PERFORMANCE BASED METHODS: FIRE SAFETY IN HISTORICAL BUILDINGS

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ABSTRACT

In historical and artistic buildings it is of primary importance to reconcile the safety of people with the need to safeguard the architectural value of buildings, as well as goods contained within them – paintings, books, manuscripts, frescos, etc. In general, fire protection for historical buildings requires to identify critical materials, elements and spaces and to declare rehabilitation and preservation objectives; the main problem is the lack of documentation of fire resistance of building elements.
In Italy a lot of laws, regulations and codes are issued by competent Authorities concerning fire prevention during design and for management and maintenance of buildings with the purpose of providing a procedure applicable in all cases, but this procedure is very difficult to apply for cultural heritage preservation.

We must consider that, in the field of construction standardisation, new concepts are gaining acceptance in defining codes and design methods based on performance criteria.
Also in accordance with the EEC approach, a Ministry Decree of March 1998 specifies guidelines to evaluate fire risks in order to offer the possibility, by alternative compensation measures, to reach the same level of safety obtained with application of rigid codes and regulations.
In fire risk assessment, identification of potential hazard and people exposed to dangers of fire, classification of fire risk levels, elimination or reduction of dangers, evaluation of suitability of safety devices and suggestions concerning further measures to reduce fire risk levels are necessary.
The application of fire performance concepts to design objectives may have benefits over prescriptive recommendations in existing buildings, because the totality of the fire package is considered in order to achieve adequate and economic solutions.

The technical parameters of fire risk are very complex, because the interaction of components – fire, buildings, people – does not allow a set of calculations and procedures that can be applied to all cases.
A National University Research Group dealing with Historical and Artistic Building Conservation is especially focussing on analysis of methodologies of fire risk assessment and to evaluate options available to the designers and to the managers.

The Group aims to develop a method of fire risk analysis based on a checklist and ranking and to apply it in historical buildings used as libraries, museums and places of assembly in order to provide a level of fire safety equivalent to that called for by regulations.

The research attempts a determination of occupancy and property fire risk parameters and a selection of fire safety parameters for compatible interventions in historical building, and their respective ranges of values.

KEYWORDS

Historical buildings, fire safety, performance based methods, checklist, ranking

INTRODUCTION

This theme is related to the general issue of preservation and reuse of historically and architecturally relevant buildings. Firstly, we must emphasise that most fire safety design in such buildings is related to upgrading the systems to current standards in order to reuse the buildings.

Historical building reconfiguration requires specific case-by-case attention since general guidelines for classes of activity cannot be provided. The severity of the standards related to material characteristics and construction elements for fire safety must be adapted to the formal and historical value of the building.

The first matter to be faced concerns the knowledge of compulsory or commonly accepted regulations in Italy. Fire safety regulations consist of an articulated, complex set of legal resolutions (laws, decrees, ministry circulars) and a set of consensually accepted standards issued by official organisms such as the Central Scientific Technical Fire Safety Committee (*Comitato Centrale Tecnico Scientifico di Prevenzione Incendi*) of the Ministry for Internal Affairs in agreement with the National Standardisation Body (*Ente Nazionale Italiano di Unificazione – UNI*). In Italy, as in general in other countries, fire prevention laws are prescriptive and compulsory. Despite being bulky and continuously updated, laws can hardly cover all the possible cases. For this reason, when dealing with historical buildings, dispensation for the regulations must be set forth by competent authorities.

FIRE RISK ANALYSIS IN ITALIAN LAWS

Various different concepts have arisen since the seventies, dictated by the behaviour of users and the new possibilities offered by production. The complexity of projects and the variety of specific cases would be impossible to solve only with traditional descriptive building codes, but requires the introduction of performance based codes.
This is the meaning of Ministry for Internal Affairs' decree dated 10 March 1998 "General Fire-safety Criteria and Criteria for Managing Emergencies at Places of Work". The decree stresses that fire is a hazard, i.e. an event that can occur and as such can be prevented and managed by implementing solutions which can be formulated in terms of probability. Fire safety risk evaluations and the concept of "equivalent safety" can be applied to reach acceptable conditions of safety by means of measures based on professional skills and updated information instead of compulsory specifications.

In Italy, the fire load is calculated according to the methods and parameters specified in Ministerial Circular 91 dated 14 September 1961. Evaluating the “fire load” is a fundamental concept in safety but does not outline the actual evolution of a fire and, consequently, the material hazard in real conditions.

The trend is to pass from an authoritative, certifying system (based on fire safety official certificates issued by the fire brigade) to a self-declaration system (based on the legal responsibility of the person in charge of activities, empowered for safety management matters, and of the engineer who is in charge of designing and implementing safety works).

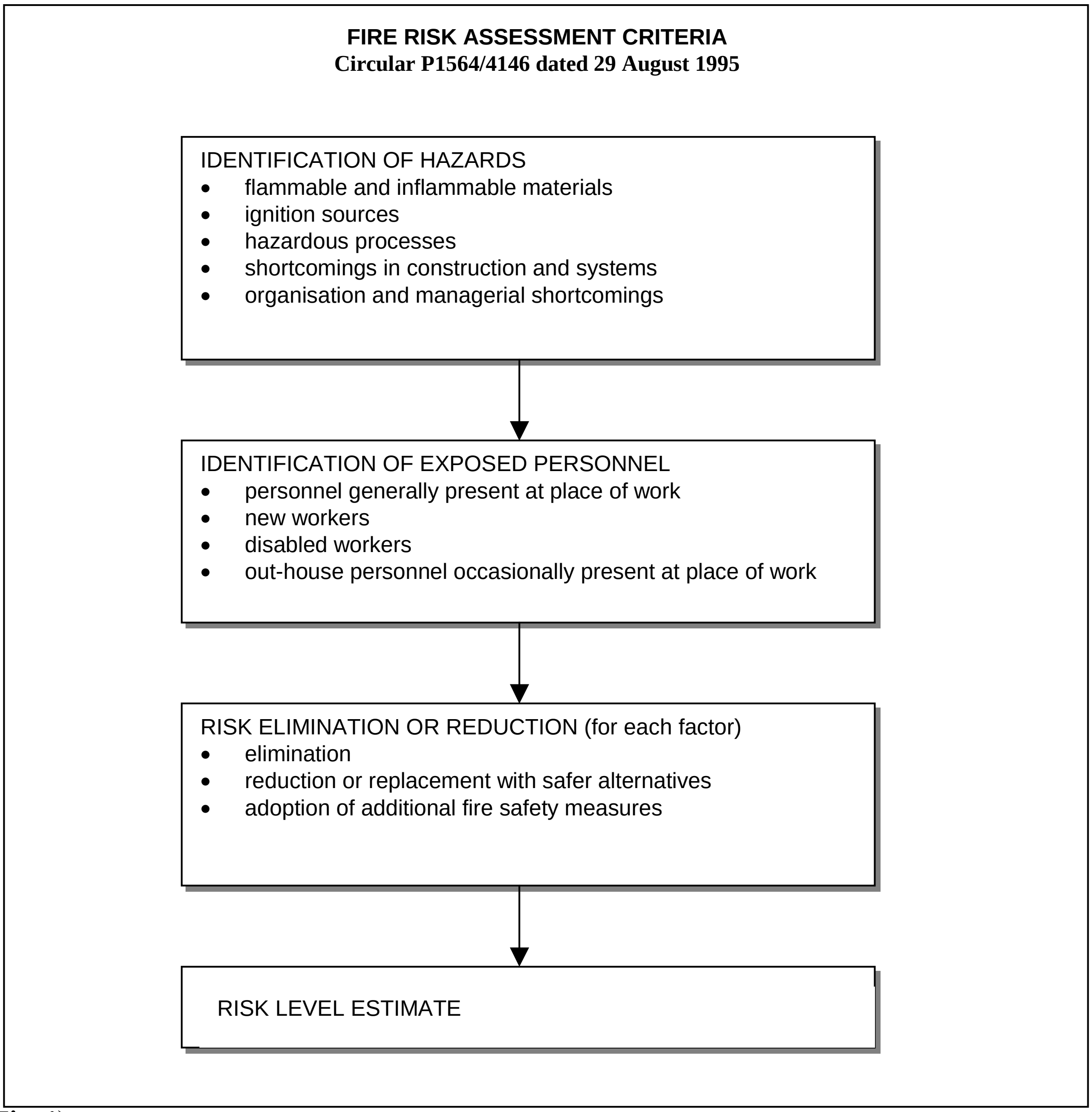
Safety assessment at places of work

Mathematical risk assessment and compensation measure analysis methods were implemented in Italian law for industrial activities in 1982 and 1989.
The general risk assessment procedure to be applied for places of work stresses entity and frequency, as well as level of exposure of the personnel to risk. Safety assessment is carried out by applying risk analysis methods, in terms of probability (frequency) and potential entity of loss and damage (magnitude) related to the fire event. The acceptable safety level is established with reference to the law and the safety measures for attaining such level are chosen in terms of costs and benefits.
The integrated approach entails the definition of safety "objectives" and the adoption of a "fire-fighting strategy", by means of:

- general "protection" measures, capable of limiting the magnitude of the fire
- "prevention" measures, capable of reducing the frequency of occurrence of fires
- "mitigation" measures, to reduce the residual risk

in accordance with national and European Community regulations for product and system certification.

The fire risk assessment criteria are shown in the following chart (Fig. 1).



(**Fig. 1**)

According to this approach, employers must:

- evaluate safety and health risks
- identify prevention and protection measures and personal protection measures
- plan the suitable measures for improving safety levels in time.

The current prospective is to establish a gradual passage towards an *integrated safety project* on overall risk assessment.

Area risk analysis

When applying risk analysis methods, the specific fire risk needs to be considered according to the most recent legal perspectives in the context of more general human and natural risks, in the area where the building is located.

General "risk analysis" methods, applicable to different civil “sources”, have been considerably developed over the past twenty years, whereby accident prevention definitions are applied to the "sources" and consequent attenuation measures are applied to "targets".

The methods are articulated in sequential phases and can be summarised as follows:

- examination of the source
- identification of accidentally generated actions
- analysis of consequences on affected targets.

The deriving procedures have reached an effective capacity, particularly in the industrial field. The methods are still scarcely developed in the case of protection of historical architectural-artistic value buildings in densely built-up historical urban areas and in green areas.

The risk definition generally used in safety engineering is given by the function:

$$\mathbf{R = f(M,P)}$$

where R is the risk, M the magnitude, i.e. the extent of the damage caused, and P the probability of the event occurring. The overall risk is given by the product of the probability of events occurring and of the estimated magnitude of the consequences of the events. The estimate can be constructed on the basis of historical data related to fires, by means of forecasting calculation tools and with the support of mathematical-analytic methods, such as the event tree. Today in Italy significant data on fire risk in historical heritage are not available.

Building fire safety analytical methods

A certain number of calculation and analysis methods have been presented and experimented on international level over the past forty years. These operative tools for designed can be classified in three groups:

1. Checklists
2. Ranking and classification methods
3. Mathematical-probabilistic models.

The first methods aim at describing the main risk situations and the most common measures for reducing said risks in simple language. Risk assessment is qualitative and referred to very general cases, so to identify *probable maximum loss* situations (*PML*). These methods aim at verifying the safety level and prospect the measures to be adopted in reference to the technical standards for experienced activities and data. The "factors" and the "measures" can generate very long checklists with consequent problems of risk factor ranking on a scale of importance, intervention priority and adaptation of the questions to the technical specifications according to rule and the characteristics of the different types of buildings.

The ranking methods in the second group better respond to specific applications. An absolute, pondered value is assigned to selected factors. Processing renders a single numeric value, which is the attained safety level. The final result can be compared against standard qualitative or numeric values or thresholds. These methods can be processed in several stages, generally structured as follows:

- Identification of fire risk factors.
- Definition of corresponding risk level.
- Planning of measures generally suited to limit the risk within acceptable limits in relation to technical specifications.
- Final overall risk assessment after applying measures.

In particular, for historical buildings, the risk factors can be estimated in a different way according to the planned activities. The measures to be applied can be selected according to the identified level and the specific characteristics of the activities and the buildings.

Finally, the analytic evaluation methods in the third group are based on mathematical-probabilistic simulation models (stochastic, network).

The mathematical-probabilistic models to be applied in high environmental risk areas or area characterised by complex activities and buildings - as well as in industrial process systems and building automation systems - are not recommended for buildings characterised by medium to low risk levels and restricted technological contents.

The method groups can be selected in a cost/benefit ratio according to the presumed risk level and the application cost:

Risk level	**Analysis-assessment method group to be applied**	**Method application costs**
High fire risk	Quantitative analysis, mathematical-probabilistic models	High
Medium fire risk	Simplified qualitative-quantitative analysis, detailed checklist methods, ranking and classification methods	Medium to low
Low fire risk	Prevalently qualitative analysis, detailed or simplified checklist methods	Low

METHOD PERSPECTIVES FOR SIMPLIFIED FIRE RISK ASSESSMENT IN HISTORICAL BUILDINGS

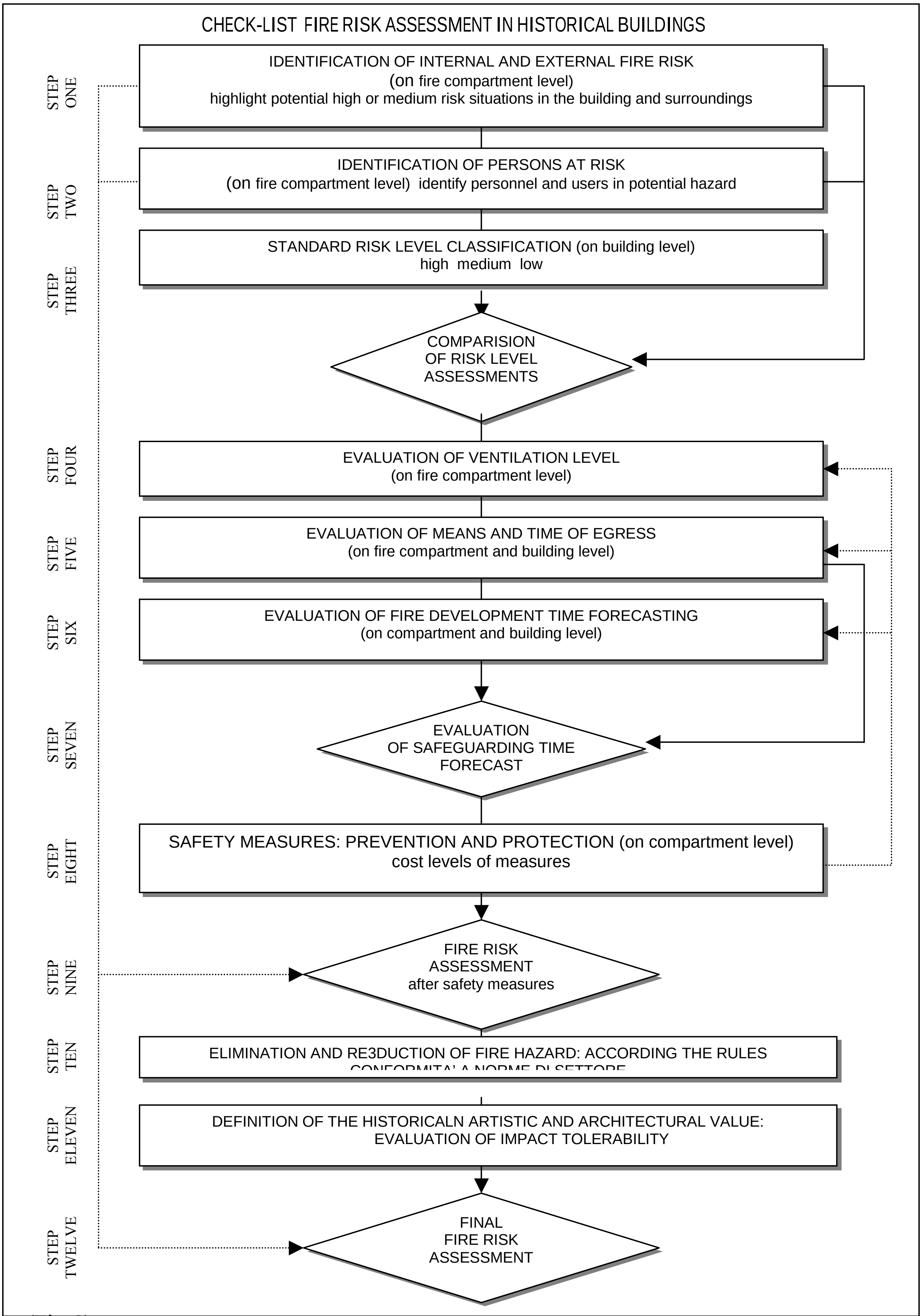
A building carrying partial or total historical-artistic relevance requires a two-fold approach aimed at protecting the physical safety of persons and safeguarding materials. The action of fire can generate large amounts of smoke, which can considerably damage surfaces also in presence of limited flames. Conversely, in the presence of major flame development, the loss of substances portions of material can be expected, particularly in the case of interior finish materials which present a high reaction to fire.
The objectives to safeguard people, to protect artistic heritage and to practice business activities are redefined in fire safety perspective:

- Reduction of possible source of fire.
- Load bearing structures stability for the time required to rescue occupants.
- Restrict generation and propagation of fire and smoke in the building and restrict propagation to buildings in the proximity.
- Possibility of occupants evacuating the building without being harmed or that occupants can be rescued in other ways considering the fire and toxic smoke development time.
- Possibility for rescue teams to work in conditions of safety.

In the specific case of fire risk assessment in historical buildings, the procedure involves:

- Identifying sources of risk.
- Identifying potential occupants, according to *pre-mobility and evacuation capacities* (low mobility users, employees, occasional occupants, resting users).
- Ranking risk level.
- Defining the "acceptable" risk, i.e. the permissible impact "corrected" according to the principle of preservation of historical values, the building, the contents of the building and the environmental context of the building, in other word defining the historical and functional vulnerability.
- Evaluating the efficacy of implemented prevention and protection instruments.
- Selecting the alternative measures to reduce or mitigate the level of risk according to the established level of tolerability.
- Outlining the specific protection and management measures for safeguarding the most valuable parts from an artistic-architectural point of view.

The analytic procedure can be defined by means of sequence of steps, i.e. choice of protection, prevention and management measures to be adopted, verified against regulatory compliance and risk level (Fig. 2).


CHECK-LIST FIRE RISK ASSESSMENT IN HISTORICAL BUILDINGS
STEP ONE
IDENTIFICATION OF INTERNAL AND EXTERNAL FIRE RISK (on fire compartment level) highlight potential high or medium risk situations in the building and surroundings
STEP TWO
IDENTIFICATION OF PERSONS AT RISK (on fire compartment level) identify personnel and users in potential hazard
STEP THREE
STANDARD RISK LEVEL CLASSIFICATION (on building level) high medium low
COMPARISION OF RISK LEVEL ASSESSMENTS
STEP FOUR
EVALUATION OF VENTILATION LEVEL (on fire compartment level)
STEP FIVE
EVALUATION OF MEANS AND TIME OF EGRESS (on fire compartment and building level)
STEP SIX
EVALUATION OF FIRE DEVELOPMENT TIME FORECASTING (on compartment and building level)
STEP SEVEN
EVALUATION OF SAFEGUARDING TIME FORECAST
STEP EIGHT
SAFETY MEASURES: PREVENTION AND PROTECTION (on compartment level) cost levels of measures
STEP NINE
FIRE RISK ASSESSMENT after safety measures
STEP TEN
ELIMINATION AND RE3DUCTION OF FIRE HAZARD: ACCORDING THE RULES
STEP ELEVEN
DEFINITION OF THE HISTORICALN ARTISTIC AND ARCHITECTURAL VALUE: EVALUATION OF IMPACT TOLERABILITY
STEP TWELVE
FINAL FIRE RISK ASSESSMENT

(Fig. 2)

The essential problems in studies of methods for analysing-assessing a widespread history wealth concern application simplicity and facility and generation of consent in risk assessment, on which the transparency of generating processes and methods depends more than accuracy of results. Qualitative risk analysis consists in systematically analysing all the possible conditions and factors in the system which may either cause the event or contribute to its occurrence.

The objective of qualitative analysis is to reach the maximum possible safety by eliminating, reducing and controlling risks.

The problem of consent is particularly complex in the case of historical buildings, for two reasons:

- the difficulty of attributing a non-economical value to the building as historical heritage
- the difficulty for experts to assess the users' perception of fire risk factors identified by means of the analysis.

From an operative point of view, the adopted method of historical building risk assessment entails:

- Analysing the risk conditions in each compartment and external area.
- Ranking the risk (high, medium, low).
- Risk reduction on the basis of the adopted protection-prevention measures.
- Finally, adoption of corrective or safety factors for safeguarding the most valuable works.

The first step of this method concerns the fire risk identification inside the building identified by risk level, due to inflammable materials, ignition sources, dangerous working procedures inside the building or fire compartment, and structure and equipment of the building (Fig. 3).

As concerns combustible and inflammable materials, inherent factors considered are both the predictable risk level, the toxicity to people following the development of smoke and gas, and the combustion speed. The risk level evaluation for particular conditions is extended to external fire dangers, taking into consideration the risk given by adjacent building blocks and by furnished or green areas.

The second step of the check list is about: a) the identification of people exposed to the danger of fire who may be in a compartment of the building; b) their ability to escape from fire, considering both their understanding of danger and their psycho-physical reaction (people with reduced ability to move because of illness or age, staff, occasional visitors, sleeping people).

Complementary checklists focusing on fire resistance, practical code definition, partitioning, interventions and prevention, evacuation route feasibility and conditions complete the method. Difficulties of *calibrating* reference values of risk indicators for historical buildings have led to preference for an indexed ranking checklist, with the possibility of assigning a risk level factor on the basis of scientific acquisitions and personal experience.

Assessment of safety measure suitability and the choice of alternative measures must follow some essential criteria:

- Knowledge and diagnostics of the conditions of the building before the intervention.
- Priority of measures assuring minimum safety.
- Minimum intervention logic, favouring restoration, repair and replacement.
- Compatible intervention cost, considering the expenditure capacity of the customer and the value of the building.
- Measures which are invisible and reversible as far as possible.
- Environmental compatibility of the material to be used to reduce problems of interfacing with laid materials, toxicity risk and combustion rapidity.
- Compatibility between measures and elements used to extinguish fires and safeguard the heritage.
- Continuous safety and monitoring plan enforced during refurbishment interventions.
- Safety management set up after rehabilitation interventions.

Considering the generally high level of protection-prevention costs in historical buildings, gradual intervention policies can be envisaged, favouring a first level of "low cost" measures which are not related to construction, i.e. user information, personnel training, organisation-managerial decisions, crowd reduction, access monitoring, systematic activity inspection and frequency interventions to remove flammable material and rubbish from specific risk activity areas and evacuation routes.

The second can include "medium cost", minor works, such as periodical inspections and maintenance interventions to maintain sufficient performance and reliability of equipment and safety, electrical equipment in general with particular reference to hazardous activity equipment, to increase safety by means of small interventions for installing-upgrading independent detection and manual extinguishing devices and to improve evacuation routes.

The third "high cost" level will include general building interventions for protecting and system works, e.g. new partitioning, replacement or addition of coverings to reduce fire reaction and toxic hazards, specific activity system modernisation, electrical system upgrading to standards, new automatic safety system (detection, warning, extinguishing, break-in alarm systems).
This checklist method consists in allocating a cost level to the identified safety measures in order to address choices as shown in the following example (Fig. 4).

The general risk level resulting from the legal classification of the risk level according to activities (DM 10.3.98) is checked against the maximum one coming out from the exact survey fixed by the check list, before and after the application of prevention and protection measures. Given the difficulty of defining acceptable safety for safeguarding historical heritage, particularly monuments, an additional "safety index" related to the particular conditions of use can be determined in addition to specific measures for decreasing the level of risk in the compartment where the high artistic-architectural value elements are located or to the entire building.

The method also consists in evaluating fire development time forecasts in the compartment and the evacuation time, in relation to the values proposed in DM 10.3.98 and in British Standards (BS 5588, *Part 6)*.

CHECK-LIST FIRE RISK ASSESSMENT IN HISTORICAL BUILDINGS **FIRE HAZARD IDENTIFICATION: INDOOR** **IGNITION SOURCES – RISK PROCESSES AND AREAS**		risk category indicators		
		high	medium	low
- machines and heat installations not adequate to standards - use of naked flames	old or temporary heating systems, not following the rules			
	old or temporary cooking equipment, not following the rules			
	portable heat equipment set, not following the rules			
	junction losses			
	open flames in heat gas equipment, in fire places			
	cooking equipment set			
	sheet metal works			
	open flames in paint stripping operations			
electrical equipment not according to standards	old electrical equipment			
	precarious electrical connections			
	electrical equipment not according to standards or used in improper manners (excessive working load, inefficient connections, faulty operation)			
	lighting appliances blowing and causing overvoltage			
	resistance-coil in contact with flammable materials			
	spark for lack of insulation			
	overhead cables for overload			
	lamps in contact with flammable materials			
	not used and not controlled supplied equipment			
human behaviors	arson risk (in areas used to store flammable or explosive materials, in shopping malls, in commercial areas, in places of assembly)			
	human error, damage risk			
	materials and elements carried and handled without caution			
	cigarette smoke (in forbidden or medium – high risk areas)			
The evaluation of the induced risk level (high, medium) is up to the specific conditions and quantities.				

(**Fig. 3**)

CHECK-LIST FIRE RISK ASSESSMENT IN HISTORICAL BUILDINGS **SAFETY MEASURE:** **PREVENTION AND PROTECTION**		cost level of measures		
		high	medium	low
FIRE DETECTION ALARM MEASURES AND SYSTEMS	installation of fire hydrants and hoses in visible, accessible points along the fire exit routes, with the exception of staircases.			
	distribution of hydrants and hoses to reach all points of the protected surface.			
	manual extinguishing media with specific notices.			
	reduction of distance with manual extinguishing media.			
	installation of automatic detection-warning system.			
	improvement of warnings to users:			
	installation of visual and acoustic warning systems.			
	installation of loudspeaker system.			
	multiple stage warning system in specific hazard, complex buildings.			
	activity reallocation for immediate fire spark identification.			
	manually operating alarm warning system upgrading to currently enforced standards.			
	installation of alarm warning system activation buttons.			
	maximum distance to each manual alarm device ≤ 30 m.			
	alarm warning system activation buttons arranged in the same point on all floor and near fire exits.			
	silent warning light system (not used as the only alarm).			

FIRE DETECTION ALARM MEASURES AND SYSTEMS	installation of multiple stage evacuation system alarm complying with technical standards: continuous acoustic alarm in fire compartments and discontinuous acoustic alarm in other compartments.			
	specific risk and artistic-architectural value buildings which fire-fighting height is > 24 m: integrated electrical alarm system and floor surveillance system.			
	installation of automatic fire detection system to alert persons in time and to warn of fires in areas which are not signed.			
	integration between automatic detection system and manual control system.			
EXTERNAL SPACE ARRANGEMENT	creation of empty spaces to prevent fire propagation to surrounding vegetation at risk.			
	creation of barriers and partitioning walls with respect to surrounding uncultivated vegetation at risk.			

(**Fig. 4**)

The determination - necessarily approximate - of the significant time available between evacuation of persons and fire flash-over allows identification of a "safeguarding time" in which emergency teams can work either to protect high historical, architectural and artistic value works or to intervene with localised, non-invasive extinguishing actions.
The method's focus on "time" aims at improving the range of choices of the measures to be adopted.
Besides, the method implies the definition of the historical, artistic and architectural value of historical buildings and of what they house.
The final phase of the proposed method consists in evaluating the tolerability of the impact according to safeguarding issues, as illustrated in the following table (Fig. 5).

CONCLUSIONS

Specific methods, such as checklists or ranking methods which account for specific typology-constructive factors, furniture-contents and "external" factors, due to the morphology of the urban or natural context, should be favoured for historical buildings. The proposed method is not universally feasible unless a case by case statement of the values allocated to each parameter. However current checklists should work as starting reference document to be detailed every time.

<table>
<tr><td colspan="2" rowspan="2">CHECK-LIST FIRE RISK ASSESSMENT IN HISTORICAL BUILDINGS
EVALUATION OF IMPACT TOLERABILITY

HISTORICAL – ARTISTIC - ARCHITECTURAL VALUE ELEMENTS</td><td colspan="3">overall level of risk in compartment or room</td><td colspan="2">tolerable risk level</td></tr>
<tr><td>high</td><td>medium</td><td>low</td><td>medium</td><td>low</td></tr>
<tr><td rowspan="3">VALUABLE FEATURES AND ELEMENTS</td><td>Presence of single high artistic value elements</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Presence of valuable groups</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Presence of buildings with decorative apparatus and generally valuable structures</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">As a general criteria, the compartment ambient of a high value element should not present specific risk conditions. Consequently, safety measures will be adopted to reduce general risk in the compartment.</td></tr>
<tr><td colspan="2">Must additional risk reduction measures be adopted?
Must additional risk reduction measures be adopted , beside those provided from the control cards:
ELIMINATION AND REDUCTION OF FIRE DANGERS – SAFETY, PREVENTION AND PROTECTION MEASURES
to reach the tolerable risk level?</td><td colspan="3">YES</td><td colspan="2">NO</td></tr>
<tr><td rowspan="9">SPECIFIC MEASURES FOR ENSURING SAFETY OF VALUABLE ELEMENTS</td><td>Valuable element protection measures:</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Additional compartments</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Protections, barriers, etc.</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Better ventilation</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Valuable element protection measures:</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Detection and manual warning devices (fire, smoke)</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Additional extinguishing devices (compatible with valuable element safeguarding principles)</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Automatic detection-signalling systems</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Automatic extinguishing systems (compatible with valuable element safeguarding principles)</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td rowspan="3">MANAGEMENT MEASURES</td><td>Formation of personnel for safeguarding activities during the emergency</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Continuous surveillance personnel requirements</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Overcrowding and access monitoring personnel requirements</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="2">FINAL RISK LEVEL EVALUATION
AFTER THE ADOPTION OF ADDITIONAL MEASURES</td><td colspan="3">tolerable risk level</td><td colspan="2">attained risk level</td></tr>
<tr><td colspan="2">medium</td><td>low</td><td>medium</td><td>low</td></tr>
</table>

(**Fig. 5**)

During this research we have found it impossible to foresee an indexed method with parameters and values applicable to every structural typology and activity sector of historical buildings, but we have pointed out the need to define values case by case, taking into account general check lists. In general, as shown, the interactions of the analysis-evaluation methods must be systematic and take account also of economical and quality requirements with technical standard and code specifications and the most general principles of management and decision making.

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