study as specifically, the risk of changes function to the protection activities is obtained. Other unknown values (w, n, s, u, y) are the score for the different parts of the protection system, which is explained in the previous sections.

Using the above functions, investigation of the impact of changing a type of protective measure to increase or decrease the level of risk with consideration of other protective activities is as simple and fast as possible.

These functions are suited to this capability; for decision making between the proposed protection alternatives; that it allows for easy comparison of the various alternatives.

In the second part of the program, the software; according to the amount of R, R1, R2 considered or the level of risk that is considered, the software will calculate the right unknown value of the equation with accuracy 0.001. According to the obtained values; and using the FRAME method guidelines, the type of protective activities is selected based on the conditions and facilities of case study.

This section of the software provides the possibility that, with consideration all the characteristics of a part of the building, the level of protective activities for it, depending on the level of risk, is determined.

If the program does not specify any amount for the unknown values (w, n, s, u, y) of the equation, that means that the highest level of protection activities may not be the chosen level of risk selected at the input of program. And it is necessary to take preventive activities to reduce the risk potential ratio to the risk acceptance level or the constant coefficient of the equation.

6.4.2 Determine the effectiveness of control measures performed in the studied unites

The performance of control activities in each sector can be evaluated according to the level of fire risk in that sector. If the activities taken have been able to provide an acceptable level of risk, they will have an appropriate effect; otherwise, and despite the existing protection activities, the risk level in the area is not acceptable, those activities will be ineffective.

In evaluating control activities based on the FRAME method, it should be noted that the primary purpose of the implementation of control activities has been in which part (buildings and contents, people and activities); Depending on the purpose of which of the three parts, the same type of risk is considered for assessing the performance of control activities, so that the actions taken are judged.

If, taking into account the existing activities, the calculated risk level is less than or equal to one indicates that the risk level is acceptable; and active and passive activities have had the necessary performance to provide adequate safety. If the risk level is greater than one, the activities are inefficient, and as the number is greater than one, the performance of the existing activities will be weaker.

6.4.3 Providing control solutions

When the potential risk and the level of acceptance are known, there is a wide range of protection systems selection. Manual protection, automatic fire detection, water spray systems, special regional protection systems, private firefighters, and etc. To find a system that is in general a suitable solution to fire protection problems, the primary selection of the protection system is based on the reference point or the same initial risk.

The initial risk determines a certain level of protection from in-structural work of the building, including the division of the building, the separation of risk, smoke ventilation, the use of fireproof materials and anti-fire buildings.

Many of these factors were considered before and during the process of calculating potential risk and acceptance levels. In fact, the initial risk is different from the general risk at the protection level.

To calculate the initial risk value, you must first calculate another value called Fire Resistance Building (F).

This value is calculated by the formula:

$$F_0 = 1 + \frac{F_s}{100} - \frac{F_s^{2.5}}{10^6}$$

In this formula, Fs is the average resistance of structural elements, such as columns, beams and load bearing walls. Which is expressed in minutes; How to obtain the resistance value of building elements in the previous steps is explained. The initial risk value is obtained from the following equation:

$$R_0 = \frac{P}{A \times F_0}$$

(P) Potential risk for building and contents (without unit)

(A) Acceptance level for building and contents (without unit)

(F) fire resistance factor (min)

After calculating the initial risk, the following protection measures can be applied using the following instructions:

Presentation of protection measures with this method to protect the building and the content; and more action may be needed to protect individuals and activities. This is inferred by using estimated risk levels for individuals and activities.

-Initial risk less than one;

Fire protection system with fire extinguishers including fire extinguisher caps, fire hose station, which is supported by firefighting interventionists. Provision of sufficient water with firefighter's intervention is required. Additional measures may be needed to protect residents.

-Initial risk value from 1 to 1.6;

An automatic fire detection fire detection system is required to provide a quick warning and response to firefighting and water supply. Some additional measures are needed to protect people and activities.

-Initial risk value from 1.6 to 4.5;

Water spray is protection system; If the initial risk is greater than 2.7, the reliability of the water supply system needs to be increased. In most cases, there is no need for additional measures to protect people, but more action may be needed to protect the activities.

-Initial risk value greater than 4.5;

Sufficient safety is not provided by the spray system; it is necessary to reduce the amount of risk by preventive measures.

To present a control solution with using risk functions, it can be used to prevent actions that do not provide acceptable risk levels. And prevented from imposing costs without proper effect.

For this purpose, the software initially calculates the potential risk and acceptance level in each section. And with respect to these two quantities, the constant coefficients of the risk functions (B, B_1, B_2) are obtained.

By using these coefficients, the risk functions and the maximum score of the various protection measures in the FRAME method, it is possible to identify the sectors that are not affordable by providing protection measures.

6.5 Conclusion

In the last chapter, two case studies have been studied to evaluate the theoretical issues in the field of historical theaters as well as fire safety, through the development of the FRAME software.

Thesis approach in selecting of case studies (Niccolini Theater and Pargola Theater) have been considered some issues; in addition to their authenticity and historicity, having the comprehensive information, including a safety plan, as well as having a history of studies and implementation of fire safety measures in these buildings.

In fact, fire safety measures in buildings that are used in this study were evaluated, according to the sensitivity and value of these buildings, they improve the level of fire safety.

According to this studies, the parts which are most at the risk of fire are; Stage, auditorium and boxes, These parts can be considered as a compartment in accordance with the conditions mentioned in the text. Therefore, the compartment is the most important part of a historical theater that has been evaluated and the rest of the building are at lower risk of fire.

The FRAME method improves the decision-making process between the alternatives of the proposed protection systems and allows an easy comparison, investigating, in a short time, the impact of changing a type of protective measure to increase or decrease the level of risk with other measures protective. In fact, with few changes to the final results of the application of the Niccolini theater, it is possible to obtain the optimal output in terms of operation, efficiency and safeguarding the cultural heritage, without changes in the structure, architecture and materials building. The choice made to reduce the number of people from 430 to 402 as an improvement action, is however economically disadvantageous for the manager resulting in a reduction in receipts of around 10%. The results of the applications to the case studies can provide the authorities responsible for protecting cultural heritage, who do not find any support in the national fire regulations, a well-defined method that allows a correct assessment of the risk of fires to which the cultural heritage is subjected and a estimate of the efficiency of fire protection measures.

Overall, the results of the frame show that in order to preserve such valuable and historically buildings, changes in the safety and security arrangements can be attained at the appropriate risk level without the need for architectural and structural changes.

As FRAME is one of the most comprehensive program in field of the fire safety and can be used for every type of buildings, we suggest that the program could be re-write and develop for historical heritage or historical theaters in MATLAB software in accordance with the features of the building under study, this proposal could be an interesting topic for the feature studies.

The study could be developed by increasing the number of case studies, could lead to the definition of guidelines to optimize the fire design of historic theaters, to which reference should be made in the event of fire prevention interventions. These guidelines would serve not only to designers, but also to theater managers, to raise awareness of the behavior of users and those working on fire prevention and protection. Furthermore, the guidelines could constitute the know-how for the improvement of fire fighting procedures and recommendations of theaters.

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Table of Figure

Appendix A; FRAME Analysis for The Niccolini Theatre

Subject of this analysis:

Building identification	Teatro Niccolini
Location	https://www.google.com/maps/d/viewer?mid=18j0aZCNTjSfaHkewZv(
Address	Via Ricasoli,3/5
City - Country	Florence,Italy

Identification of the compartment and the occupancies / activities present.

The building has the common structure of historical theaters, 2500 m² in a horseshoe-shape, with 4 levels of boxes, very thick stone and masonry walls, wooden floors, some with tiles, slate roof on massive oak structure. No effective compartmentation because of two monumental stairs joining the four levels.The compartment 466 m² , included; auditorium,boxes and stage.

Author of this calculation

Naeimeh Zarabadi

Date of this analysis: January,February 2019

Description of the Fire safety concept of the reference status

The reference situation is usually the actual status.

Description of the Fire safety concept of Variant 1.

Variant 1 describes usually the proposed improvements, e.g. automatic fire detection + fire proofing

Description of the Fire safety concept of Variant 2.

Variant 2 can be used for an alternative proposition, e.g. sprinkler protection

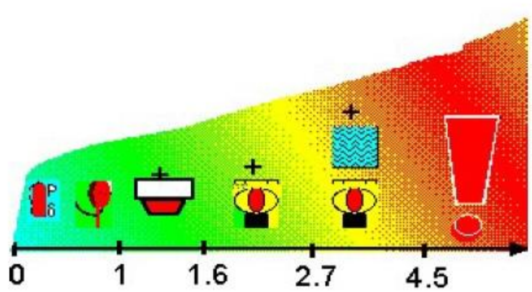
Risk for:		Reference	Variant 1	Variant 2
Property	R	0.41	#DIV/0!	0.41
Occupants	R1	1.36	#DIV/0!	1.85
Activities	R2	0.10	0.08	0.10

		Reference	Variant 1	Variant 2
Potential risk	P	1.40	1.03	1.40
	P1	2.49	1.84	2.49
	P2	0.85	0.63	0.85
To INFO P		To P-REF	To P-V1	To P-V2
Acceptable risk	A	0.48	#DIV/0!	0.46
	A1	0.18	#DIV/0!	0.16
	A2	0.61	0.61	0.61
To INFO A		To A-REF	To A-V1	To A-V2
Protection Level	D	7.02	10.32	7.26
	D1	10.35	10.35	8.51
	D2	13.73	13.73	14.42
	Fo	1.15		
To INFO D		To D-REF	To D-V1	To D-V2

Orientation Value Ro, Initial Risk **2.52**

Proposed Fire protection concept, based on Ro of "Reference" **Install sprinklers**

Info on Ro	
0	Use manual fire protection
1	Add automatic fire detection
1.6	Install sprinklers
2.7	Sprinklers with improved water supplies
4.5	Too hazardous: reduce risk



Potential risk calculation

The reference situation is usually the actual status.

DATA	Symbol	Unit				Result
Fire load factor q.						
Immobile (building) fire load density:	Qi	MJ/m²	5. Incombustible structure, combustible finishing.	1000	0	1000
Mobile (moveable) fire load density	Qm	MJ/m²	13. Dwellings	500	500	1000
			The calculated value of q is =	q	=	1.65
Fire spread factor i.						
Temperature rise	T	INFO P	4. Textile, wood, paper, food (200 °C - 400 °F)	200		200
Average dimension of content	m	INFO P	Calculated average dimension	0.33		0.33
Reaction to fire class of surfaces	M	INFO P	5. Combustible surfaces e.g. Class D per EN13501 or EN12845 cat. II	3.0		3.0
			The calculated value of i is :	i	=	1.15
Area factor g						
Theoretical length	L	m	Define the longest distance between the centres of two sides of the compartments' perimeter. This is the theoretical length l.		30.00	30.00
Total compartment area	Atot	m²	Define the total area of the compartment		466	466
Equivalent width	b	m	Divide this area by the theoretical length to obtain the equivalent width b.			15.53
Frontage			Building accessible at its long side	long		long
		INFO P	**The calculated value of g is :**	g	=	0.56
Venting factor v						
Mobile (moveable) fire load density	Qm	MJ/m²	The mobile fire load Qm, which is already entered, is used here.			1000
STEP 1 : Floor to ceiling height	h	m	*Define the average height between floor and ceiling in the compartment.*		2.8	2.8
Smoke venting ratio	k		*Define the smoke-venting ratio k as follows:*			
	STEP 2	m²	Total area of single glazed windows, glass and plastic skylights in the ceiling (roof) and upper third op the walls giving to the outside.		4.0	1.2
	STEP 3	m²	Measure the aerodynamic area of static smoke vents in m²			0.0
		Nm³/h	Nominal flow of mechanical (smoke) ventilation systems		0	0
		m²	Total area of compartment	466	ratio	0.26%
		%	The smoke venting ratio k (calculated with these values) or estimated	k=		0.26%
		INFO P	**The calculated value of v is:**	v	=	1.07
Level factor e						
Level	E	#.#	*Mezzanines and platforms : add decimal value to level number*		1.00	1.00
		INFO P	**The calculated value of e is:**	e	=	1.22
Access factor z						
The number of access directions	Z	#	The number of accessible directions is Z (1 to 4).		3	3
Height difference	H	m	Height difference in meter (positive or negative)		13.45	13.45
	b	m	already entered for factor g			15.53
		INFO P	**Access factor z**	z	=	1.00
Potential Risks						
			Potential risk values for :			
Fire load factor q.	q	1.65	property (building and content)	P	1.40	
Fire spread factor i.	i	1.15	occupants (people)	P1	2.49	
Area factor g	g	0.56	activities	P2	0.85	
Level factor e	e	1.22				
Venting factor v	v	1.07				
Access factor z	z	1.00				

Acceptable risk calculation

The reference situation is usually the actual status.

DATA	Symbol	Unit				Results
Activation factor			DEFINE all relevant situations			
Main activities	a1		01. Non industrial occupancies: offices, residential, assembly, educational	0.00		0.00
Process and room	a2		1. Heat transfer through water, steam, or solids	0.00		0.00
heating systems	a3		1. Heat generator in a fireproof separated room	0.00		0.00
	a4		1. Energy source: electricity, coal, fuel oil.	0.00		0.00
Electrical Installations.	a5		1. In compliance with the rules and regularly checked	0.00		0.00
Explosion risks.	a6		0. Not applicable	0.00		0.00
Dust hazard	a7		0. Not applicable	0.00		0.00
Secondary activities	a8		NO secondary welding operations	NOK		0.10
	a9		NO additional woodworking or use of plastics	NOK		0.10
Painting, spraying, glues, etc.	a10		3. Without separation	0.2		0.20
Others	a11		NO Special hazards (e.g. non-controllable smokers)	OK		0.00
		INFO A	**Total value of the activation factor a:**	a	=	0.40
Evacuation time factor						
	b	m	*value entered at: potential risk factor g*			15.53333
	l	m	*value entered at: potential risk factor g*			30
Number of occupants	X	persons/m²	00. User defined total number of persons in the compartment	m	430	430
Total of exit units	x	exit units	x is the number of exit units. The minimal width for an exit is 0.6 m (or 2 ft) unless law or practical conditions specify it otherwise.	9.4	45.74468	9.4
Exits to outside the building	O		Number of exits (doors and stairs) that end in the open air	1	paths:	1
DISTINCT exit paths	K	number	Calculated number of distinct exit paths:.	2.623256	gives:	2
Mobility factor	p	INFO A	B. Mobile persons needing guidance (pupils, visitors)	2		2
			NO people with limited perception of the risk present	NOK		2
			There is a clear evacuation plan:	OK		0
			There is NO danger for panic	NOK		2
		INFO A			p =	6
Equivalent length of vertical travelling path		m	*based on H+ or H- value entered at potential risk factor z*		13.45	16.8125
		second	*Calculated egress time (FRAME)*	305		
RSET		second	*As defined with EGRESS SIMULATION software*	0		
			Evacuation time factor	t	=	0.42
Content factor						
Relative value	c1		c. the contents are unique.	0.2		0.2
Absolute value of property			Actual value in million of CURRENCY (e.g. EUR, GBP, USD, SWF...)	20.00	million	EUR
Building cost index		INFO A	EURO AREA GDP DEFLATOR VALUE this year	120		
Correction for inflation			EURO AREA GDP DEFLATOR VALUE in 2000	100	in 2000:	16.67
Exchange rate		EUR	1 CURRENCY = x.yz EURO	1.0000	in EURO	
Reference value			Value in EURO , at given exchange rate and corrected for inflation			16.67
Content value factor	c2					0.09
			Content factor	c	=	0.29
Environment factor						
	Qi		*value entered at potential risk factor q*			1000
	M		*value entered at potential risk factor i*			3
			Environment factor	r	=	0.60
Dependency factor						
Added value /turnover ratio	d	INFO A	f. Average for most businesses	0.30	0.00	0.30
			Dependency factor	d	=	0.30
Acceptable Risks						
			Acceptable risk values for :			
Activation factor	a	0.40	property (building and content) = 1.6 - a - t - c	A	0.48	
Evacuation time factor	t	0.42	occupants (people) = 1.6 - a - t - r	A1	0.18	
Content factor	c	0.29	activities = 1.6 - a - c - d	A2	0.61	
Environment factor	r	0.60	**WARNING :If the value of A or A1 or A2 is lower than 0.2 or even negative,**			
Dependency factor	d	0.30	**an unacceptable risk situation exists ! CHANGE first a, t, c, r or d**			

Calculation of the Protection Level D

The reference situation is usually the actual status.

DATA	Symbol	Unit				Results
Water supply factor						
Water storage type	*w1*		1. Water storage for general use, automatically filled	0		0
Water storage capacity		m³	Estimated capacity of water storage available for fire fighting	300	m³	
		m³	Required Capacity for fire extinguishment	500	m³	
	w2		Available capacity as % of required	60%		4
Distribution network						
Nominal diameter of main water piping		mm	4. DIA 150 (6")	flow capacity	134.3	
Looped network ?			OK	total m³/h	268.6	
	w3		Distribution network supply capacity	ADEQUATE		0
Hydrant hose connections		m	Building perimeter (= 2 * (b+ l))	91.07	m	
		#	Number of available 2.5" (70) connections	20		
		#	Number of available 3" (80) connections	0		
		#	Number of available 4" (110) connections	0		
			Equivalent number of 2.5" (70) connections	20		
	w4		Average distance between connection on the building perimeter	4.55		0
Static pressure		m	*Floor level height H+ or H- + ceiling height*	16.3		
		bar	Required network static pressure	5.1	bar	
	w5	bar	Available static pressure in the distribution network	5.3	bar	0
				w	=	4
			Water supply factor	W	=	0.81
Normal protection Factor						
Discovery	*n1*		Continuous human presence , watchman service	OK		0
warning			There is also a (manually operated) warning system	OK		0
Call to fire brigade			Guaranteed transmission to the fire service	OK		0
Occupants alarm			There is also an alarm to the occupants	OK		0
Extinguishers	*n2*		1. Extinguishers adequate (type and quantity)	0		0
Fire hose stations	*n3*		1. Adequate number and location	0		0
Fire brigade arrival	*n4*		1. First fire brigade arrival in less than 10 min	0		0
Occupants' training	*n5*		2. Only a limited number of persons trained	2		2
				n	=	2
			Normal protection Factor	N	=	0.90
Special protection factor						
Automatic fire detection	*s1*		Guaranteed transmission of the detection signal to the fire brigade directly / through control room	OK		
			3. by smoke or flame detectors	8		8
			Electronic supervised system - fault monitoring	OK		2
			Individual identification of small fire zones (detector, room)	OK		2
Improved water supply	*s2*		Inexhaustible water supplies (4 times adequate)	OK		3
	s3		Reserved for fire fighting only	OK		2
Control of water supply	*s4*		Under control of building user (independent)	NOK		0
Pressure / Flow energy source	*s5*		1. Single flow/pressure source	0		0
Sprinkler protection	*s6*		1. Sprinklers with one (public) water supply	11		11
Other automatic	*s7*		1. WITH compartment protection by foam, water mist, powder, CO2, or inert gas	11		11
Responding fire station	*s8*		1. Full time station 24 h/24 7 days/7	8		8
Industrial fire brigade	*s9*		0. None	0		0
				s	=	47
			Special protection factor	S	=	9.91
Fire resistance factor						

Structural /compartments	fs	min.	Average fire resistance (REI) of the structural and separating elements:	15	min.	15
Outside walls	ff	min.	Average fire resistance of the outside walls (E = flame tightness)	60	min.	60
Ceiling or roof	fd	min.	Average fire resistance of the ceiling or the roof (RE)	15	min.	15
Interior walls	fw	min.	Average fire resistance of interior walls (EI)	0	min.	0
			Calculated weighed average for fire resistance	f	min.	24.38
			Initial structural fire resistance (structural stability only)	Fo	=	1.15
			Fire resistance factor	F	=	0.96
Escape protection factor						
Automatic fire detection	*u1*		*Some data are already entered at factor S*			
			3. by smoke or flame detectors	8	see at S	8
			Electronic supervised system - fault monitoring	OK	see at S	2
			Individual identification of small fire zones (detector, room)	OK	see at S	2
			Partial detection system, only in areas critical for people safety	OK		0
			No more than 300 persons to be warned simultaneously	NOK		0
			Evacuation alarm with spoken messages by voice communication system	OK		6
Sub compartments	*u2*		0. None	0		0
Exit path protection	*u3*		3. More than one enclosed inside stair	2		2
Horizontal exits			1. Horizontal exit to adjacent compartment min. 50% of required capacity	2		2
Signage and illumination			Exit paths completely marked and illuminated	OK		4
Sprinklers?	*u4*		1. Sprinklers only in areas with increased fire risk	5		5
Other automatic system	*u5*		1. WITH compartment protection by foam, water mist, powder, CO2, or inert gas	11	see at S	11
Smoke vents actuation	*u6*		Smoke venting actuated by automatic detection	NOK		0
Responding fire station	*u7*		1. Full time station 24 h/24 7 days/7	8	see at S	8
Industrial fire brigade	*u8*		0. None	0	see at S	0
				u	=	50
			Escape protection factor	U	=	11.47
Salvage factor						
Compartmentation	yi		0. None	0		0
PHYSICAL PROTECTION						
Detection	yi		Partial detection system, only in areas critical for business continuity	OK		0
Sprinkler			Local sprinkler protection for critical equipment	OK		0
Other systems	yi		Other LOCAL automatic extinguishing systems (CO2, foam, inert gas)	NOK		0
ORGANISATION						
FINANCIAL	yi		Safeguarded financial and economical data	OK		2
EQUIPMENT	yi		Easy access to spare parts and replacements	NOK		0
REPAIRS	yi		Repairs possible with minimal help	NOK		0
RELOCATION			Immediate transfer of activities possible	OK		4
COOPERATION	yi		Written agreements for relocation exist	OK		3
PRODUCTION CENTRES	yi		Production capacity available at more than one location	OK		4
				y	=	13
			Salvage factor	Y	=	1.89
Protection Levels D						
			Protection levels for:			
Water supply factor	W	0.81	Property	D	7.02	
Normal protection Factor	N	0.90	Occupants	D1	10.35	
Special protection factor	S	9.91	Activities	D2	13.73	
Fire resistance factor	F	0.96				
Escape protection factor	U	11.47				
Salvage factor	Y	1.89				

Appendix B; FRAME Analysis for The Pergola Theatre

Subject of this analysis:

Building identification	Teatro Della Pergola
Location	Historical District of the City
Address	Via Della Pergola 12/32
City - Country	Florence, Italy

Identification of the compartment and the occupancies / activities present.

Auditorium, Stage and Palchi

Author of this calculation

Naeimeh Zarabadi

Date of this analysis: February 2019

Description of the Fire safety concept of the reference status

The reference situation is usually the actual status.

Description of the Fire safety concept of Variant 1.

Variant 1 describes usually the proposed improvements, e.g. automatic fire detection + fire proofing

Description of the Fire safety concept of Variant 2.

Variant 2 can be used for an alternative proposition, e.g. sprinkler protection

Risk for:		Reference	Variant 1	Variant 2
Property	R	0.10	0.05	0.13
Occupants	R1	0.25	0.18	0.30
Activities	R2	0.02	0.02	0.04

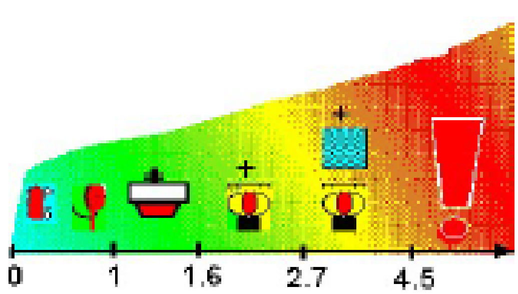
Potential risk	P	0.89	0.61	0.89
	P1	0.81	0.60	0.81
	P2	0.42	0.31	0.42
To INFO P		To P-REF	To P-V1	To P-V2
Acceptable risk	A	0.88	0.88	0.88
	A1	0.20	0.20	0.20
	A2	0.78	0.78	0.78
To INFO A		To A-REF	To A-V1	To A-V2
Protection Level	D	9.95	14.82	8.04
	D1	18.88	18.88	13.87
	D2	22.48	22.48	16.21
	Fo	1.16		
To INFO D		To D-REF	To D-V1	To D-V2

Orientation Value Ro, Initial Risk **0.91**

Proposed Fire protection concept, based on Ro

of "Reference" **Use manual fire protection**

Info on Ro	
0	Use manual fire protection
1	Add automatic fire detection
1.6	Install sprinklers
2.7	Sprinklers with improved water supplies
4.5	Too hazardous: reduce risk



Potential risk calculation

The reference situation is usually the actual status.

DATA	Symbol	Unit				Result
Fire load factor q.						
Immobile (building) fire load density:	Qi	MJ/m²	5. Incombustible structure, combustible finishing.	1000	0	1000
Mobile (moveable) fire load density	Qm	MJ/m²	13. Dwellings	500	500	1000
			The calculated value of q is =	q	=	1.65
Fire spread factor i.						
Temperature rise	T	INFO P	4. Textile, wood, paper, food (200 °C - 400 °F)	200		200
Average dimension of content	m	INFO P	Calculated average dimension	0.22		0.22
Reaction to fire class of surfaces	M	INFO P	5. Combustible surfaces e.g. Class D per EN13501 or EN12845 cat. II	3.0		3.0
			The calculated value of i is :	i	=	1.17
Area factor g						
Theoretical length	L	m	Define the longest distance between the centres of two sides of the compartments' perimeter. This is the theoretical length l.		40.00	40.00
Total compartment area	Atot	m²	Define the total area of the compartment		980	980
Equivalent width	b	m	Divide this area by the theoretical length to obtain the equivalent width b.			24.50
Frontage			Building accessible at its long side	long		long
		INFO P	**The calculated value of g is :**	g	=	0.84
Venting factor v						
Mobile (moveable) fire load density	Qm	MJ/m²	The mobile fire load Qm, which is already entered, is used here.			1000
STEP 1 : Floor to ceiling height	h	m	*Define the average height between floor and ceiling in the compartment.*		2.7	2.7
Smoke venting ratio	k		*Define the smoke-venting ratio k as follows:*			
	STEP 2	m²	Total area of single glazed windows, glass and plastic skylights in the ceiling (roof) and upper third op the walls giving to the outside.		5.7	1.7
	STEP 3	m²	Measure the aerodynamic area of static smoke vents in m²		375.0	375.0
		Nm³/h	Nominal flow of mechanical (smoke) ventilation systems		0	0
		m²	Total area of compartment	980	ratio	38.44%
		%	The smoke venting ratio k (calculated with these values) or estimated	k=		38.44%
		INFO P	**The calculated value of v is:**	v	=	0.35
Level factor e						
Level	E	#.#	*Mezzanines and platforms : add decimal value to level number*		1.00	1.00
		INFO P	**The calculated value of e is:**	e	=	1.22
Access factor z						
The number of access directions	Z	#	The number of accessible directions is Z (1 to 4).		3	3
Height difference	H	m	Height difference in meter (positive or negative)		12.40	12.40
	b	m	already entered for factor g			24.50
		INFO P	**Access factor z**	z	=	1.00

Potential Risks

			Potential risk values for :		
Fire load factor q.	q	1.65	property (building and content)	P	0.69
Fire spread factor i.	i	1.17	occupants (people)	P1	0.81
Area factor g	g	0.84	activities	P2	0.42
Level factor e	e	1.22			
Venting factor v	v	0.35			
Access factor z	z	1.00			

Teatro Della Pergola — **Auditorium, Stage and Palchi**

Acceptable risk calculation

The reference situation is usually the actual status.

DATA	Symbol	Unit				Results
Activation factor			DEFINE all relevant situations			
Main activities	a1		01. Non industrial occupancies: offices, residential, assembly, educational	0.00		0.00
Process and room	a2		1. Heat transfer through water, steam, or solids	0.00		0.00
heating systems	a3		1. Heat generator in a fireproof separated room	0.00		0.00
	a4		1. Energy source: electricity, coal, fuel oil.	0.00		0.00
Electrical Installations.	a5		1. In compliance with the rules and regularly checked	0.00		0.00
Explosion risks.	a6		0. Not applicable	0.00		0.00
Dust hazard	a7		0. Not applicable	0.00		0.00
Secondary activities	a8		NO secondary welding operations	NOK		0.10
	a9		NO additional woodworking or use of plastics	NOK		0.10
Painting, spraying, glues, etc.	a10		3. Without separation	0.2		0.20
Others	a11		NO Special hazards (e.g. non-controllable smokers)	OK		0.00
		INFO A	**Total value of the activation factor a:**	a	=	0.40
Evacuation time factor						
	b	m	*value entered at: potential risk factor g*			24.5
	l	m	*value entered at: potential risk factor g*			40
Number of occupants	X	persons/m²	15. LOCAL CODE DEFINED OCCUPANT LOAD FACTOR	0.1	700	98
Total of exit units	x	exit units	x is the number of exit units. The minimal width for an exit is 0.6 m (or 2 ft) unless law or practical conditions specify it otherwise.	13.81	7.096307	13.81
Exits to outside the building	O		Number of exits (doors and stairs) that end in the open air	1	paths:	1
DISTINCT exit paths	K	number	Calculated number of distinct exit paths:	16.9102	gives:	1
Mobility factor	p	INFO A	A. Mobile and independent persons (adults, workers)	1		1
			NO people with limited perception of the risk present	NOK		2
			There is a clear evacuation plan:	OK		0
			There is NO danger for panic	NOK		2
		INFO A			p =	5
Equivalent length of vertical travelling path		m	*based on H+ or H- value entered at potential risk factor z*		12.4	15.5
		second	*Calculated egress time (FRAME)*	290		
RSET		second	*As defined with EGRESS SIMULATION software*	0		
			Evacuation time factor	t	=	0.40
Content factor						
Relative value	c1		a. the contents can be easily replaced	0		0
Absolute value of property			Actual value in million of CURRENCY (e.g. EUR, GBP, USD, SWF...)	30.00	million	EUR
Building cost index		INFO A	EURO AREA GDP DEFLATOR VALUE this year	120		
Correction for inflation			EURO AREA GDP DEFLATOR VALUE in 2000	100	in 2000:	25.00
Exchange rate		EUR	1 CURRENCY = x.yz EURO	1.0000	in EURO	
Reference value			Value in EURO , at given exchange rate and corrected for inflation			25.00
Content value factor	c2					0.14
			Content factor	c	=	0.14
Environment factor						
	Qi		*value entered at potential risk factor q*			1000
	M		*value entered at potential risk factor i*			3
			Environment factor	r	=	0.60
Dependency factor						
Added value /turnover ratio	d	INFO A	f. Average for most businesses	0.30	0.00	0.30
			Dependency factor	d	=	0.30

Acceptable Risks

			Acceptable risk values for :		
Activation factor	a	0.40	property (building and content) = 1.6 - a - t - c	A	0.66
Evacuation time factor	t	0.40	occupants (people) = 1.6 - a - t - r	A1	0.20
Content factor	c	0.14	activities = 1.6 - a - c - d	A2	0.76
Environment factor	r	0.60	**WARNING :If the value of A or A1 or A2 is lower than 0.2 or even negative,**		
Dependency factor	d	0.30	**an unacceptable risk situation exists ! CHANGE first a, t, c, r or d**		

Teatro Della Pergola — **Auditorium, Stage and Palchi**

Acceptable risk calculation

The reference situation is usually the actual status.

DATA	Symbol	Unit				Results
Activation factor			DEFINE all relevant situations			
Main activities	a1		01. Non industrial occupancies: offices, residential, assembly, educational	0.00		0.00
Process and room	a2		1. Heat transfer through water, steam, or solids	0.00		0.00
heating systems	a3		1. Heat generator in a fireproof separated room	0.00		0.00
	a4		1. Energy source: electricity, coal, fuel oil.	0.00		0.00
Electrical Installations.	a5		1. In compliance with the rules and regularly checked	0.00		0.00
Explosion risks.	a6		0. Not applicable	0.00		0.00
Dust hazard	a7		0. Not applicable	0.00		0.00
Secondary activities	a8		NO secondary welding operations	NOK		0.10
	a9		NO additional woodworking or use of plastics	NOK		0.10
Painting, spraying, glues, etc.	a10		3. Without separation	0.2		0.20
Others	a11		NO Special hazards (e.g. non-controllable smokers)	OK		0.00
		INFO A	**Total value of the activation factor a:**	a	=	0.40
Evacuation time factor						
	b	m	*value entered at: potential risk factor g*			24.5
	l	m	*value entered at: potential risk factor g*			40
Number of occupants	X	persons/m²	15. LOCAL CODE DEFINED OCCUPANT LOAD FACTOR	0.1	700	98
Total of exit units	x	exit units	x is the number of exit units. The minimal width for an exit is 0.6 m (or 2 ft) unless law or practical conditions specify it otherwise.	13.81	7.096307	13.81
Exits to outside the building	O		Number of exits (doors and stairs) that end in the open air	1	paths:	1
DISTINCT exit paths	K	number	Calculated number of distinct exit paths:	16.9102	gives:	1
Mobility factor	p	INFO A	A. Mobile and independent persons (adults, workers)	1		1
			NO people with limited perception of the risk present	NOK		2
			There is a clear evacuation plan:	OK		0
			There is NO danger for panic	NOK		2
		INFO A			p =	5
Equivalent length of vertical travelling path		m	*based on H+ or H- value entered at potential risk factor z*		12.4	15.5
		second	*Calculated egress time (FRAME)*	290		
RSET		second	*As defined with EGRESS SIMULATION software*	0		
			Evacuation time factor	t	=	0.40
Content factor						
Relative value	c1		a. the contents can be easily replaced	0		0
Absolute value of property			Actual value in million of CURRENCY (e.g. EUR, GBP, USD, SWF...)	30.00	million	EUR
Building cost index		INFO A	EURO AREA GDP DEFLATOR VALUE this year	120		
Correction for inflation			EURO AREA GDP DEFLATOR VALUE in 2000	100	in 2000:	25.00
Exchange rate		EUR	1 CURRENCY = x.yz EURO	1.0000	in EURO	
Reference value			Value in EURO , at given exchange rate and corrected for inflation			25.00
Content value factor	c2					0.14
			Content factor	c	=	0.14
Environment factor						
	Qi		*value entered at potential risk factor q*			1000
	M		*value entered at potential risk factor i*			3
			Environment factor	r	=	0.60
Dependency factor						
Added value /turnover ratio	d	INFO A	f. Average for most businesses	0.30	0.00	0.30
			Dependency factor	d	=	0.30

Acceptable Risks

Activation factor	a	0.40	property (building and content) = 1.6 - a - t - c	A 0.66
Evacuation time factor	t	0.40	occupants (people) = 1.6 - a - t - r	A1 0.20
Content factor	c	0.14	activities = 1.6 - a - c - d	A2 0.76
Environment factor	r	0.60	WARNING :If the value of A or A1 or A2 is lower than 0.2 or even negative,	
Dependency factor	d	0.30	an unacceptable risk situation exists ! CHANGE first a, t, c, r or d	

Acceptable risk values for : (heading of the formula column above)

Structural /compartments	fs	min.	Average fire resistance (REI) of the structural and separating elements:	15	min.	15
Outside walls	ff	min.	Average fire resistance of the outside walls (E = flame tightness)	60	min.	60
Ceiling or roof	fd	min.	Average fire resistance of the ceiling or the roof (RE)	15	min.	15
Interior walls	fw	min.	Average fire resistance of interior walls (EI)	0	min.	0
			Calculated weighed average for fire resistance	f	min.	24.38
			Initial structural fire resistance (structural stability only)	Fo	=	1.15
			Fire resistance factor	F	=	0.80
Escape protection factor						
Automatic fire detection	*u1*		*Some data are already entered at factor S*			
			3. by smoke or flame detectors	8	see at S	8
			Electronic supervised system - fault monitoring	OK	see at S	2
			Individual identification of small fire zones (detector, room)	OK	see at S	2
			Partial detection system, only in areas critical for people safety	NOK		0
			No more than 300 persons to be warned simultaneously	NOK		0
			Evacuation alarm with spoken messages by voice communication system	OK		6
Sub compartments	*u2*		2. EI60 Sub compartments (fire areas of max.1000 m²)	4		4
Exit path protection	*u3*		4. At least one enclosed and smoke protected inside stair	3		3
Horizontal exits			1. Horizontal exit to adjacent compartment min. 50% of required capacity	2		2
Signage and illumination			Exit paths completely marked and illuminated	OK		4
Sprinklers?	*u4*		2. Whole compartment protected by sprinklers	10		10
Other automatic system	*u5*		1. WITH compartment protection by foam, water mist, powder, CO2, or inert gas	11	see at S	11
Smoke vents actuation	*u6*		Smoke venting actuated by automatic detection	NOK		0
Responding fire station	*u7*		1. Full time station 24 h/24 7 days/7	8	see at S	8
Industrial fire brigade	*u8*		0. None	0	see at S	0
				u	=	60
			Escape protection factor	U	=	18.68
Salvage factor						
Compartmentation	yi		2. EI60 Sub compartments (fire areas of max.1000 m²)	4		4
PHYSICAL PROTECTION						
Detection	yi		Partial detection system, only in areas critical for business continuity	OK		0
Sprinkler			Local sprinkler protection for critical equipment	OK		0
Other systems	yi		Other LOCAL automatic extinguishing systems (CO2, foam, inert gas)	NOK		0
ORGANISATION						
FINANCIAL	yi		Safeguarded financial and economical data	OK		2
EQUIPMENT	yi		Easy access to spare parts and replacements	OK		4
REPAIRS	yi		Repairs possible with minimal help	OK		2
RELOCATION			Immediate transfer of activities possible	NOK		0
COOPERATION	yi		Written agreements for relocation exist	NOK		0
PRODUCTION CENTRES	yi		Production capacity available at more than one location	NOK		0
				y	=	12
			Salvage factor	Y	=	1.80
Protection Levels D						
			Protection levels for:			
Water supply factor	W	0.90	Property	D	9.95	
Normal protection Factor	N	0.90	Occupants	D1	16.86	
Special protection factor	S	15.37	Activities	D2	22.48	
Fire resistance factor	F	0.80				
Escape protection factor	U	18.68				
Salvage factor	Y	1.80				