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Building 'Fire Safety Case' in Operation: a structured approach to manage fire safety during lifecycle of the built assets

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Introduction

The presence of high-rise buildings made of innovative materials (including cladding, insulation), coupled with the architectural complexity, has thrown up a global challenge to fire safety, which, as is well known from press reports from Milan, Valencia and London in recent years, has been severely tested by "relatively few" but absolutely severe events in terms of magnitude and loss of life.

All of this has led the scientific world to question how to improve the fire safety of these buildings even at the design stage, and significant strides are being made every day. However, it should be pointed out that this improvement footprint affects only newly constructed buildings. It is therefore essential to ensure a structured approach to fire risk management over time in the operational phase, not only for new buildings but also, and especially, for existing buildings. This approach, hinged in the Safety Case, then becomes extendable to other building types, such as protected historic buildings, a case study of which will be presented.

The Safety Case approach

A safety case is a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment. A building can be considered a complex socio-technical system and the 'safety case' approach can also be applied to it. The safety case contains a structured argument (rationale) demonstrating that the evidence contained therein is sufficient to show that the system is safe. The argument should be commensurate with the potential risk, the system's complexity, the novelty of approach or technology, the uncertainty of the context of use, etc. The distinction between claims, arguments and evidence is very important, because it provides a common language and notation, it helps build a logical structure and it allows for focus on each component and their relationship, thus enforcing the reasoning, helping the communication and facing the challenge.

Both the CAE (Claim-Argument-Evidence) and the GSN (Goal-Structuring-Notation) are two well established graphical notations to practically achieve these objectives.

The core node types are broadly equivalent for CAE and GSN notation (Claim – Goal, Argument – Strategy, Evidence – solution). The goal type in GSN is really a claim, as per the GSN standard.

Moreover, for both the two notations, the nodes are linked to show lines of support for each argument element, and each branch ends with evidence, solutions or data. As shown in the following figures, the two notations use different shapes and the GSN has much more elements. This does not mean that one method is more efficient that the other, simply the CAE puts more emphasis on supporting narrative. Even if the arrows direction is different, the semantics are the same.

Claim / Goal

A claim is an asserted position the author is putting forward for acceptance. It can be determined to true or false and are often in the form "noun phrase verb phrase", avoiding to describe just activities or things and usually including a qualifier.

Argument/strategy

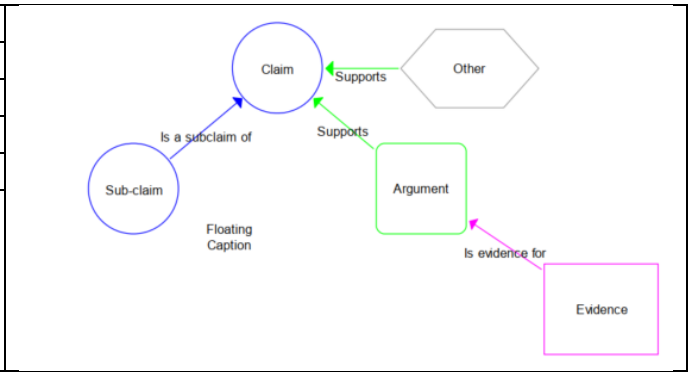
It is used to clarify and to declare the taken approach. Usually they seem to be "self-evident", like prescription by standards or laws.

Evidence

The purpose of the evidence is to ground the argument. Evidence nodes are intended to be factual, not loaded with evaluation, generally non-contentious. Evidence node titles are usually noun phrases, depicting "things in the world", like reports, testing results, and written procedures.

CAE – Safety Argumentations notation

Node type	Graphical notation
Claim	Blue ellipse
Argument	Green rounded rectangle
Evidence	Pink rectangle
Other	Grey hexagon
Caption	Transparent



The Bow-Tie for fire risk barrier visualization and management

Fire risk management for buildings, once context analysis and risk assessment are completed, results almost entirely in the management of fire risk control measures, or barriers. Managing risk over time, ensuring that it remains within certain acceptability values, effectively means ensuring that the measures put in place by the organization to contain the risk remain intact, effective and efficient over time. This approach is completely compliant with the framework of the ISO 31000 standard for risk management and can be adopted for the implementation of modern risk-based HLSs. The barrier is, therefore, a measure of control or grouping of control elements that, in itself, can prevent the development of a cause in a top event (preventive barrier) or can mitigate the consequences of the top event once it has manifested itself (mitigating barrier).

From this perspective, the Bow-Tie, based on the well-known Swiss Cheese Model by James Reason, seems the right methodology for the objective being analysed in this paper.

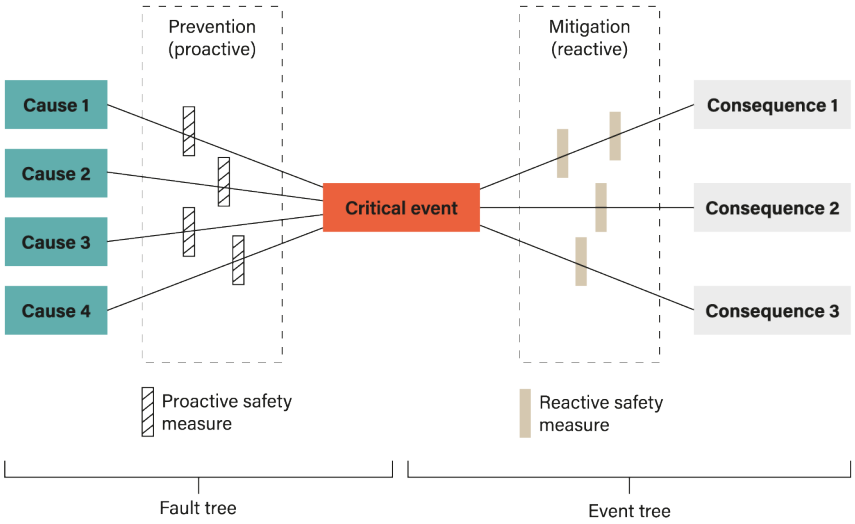


Figure 1: Typical structure of a BowTie

Case study

Building description

Case study relates to a listed historic building located in Milano near “Duomo” Cathedral.

Figure 2: Building under consideration

Building consists of a set of units developed over three bodies having different occupancies (libraries, offices, archives, residences, commercial spaces including some shops) pertaining to a single manager. Both the property kept in the libraries spaces and the buildings housing have historical/artistic significance and are subject to the protection of the local Superintendency of Cultural Heritage.

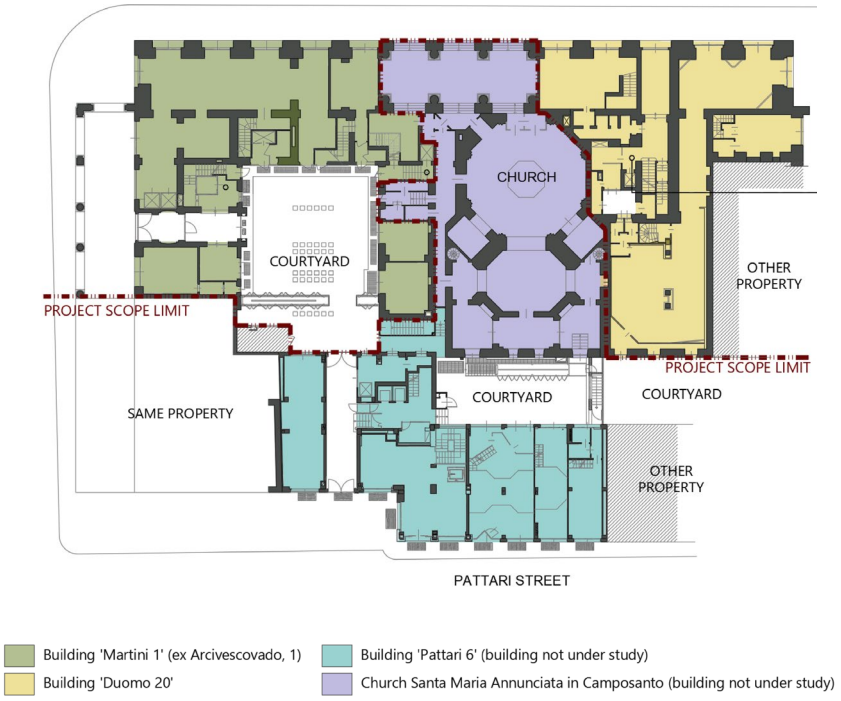


Figure 3: Building under consideration - Portions

The assessment of the building is part of a specific study from (Fiorentini, 2022). A portion of the building has been selected as case study for the development of a fire safety case. As identified later in this document the selected portion is fire compartment 'M1". It includes staircase S.1, the offices of the main owner as well as offices of third parties and residences rented to third parties. Fire safety case has been developed for the "Martini 1" and "Duomo 20" building units, while the safety case considers the remaining units ("Pattari 6" and the internal church) as functional connections.

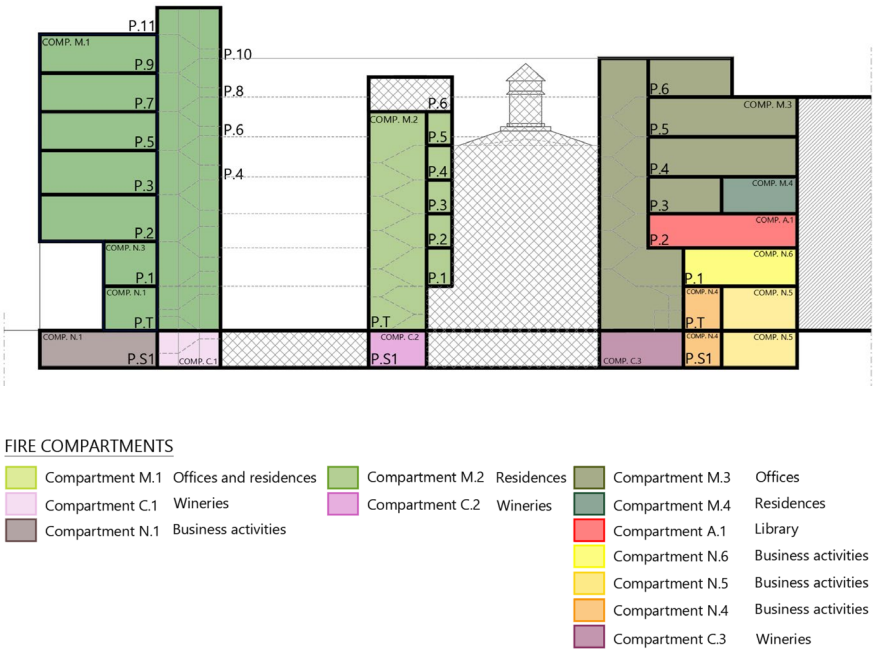


Figure 4: Fire compartment

The “Emergency exodus of occupants” performance-based strategy

Fire safety strategies, as defined by the Italian legislation, have been verified with compliant solutions (fire safety achieved via prescriptive requirements given by the applicable regulations) with the exception of the strategy “emergency exodus of occupants” where an alternative solution has to be defined and verified with a performance-based approach, due to the length of the emergency paths exceeding the max length for a compliant solution. Performance based approach demonstrated that occupants are able to reach a safe place before the fire leads to incapacitating conditions.

Performance-based approach has been based on specific scenarios defined by a fire risk assessment.

Through the use of advanced calculation methods, aimed at verifying the performance design for the protection of life, in accordance with the ASET/RSET criterion given by the Italian fire code where ASET is the available safe egress time and RSET is the required safe egress time. Criterion is verified if: RSET < ASET.

The fire scenarios represent a schematization of the most severe events that can reasonably be expected to occur in the activity (credible worst-case scenarios) in relation to the characteristics of the hearth, building, and occupants. The scenarios assumed are taken from the NFPA 914 standard (NFPA, 2023).

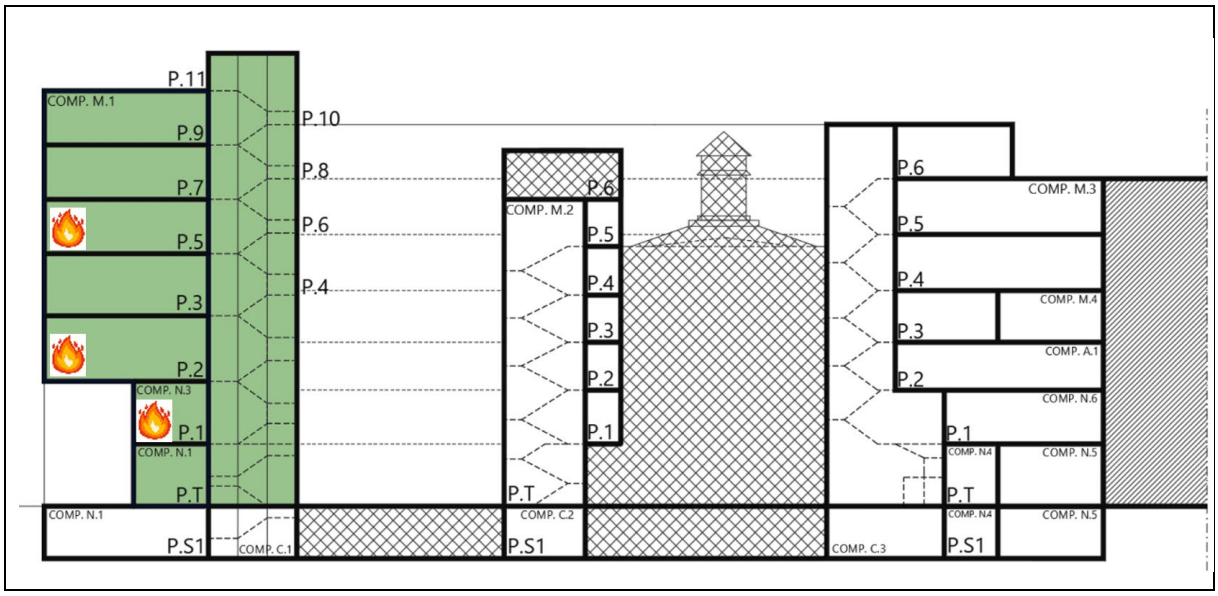


Figure 5: Fire scenarios localization

Performance based assessment for the scenario identified involved a number of activities aimed to verify different alternative strategies, as summarized, for scenario 1 in compartment M1 in the following figure.

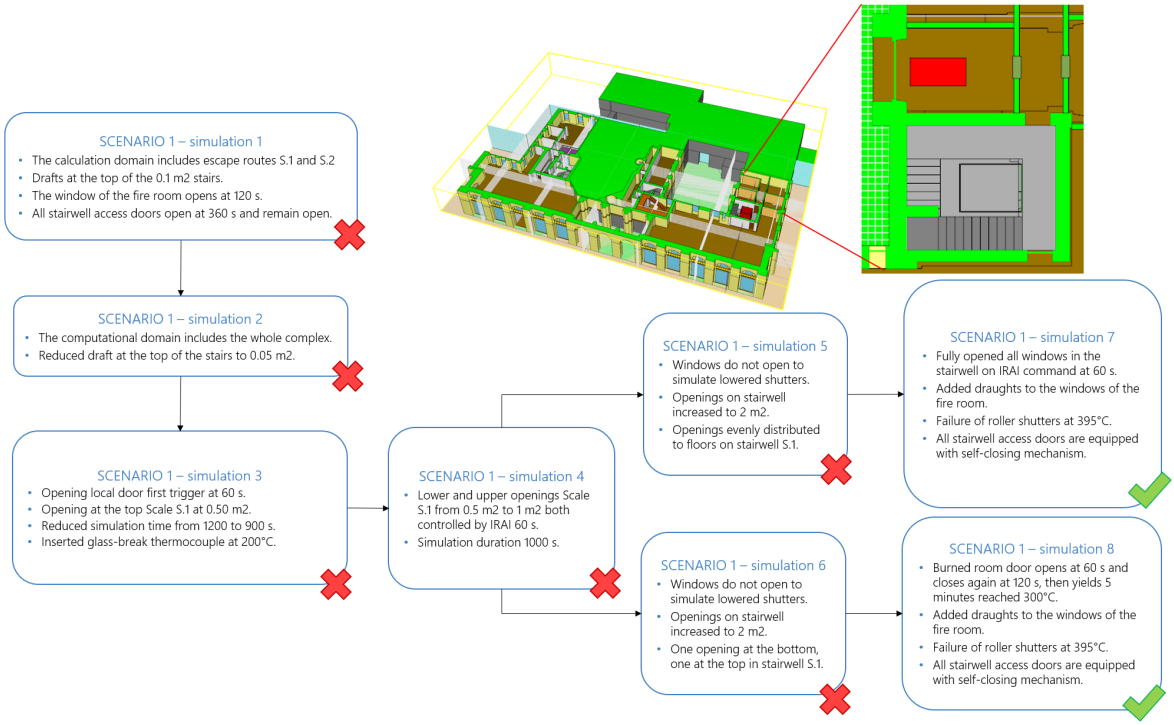


Figure 6: Compartment M1 - Outline of verifications

The Fire Safety Case Template

A specific template, using CAE notation, has been defined for each building life-cycle phases considering the Italian fire safety regulation as per the following Table.

Table 1: Fire safety case template structure

TAG	SC Design / Operation Phase	Goal	Building Life Cycle Phase
FSC-1A	DESIGN	Conceptual and executive summary	Conceptual
FSC-1B		Fire safety design	Detailed engineering
FSC-2A	OPERATION	Fire safety in final configuration	Construction
FSC-2B		Fire safety management	Operation

The following template refers to the fire safety management phase (FSC-2B).

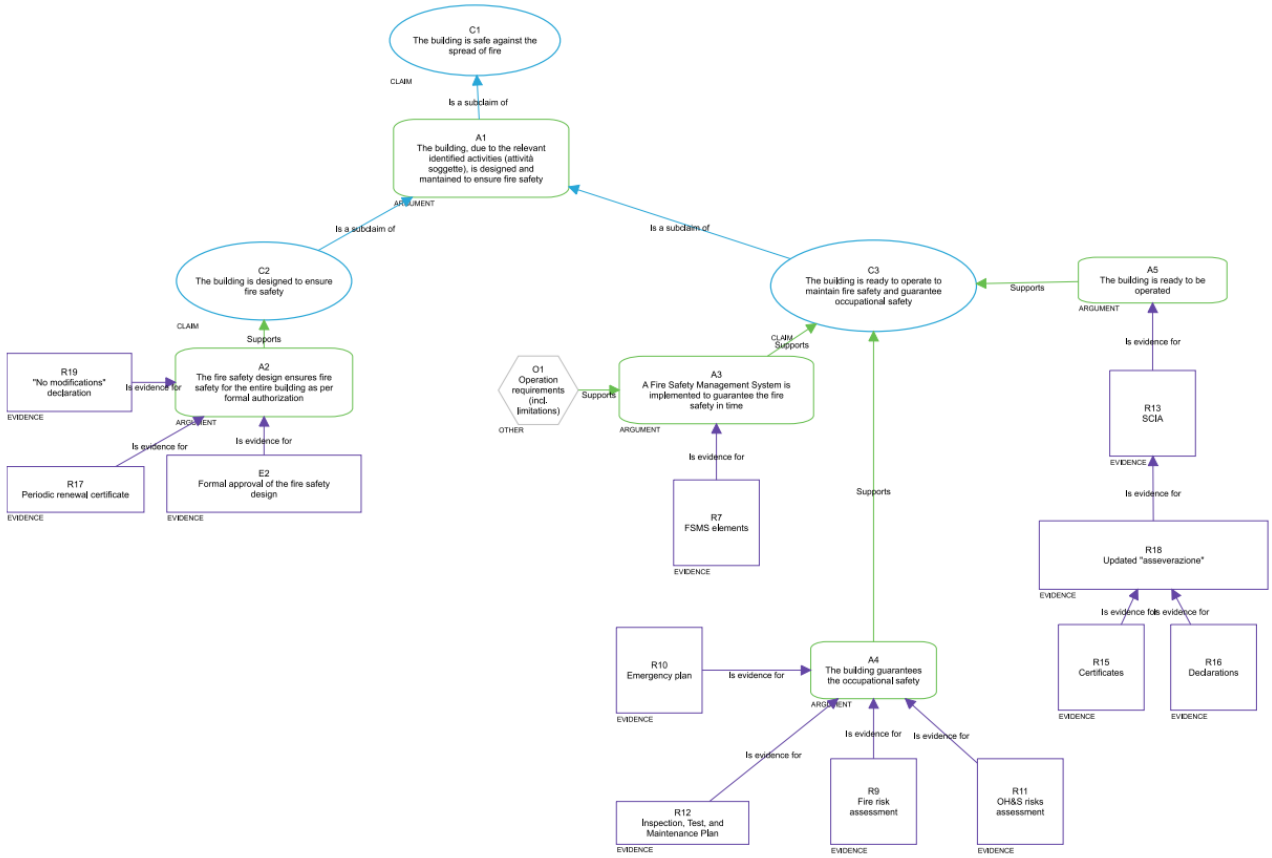


Figure 7: Fire Safety Case in operation phase for fire safety management over time and periodic validation - Overview

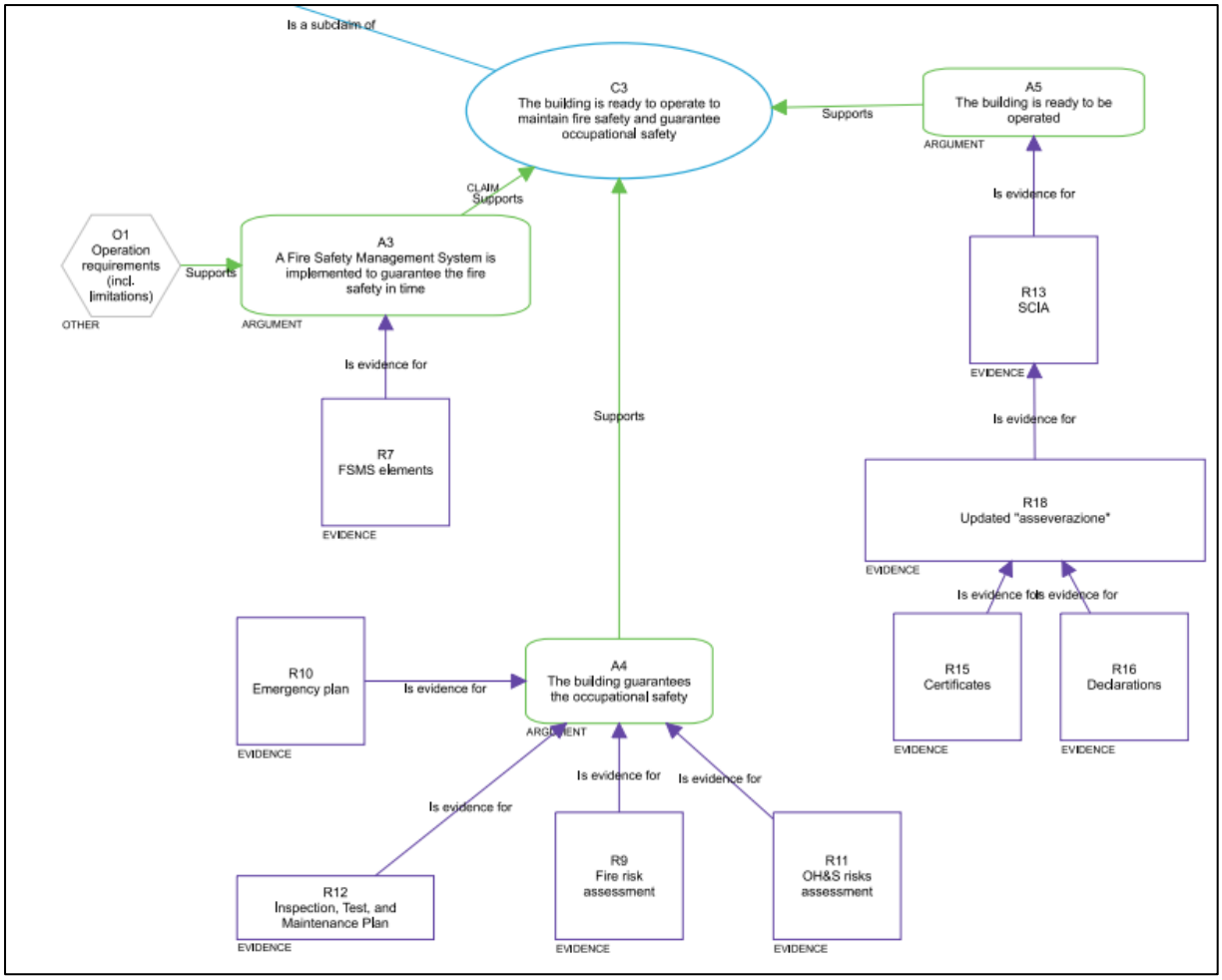


Figure 8: Fire Safety Case in operation phase - Details

Validation criterion

A validation criterion for a fire safety case has been also developed, to assess the completeness and the quality of the Building Fire Safety Case, according to the following scoring model and requirements.

🔴	Requirement not fulfilled. Corrective action mandatory (see remarks)
🟡	Requirement fulfilled but it can be improved. Suggestions made (see remarks)
🟢	Requirement fully fulfilled. No mandatory actions or suggestions

Figure 9: Proposed qualitative scoring model

Table 2: Proposed validation requirements

N	REQUIREMENT	QUALITATIVE SCORE	REMARKS
GENERAL QUALITY – PSHAPED APPROACH			
1	Is the fire safety case attributable to one of the 1A, 1B, 2A or 2B phases?	Choose a score filling the circle with color	
2	Do the "claim" nodes indicate properties of the system or of a subsystem being analyzed?		
4	Do the "argument" nodes correctly link the evidence with the claim nodes, through deterministic, probabilistic or qualitative evaluations?		
5	Does the fire safety case report the revision details?		
6	Is the FSC succinct?		
7	Is the FSC home-grown?		
8	Is the FSC assessable?		
9	Is the FSC proportionate?		
10	Is the FSC easy to understand?		
11	Is the FSC document-lite?		
SYNTAX AND ARTICULATION REQUIREMENTS			
12	Does the fire safety case have a single claim at the top?		
13	Does the FSC have two subclaims, one for design and one for operation?		
14	With regard to the portion of the FSC dedicated to design, is there a single claim/argument for the entire building?		
15	Are there subclaims/arguments below the node dedicated to the entire building, in a number equal to the number of compartments identified?		

References

[1] Fiorentini, L. (2021). Bow-Tie Industrial Risk Management Across Sectors: A Barrier-Based Approach (1st ed.). John Wiley & Sons.

[2] Fiorentini, L. (2022). Relazione tecnica di sicurezza antincendio istanza per “valutazione progetto” secondo il dm 03/08/2015, come modificato dal dm 18/10/2019 e dal dm 24/11/2021 ed integrato dal dm 10/07/2020, dal dm 14/10/2021 e dal dm 19/05/2022 edifici, sottoposti a tutela ai sensi del decreto legislativo 22 gennaio 2004, n. 42, aperti al pubblico.

[3] Fiorentini, L., & Cancelliere, P. G. (2023, March). Functional fire safety requirements in performance-based design: first steps. Fire Protection Engineering Magazine, 40–44.

[4] Fiorentini, L., & Dattilo, F. (2023). Fire risk management: principles and strategies for buildings and industrial assets (1st ed.). John Wiley & Sons.

[5] NFPA. (2023). NFPA 914 - Code for the protection of historic structures.