INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

MANAGEMENT OF FIRE SAFETY IN BUILDINGS IN SUSTAINABLE CITIES

Two cases studies

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Jury

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1. INTRODUCTION

The current regulations for fire safety in buildings, Legal status - *Regulamento de Segurança Contra Incêndio em* Edifícios (Rules of Fire Safety in Buildings), DL (Law) n. º 220/2008 and

supplementary edicts, in addition to the passive and active measures required in design and work in-situ, presents an innovation in requiring self-protection measures, in terms of organization and security management for all buildings, including the pre-existing.

The Self-protection measures, such as, Preventive Measures, Intervention measures in case of emergency, Security Records, Fire Safety Training and Fire Simulations in buildings, are one of the most important aspects during the life of buildings [8]. We analyzed two case studies: *Caixa Geral de Depósitos* (bank), and *D. Maria II* Theatre.

The issue of sustainability was addressed from the perspective of "Sustainable Construction" and its adaptability to fire safety. The issue of Environmental Certification in Portugal, lead by environment, "LiderA": voluntary system of evaluation of sustainable construction and environment was also addressed.

This presentation is focused on: the Portuguese fire safety legislation, and on the concept of the Fire Safety Management in Buildings and its application in two case studies in Portugal, the Headquarters of Caixa Geral Depósitos and D. Maria II Theatre, both in Lisbon.

Fire Safety is based on three major areas:

- Passive measures;
- Active measures;
- Self Protection Measures

Some examples of inadequate or dangerous situations are [3]:

- Over the lifetime of a building, compartmenting is useless if wedges are used in fire doors, keeping them open during the fire;
- Evacuation routes can be inadequate if we put obstacles along the emergency exits and/or the exit doors are locked;
- Fire extinguishers out of reach, covered or out of place, or without proper maintenance;
- Fire hoses unpressurized, due to closed valves or turned off water pumps;
- Poor maintenance of emergency lighting, or due to exhausted batteries, or generators out of work;
- Automatic Detection Systems turned off, due to false alarms.

2.Caixa Geral Depósitos Headquarters

The Headquarters of CGD [1] consists of 17 floors, top and bottom floors containing only technical, distributed as follows:

- 10 Floors above ground (includes turrets);
- 7 Underground Floors (includes technical cable tunnel).

The building consists of 3 blocks (Central, East and West), in its conception and construction. The highest Block (Central), has 10 floors above ground and 7 underground floors.
The building areas are distributed as follows: Central Block – 26.500m^2; East Block – 42.500m^2 and West Block – 10.000 m^2(Figures 2.1 and 2.2)

Figures 2.1 and 2.2- Caixa Geral de Depósitos central and East Blocks

The building is rated as a tall building (higher than over 28 meters) and has great development in plant.
The building has multiple uses (mixed use): Type III (Administrative), Type II (Car Parks), Type V (Clinical / Hospital), Type VI (Entertainment), Type VII (Restaurants), Type VIII (Commerce), Type IX (Sport), Type X (Museum), Type XI (Library), and Type XII (Workshop).
The building is rated in as a 4th Category of risk taking into account several criteria: building height above ground, number of basement levels, effective number of permanent staff and visitors.

To achieve safety and security targets, the various players are grouped according to specific missions and articulated in a hierarchical structure, as shown in Figure 2.3

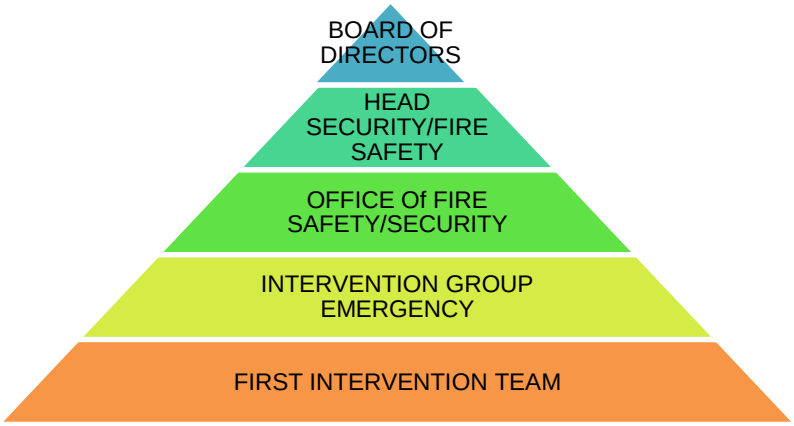


Figure 2.3 – Organisation and Management of fire

This organization is sized for two distinct functions:

1 - Maintenance / operation of equipment and systems to ensure operability;
2 – Safety and security routines and response to an emergency situation.

The Security Office bases fire security management in a correct sizing of existing human resources in the building; in order to give an adequate response to the risks arising from the building itself and from the activities developed therein.

The Head of security of the building is integrated into the Security Office, which is in charge safety and security for all buildings of Group CGD.

Response to an emergency in the building is supported upon:

- A 4 people Intervention Group for Emergency (IGE), available 24 hours a day;
- A crew chief, 24 hours a day, with the same training as GIE;
- Other elements of security staff that can be diverted to support relief operations;
- About three hundred elements belonging to First Intervention Teams, trained in first aid and firefighting;
- In case of evacuation teams, are reinforced with an element of IGE, from another CGD building nearby.

"Caixa Segura" [2]

Security Office of CGD launched in 2009 a novel civil protection program, named "Caixa Segura ". Knowing for the collective risks to which employees are exposed, it was decided spread regarding safe behavior in situations of serious accidents or disasters, in order to mitigate their effects and to protect people and property if these events occur.

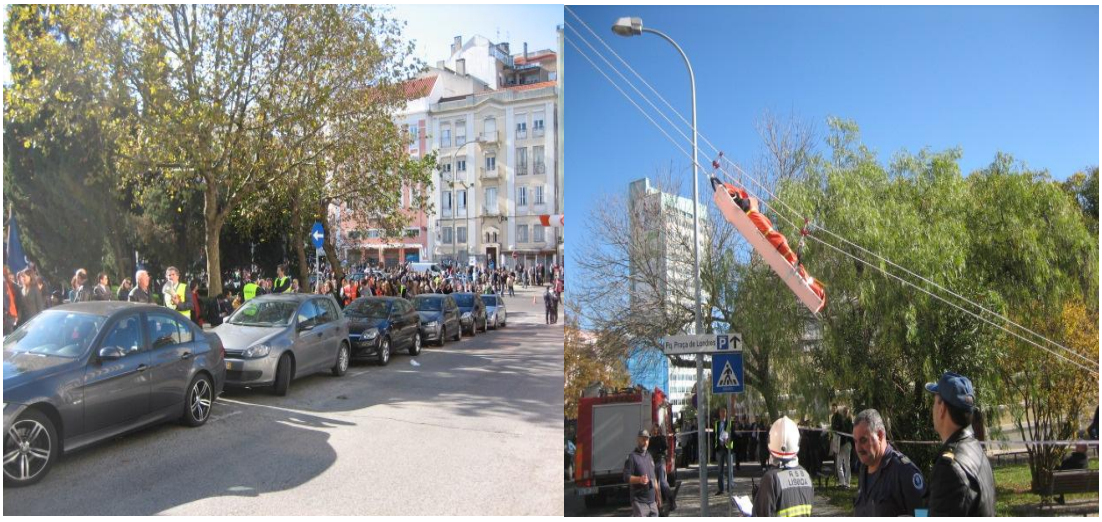
Safety engineering in the CGD group, devolved significantly with this space of awareness, information and training of measures for self-protection. This company staff learned how to behave in situations of accident / incident or emergency management, and they will transmit this knowledge to friends and relatives.

"Caixa Segura " environment aims to be an extension of the Security Office, in all matters of personal safety. This space presents itself as the first location for training, information and communication on issues of operational safety namely:

- Fire and evacuation of buildings;
- Accidents; Sudden Illness;
- Measures of self-protection for all collective risks;
- First aid and use of fire extinguishers

Simulation of incidents

During a building lifetime simulation of incidents are used to check whether the security organization is able to identify an emergency, assess their consequences, inform employees and external organizations, make decisions about protective actions and respond appropriately to the situation.
In order to evaluate the effectiveness and accuracy of the Emergency Plan is necessary it is necessary to conduct simulations in accordance with the legislation, which indicates the periodicity of this exercises indexed to Usage-Type of buildings and risk category.
The last simulation of incidents was in 24/11/2011.



Figures 1.4 and 1.5 – Simulation of incidents, 24/11/2011

3. The D. Maria II Theatre

The justification for an emergency plan is evident, but resistance to its implementation (including training sessions and practice simulations) are many. It is a combination of acceptance / denial. But it is a mixture of common sense and responsibility [John Walsh, Director of the Getty Museum].

The National Theatre D. Maria II opened in 1846, closed due to fire in 1964 and reopened in 1978, Fig. 3.1 and 3.2.

Figures 3.1 and 3.2 - Theatre D. Maria II

The building is classified as an UT VI, 3rd risk category, taking into account the following criteria: the building is for spectacles, the height of the latter occupancy level is 16.28 m, the number of floors below the reference plane are 2, and total crew of 717 persons Self-protection measures vary depending on Use - Type of the building and risk category[4].
In the case of D. Maria II Theatre the following measures are required:

- Security Registration;
- Prevention Plan;
- Internal Emergency Plan;
- Awareness sessions;
- Training and Simulations

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The Security Officer is the CEO. He provides the necessary organization in order to implement the measures of Self-Protection.
The four delegates of security are respectively the Security Prevention Chief, Building Maintenance Chief and two from Emergency Crew (one must be present whenever are public in the building).
In Theatre there are three Security stations: At the reception/, entrance of artists, Security station at Fire Detection Central (FDC), located near the entrance of artists, and finally Security station at the stage, located at the lower level onstage.

These stations have the following utilities: Security post in reception of artists, a direct telephone line for Fire Department and a siren, Security post at FDC has a keychain emergency and the Security post of the stage there is a manual control to flood the stage, manual control of irrigation system of flameproof curtain, manual control of smoke control system and direct telephone line to Fire Department.
In the Prevention Plan are listed plants of all floors referring emergency lighting, fire detection, location of fire extinguishers, location of fireplugs and forms for prevention activities and maintenance.
Maintenance actions, records of anomalies, records and other changes must be included in the dossier Security Records, which is on security post at reception and entrance of artists.

The Internal Emergency Plan aims to: organize the evacuation of occupants who are in risk and limit the spread and consequences of fires, using its own means. The actions in case of emergency are alarm procedures, alert procedures and evacuation procedures. The protection of local risk identifies in the Theatre the following hotspots: the Security stations, evacuation routes and library at its enormous value in terms of patrimony.

There are no means of partitioning to enable effective protection of these sites in case of accident, and their protection is achieved by the containment of occurrence.
The Theatre II is a success in fire safety engineering, according to the observed on-site analysis of the measures of Self-Protection and the results obtained from the calculation of the index of effectiveness of security measures, through the program FiRE-TECH, described below. It is a cultural reference in Portuguese Heritage.

4. Fire Risk versus Effectiveness Index of fire safety measures

Another objective of the present dissertation was to analyze the effectiveness index of fire safety measures, based on FiRE-TECH program. The building studied was *D. Maria II* Theatre, which is part of the built cultural heritage. The results concluded that the implemented safety measures led to fire risk reduction. The proposed methodology is presented as a tool for decision support and versatile use.

A Hierarchical Approach has been used to calculate the values of an Effectiveness Index E and corresponding to different sets of fire safety measures or “fire safety alternative”, in relation to a pre-defined fire safety policy. This approach was also used to compare the influences of the fire safety alternative on each of the pre-defined objectives. The Excel spread sheet “Cost_Effectiveness.xls” has been used for the calculations [5].

The increasing of fire is controlled by raising fire safety measure

The following case study is an application to the building “Theatre D. Maria II”. Taking the existing conditions, as the base case, one fire safety alternative is proposed and analysed and the possible benefits are compared to the initial situation.

Use of a Hierarchical Approach to calculate the Effectiveness Index E of a given set of fire safety measures

The defined hierarchy comprises the following five levels: Policy – PO, Objectives – OB, Strategies – ST, Fire Safety Measures – M and Grade of implementation of the fire safety measures – G.

Identified were 6 objectives, 5 strategies, 19 classes of fire safety measures and the corresponding 19 implementation grades.

In this way, an Effectiveness Index E(PO), Figure 4.1, can be defined for a given fire safety alternative in relation to the pre-defined policy, such that

$$E(PO) = \sum_{i=1}^{6} \sum_{j=1}^{5} \sum_{k=1}^{19} OB(i) \cdot ST(ji) \cdot M(kj) \cdot G(k) \quad (1)$$

The policy in this analysis will be, Reduce the fire risk, because this study was done aiming to reduce the risk of fire in buildings in one old urban area, representing the Portuguese cultural heritage.

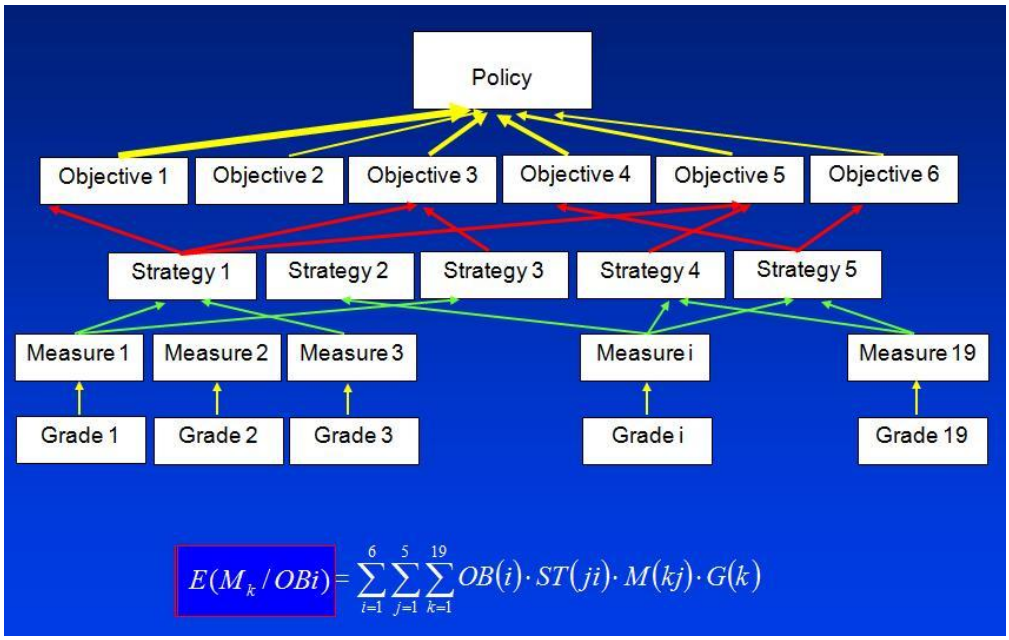

Figure 4.1 – Effectiveness Index

The results of the study are supposed to provide guidance on the most effective fire safety measures to be promoted to achieve the pre-defined policy.

The specific interest in this case is to protect this urban area for what it represents in terms of the past of Lisbon. In general, the following 6 objectives should be considered: OB1 - Protect the occupants, OB2 - Protect the firemen, OB3 - Protect the building, OB4 – Protect the contents, OB5 - Safeguard continuity of activity and OB6 - Protect the environment.

Now to the important but somehow difficult task of weighing the importance of each of the objectives on the above defined policy. This is clearly a political task. Usually, the protection of the life of the occupants would receive the highest score. Bearing in mind that we have here the particular intention of protecting this old urban area from fire, we have weighed equally the protection of the life of the occupants and the protection of the urban environment and the protection of the building. The scores attributed to the objectives above can be found in Table 4.1 In order to make the task of choosing the weights in this hierarchy method easier we used a scale between zero and nine.

	OB1 Protect the occupants	OB2 Protect the firemen	OB3 Protect the building	OB4 Protect contents	OB5 Safeguard continuity of activity	OB6 Protect the environment
PO - Reduce the fire risk	9	5	9	7	5	9

Table 4.1 – Scores given to the objectives in relation to the policy

Strategy- To achieve the six objectives five different strategies are identified: ST1 - Reduce the probability of fire start, ST2 - Limit fire development/ propagation, ST3 - Facilitate egress, ST4 - Facilitate fire fighting and rescue operations and ST5 - Limit the effects of fire products

Fire safety measures -To serve these five strategies, 19 classes of fire safety measures were identified. Each class will be shortly commented next. For each strategy, these classes were then ordered in 6 groups of decreasing importance, corresponding to the scores 9, 7, 5, 3, 1 and 0.

M1 - Reaction to fire (This class of fire safety measures refers to the control of the fire reaction characteristics of the construction materials used in the building, including structural materials, coating materials and finishing materials, applied on interior as well as on exterior surfaces), **M2 - Fire resistance of the structure (**This class of fire safety measures refers to the fire resistance of the load bearing elements), **M3 - Fire resistance of partitions(**This class of fire safety measures refers to the fire resistance of all those elements from which it is expected an adequate performance on preventing the fire spread between distinct fire compartments. It includes the integrity and the insulation criteria, and also, if adequate, the load bearing criterion), **M4 - Size of fire compartments (**This class of fire safety measures aims at limiting the consequences of a fire and at facilitating the fire fighting operations. In new buildings, different floors are usually distinct fire compartments. This is often not so in old buildings, where the whole building sometimes corresponds to one single fire compartment. Correcting this in historic buildings is frequently difficult. Compensation by other fire safety measures is then the solution. Nevertheless, in some cases, it may be possible to improve the fire resistance of existing elements in order to reduce the size of a fire compartment), **M5 - Characteristics and location of the openings on the facades (**This class of fire safety measures aims at limiting the fire spread between floors), **M6 - Distance between buildings (**This class of fire safety measures is intended to limit the fire propagation between facing buildings. In old urban areas this is frequently a critical factor), **Geometry of egress paths (**This class of fire safety measures is intended to facilitate the quick egress of the building), **M8 - Access for the firemen(**This class of fire safety measures is intended to facilitate the fire fighting and rescue operations by the firemen), **M9 - Means for fire detection(**This class of fire safety measures has the purpose of detecting the fire as early as possible in order to alarm the occupants, transmit the alert to the fire brigade and begin the fire fighting operations), **M10 - Means for fire suppression(** This class of fire safety measures has the purpose of extinguishing the fire within the shortest period of time), **M11 - Smoke control(**This class of fire safety measures has the purpose of keeping the egress paths free from smoke, and of limiting the effects of smoke on people, contents and building. It also aims at facilitating the action of firemen), **M12 - Emergency and alarm signs (This** class of fire safety measures has the purpose of warning the occupants about an existing fire, to give them indications about the evacuation process and to guarantee enough visibility during the evacuation), **M13 - On site firemen(**This class of fire safety measures has the purpose of initiating the fire suppression as early as possible. On site fire brigades possess a good knowledge of the building which increases their effectiveness), **M14 - Fire brigade (**This class of fire safety measures has the purpose of fighting the fire once it has been detected and the alert transmitted. The time they need to arrive and their equipment are important factors to consider), **M15 - Maintenance of fire safety systems (**This class of fire safety measures aims at reducing the probability of failure of the fire safety systems. Inspection and testing of the fire safety systems should be done on a regular basis), **M16 - Education for fire safety(**This class of fire safety measures is intended to increase the level of knowledge of the occupants about the fire phenomena, making them aware of the correct behaviour in order to prevent fires and to limit their consequences),**M17 - Emergency planning + training(**This class of fire safety measures is intended to anticipate every possible risk, to establish the right procedure for every situation and to test these procedures), **M18 - Salvage operation management(**This class of fire safety measures consists in defining and testing in advance the set of adequate procedures to minimize the damage to the contents of the building), **M19 - Periodic inspection of the building(**This class of fire safety measures aims at identifying possible sources of fire start).

Grades of implementation of the fire safety measures - Application to the Theatre D. Maria II

In a given situation each class of fire safety measures will be implemented to a certain degree. This implementation grade ranges from zero, when the class of fire safety measures is totally absent, to the value of one, when the class is fully and satisfactorily implemented.

The hierarchical approach outlined above will in the following be applied to the case study.

Effectiveness Index of the original situation in relation to the policy

The calculated Effectiveness Index of the original situation in relation to the pre-defined policy amounts to 0.44. This is a reasonable value. A value of 1.0 would mean the implementation of all relevant fire safety measures to 100%.

Proposal to decrease the fire risk - Fire safety alternative 1

In this fire safety alternative, a proposal is made for each class of fire safety measures where an improvement is possible and feasible.

For the whole class of fire safety measures a consideration was done, that this improvement would place the implementation from 0, 8 to 1 in G.2, G.9, G.12 and G.15. The calculated Effectiveness Index of the fire safety alternative 1 in relation to the pre-defined policy amounts to 0.62, a substantial increase when compared to the initial value of 0.44. It can be argued that it is not as high as we could wish. However, it should be kept in mind that the present task was to decrease the fire risk in an existing old building, with constraints that cannot be overcome.

5. CONCLUSIONS

The main innovations in current legislation on fire safety are related to the definition of a risk category for each type of building use, and to the need for implementation of safety management and self-protection measures in all buildings (in construction or already built). The research effort has fallen not only in conception/construction, but also in operation, with significant concerns regarding its lifetime.

The creation of a safety culture is one of the purposes of these requirements related to Self-Protection Measures. These measures are essential throughout the lifetime of a building, and they are a very important factor to ensure people and property safety. In this sense it is necessary that all buildings, especially those receiving public, have risk mitigation measures; these should be adapted to the size of the building.

In the field of fire safety, multiple sustainable strategies can be applied, but all of them should induce a mitigation of fire risk, as the sustainability of cities is also reflected in buildings with high levels of efficiency in terms of fire safety.
After analysis of the two case studies, we concluded that they are successful stories in engineering fire safety:

Headquarters of CGD is one of the most iconic buildings Portugal. This is due to several factors including: size of the building, quality of the project, work performed, effective implementation of the organization / management of fire safety and “Caixa Segura”, an innovative program, created in 2009, which is a way to improve safety culture and an example to follow.

D. Maria II Theater is an historical heritage building, built after the earthquake of 1755. Despite presenting many weaknesses in terms of current fire security legislation, significant efforts were made to implement Self-protection measures. Such measures can substantially reduce fire risk and in case of accident / incident they minimize the risk of life and property loss.

Program FiRE-TECH can quantify the effectiveness index of the set of fire safety measures implemented in a building. Moreover, it also identifies the most effective fire safety measures and the ones for which investment will bring greatest benefits. It shows that very often there

are low-cost measures whose return in terms of effectiveness is often much higher than what would be expected.

In a listed building as D. Maria II Theater, we applied FiRE-TECH program and calculated the effectiveness index of self-protection measures, concluding that the implementation of these measures have largely contributed to a decrease in fire risk.

Acknowledgements

Caixa Geral de Depósitos, Board of Directors

D. Maria II, Theatre, Board of Directors

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