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A BIM-BASED APPROACH SUPPORTING FIRE ENGINEERING




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ABSTRACT

From performance based approach to BIM-based approach. The exploitation of Building Information Modelling within Fire Engineering can be considered a further technical and technological development. The objective is to implement the BIM model with the most significant Fire Prevention information in order to use them during the building lifecycle by operators and rescuers, in particular for maintenance and emergency management. According to the phase of the project, it is possible to extend the data richness about structures, introducing materials and physical properties to the components, supporting for example the fire resistance checks. Furthermore, data exchange towards specialized software, as CFD analysis, is enabled through to the interoperability process optimizing time and accuracy of simulations.
Keywords: Performance based approach, BIM, Integrated process, Digital model, Risk management.

1 INTRODUCTION

In recent years the Fire Prevention discipline has been affected by a regulatory evolutionary process based on the performance approach. This new concept has been introduced by the Italian D.M. 09.05.2007, regarding instructions in respect of engineering approach to fire safety, and includes both engineering and management aspects. The prescriptive method is overcome by the principle of performance to determine the procedural aspects, the Risk Assessment criteria and the resulting active/passive/management safety measures to offset the assessed risk. The goal is to maintain the consistency and effectiveness/efficiency of these safety measures over time by integrating protective and preventive actions with management procedures, including the adoption of the Fire Safety Management System (S.G.S.A.). In line with the EU 305/2011 Regulation objectives, these provisions define a turning point in the fire risk prevention and protection field, providing an

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organizational and management model that hold responsible both the designer and the building manager as well as the technician in charge of fire safety. In this way, “content” and “container” as well as “activities” carried out inside the building can be carefully evaluated in the context of an overall view. The exploitation of digital models and advanced methods provides significant possibilities for the integration of design, authorization, construction and management aspects. In this framework, the fire prevention strategies and the safety management should necessarily involve the use of innovative governance tools that are able to make virtually available both space information and attributes, aside from the accident scenarios and the related compensatory measures previously analyzed. If the knowledge of the building is stored in a structured and smart way, a greater number of users – designer, maintenance technician, final user of the asset, internal resource in charge of security in accordance with the provisions of D.Lgs. 81/08, fireman – can access the information according to different levels of detail.

2 METHODOLOGY

2.1 BIM based approach

Building Information Modelling (BIM) is rapidly changing the ways companies work together to design, build and operate projects. For this reason, it is important that the fire protection sector will become an integral part of this collaborative process. As a database, the BIM model can collect and organize a large amount of information coming from the different disciplines involved in the construction industry. It represents the common environment where data about architecture, structure and systems can be display in their most recent version in an integrated way, enabling the development of a more effective fire strategy due to a better three-dimensional comprehension of the artefact. The powerful spatial coordination capability of BIM, also known as clash detection, is the primary way projects involving multiple trades are taking advantage of BIM. This aspect initially is a disadvantage for those disciplines that are traditionally represented in two dimensions as 3D BIM is more design-intensive and it requires more steps and extra work. However the effort required for the smart objects creation is compensated by the field benefits during the building life cycle. To support this activity there are several software able to speed up the modelling phase of fire systems, such as sprinkler system and fire alarm control panels, and there is a growing demand for manufacturers to create a full range of BIM-compliant content and information about their fire protection products.

According to the corresponding process stage, the parametric objects of the model can be characterized by a different level of Detail/Development (LOD), both in terms of graphic representation and associated information. In particular, through the implementation of parameters is it possible to enrich the model data structure, providing additional technical information as well as external links to documents or management information platforms. In relation to this concept, which can be applied to all components, the American Institute of Architects (AIA) annually provides specification in terms of content although not totally comprehensive. At national level, LODs will be included in the UNI 11337 *Edilizia e opere di ingegneria civile – Gestione digitale dei processi informativi delle costruzioni* (Construction and civil engineering works - Digital management of construction information processes), currently under publication. This standard marks a significant step within BIM processes, also according to the new Italian Public Procurement Code which introduces methods and tools that take advantage of interoperable platforms in an optimized digital vision (See. D.lgs. n. 50/2016, Art. 23, paragraph 13).

During the preliminary design phase, geometry, stratigraphy and materials of building components are defined and physical and fire resistant properties can be included in the model. In this way, the fire designer can check the fire resistance properties of the structures from the earliest stages of project definition, according to an iterative process that takes into account the possible architectural/structural layout updates. The BIM model can be used, on the one hand, to make the specialized simulations for the structural elements fire resistance check or, on the other hand, in order to make the results of these assessments and calculations promptly accessible during the later stages. Particular attention can be paid to the steel structures which give back simulations of complex structures behavior in case of fire in addition to the static and dynamic analysis and verification thanks to the use of specialized software integrated with the BIM model

During the detailed design phase, the project performance requirements can be easily verified according to possible variations/variants, both in terms of layout and of selected materials.

During the construction phase, technical specifications, certifications and acceptance of work documentation of the installed components can be collected and integrated in the model, completing the database of information used as the basis for the subsequent maintenance and emergency management phases. With respect to this process, it is easier to set up alternative project and construction site scenarios.

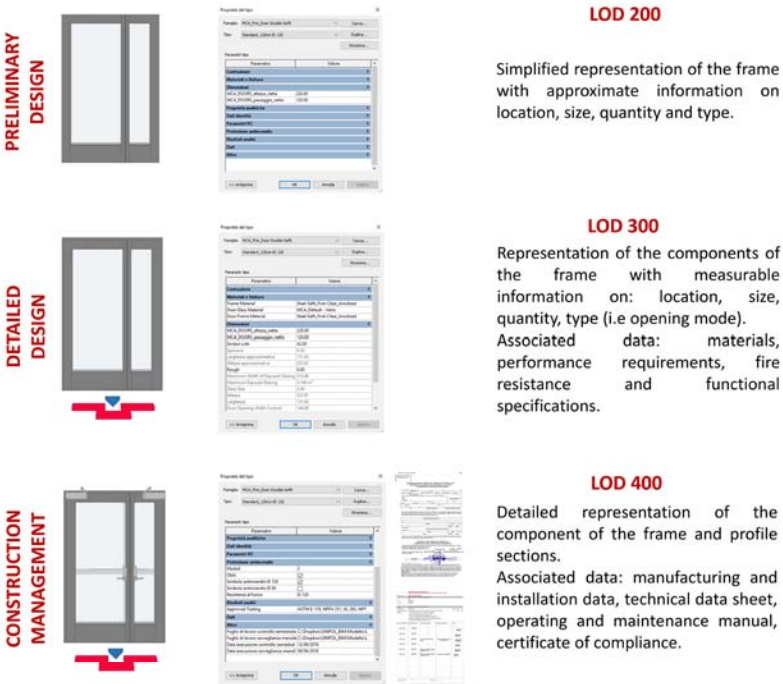

Fig. 1. Fire door LODs elaboration example

Fig. 1 shows an example of building element data implementation among the different stages, from a preliminary requirements definition to a design specifications compliance check of the installed components, from the certifications integration to the connection to management platform and to Fire inspections register.

2.2 Case study

Tests described in this papers have been processed on the new UnipolSai headquarter in Milan that provides an excellent case study to explain this innovative methodology applied to high-rise complex buildings. The tower building, made of steel, wood and glass, is part of Porta Nuova district, the largest Italian urban transformation of the last few decades, and it is spread over 22 floors above ground on a total area of 35,000 square meters. Currently under construction, the complex will house a large auditorium and retail space besides the offices. The central empty space, the mesh metal structure characterizing the facade and the auditorium are elements that take particular care with respect to fire safety.

2.3 BIM model implementations

Within this study, several specific functionalities concerning Fire Prevention have been developed and implemented in the BIM virtual environment in order to include parameters and requirements belonging to the prescriptive fire strategy as well as to the Fire Safety Engineering.

1. *Fire BIM objects.* All indications traditionally represented in the fire project through symbols has been transferred into the BIM model as three-dimensional parametric objects, as shown in *Fig. 2*. This allow a dynamic management of information over time supported by the use of shared parameters to enriched the elements data and by the setting of ad hoc schedules of building components.
2. *Fire load calculation.* The calculation of the fire load has been developed directly into the BIM model by introducing the characteristics of materials (e.g. weight and specific fire load) and by setting the algorithm in the materials schedule.
3. *Data exchange.* The implemented BIM model has been used as the starting point to perform specialized simulations

As previously mentioned, these implementations increase the consistency of the information contained in the Fire Project with respect to the architectural, structural and systems disciplines.

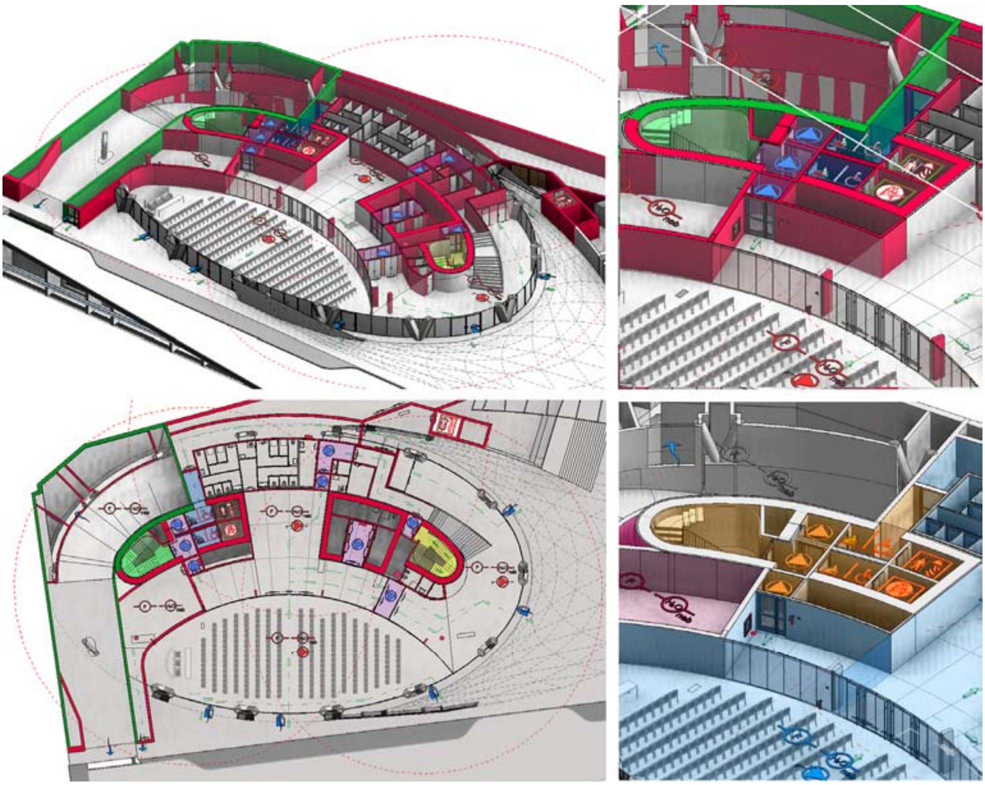

Fig. 2. Fire Strategy BIM implementation

The horizontal and vertical travel distance to exits have been created by a customized family, consisting of straight elements and arrow-shaped object, in order to automatically calculate and verify the relative lengths. In this context, it is also possible to check the necessary/available egress modules along the escape route or in a specific room according on the exhibit/furniture set-up, as well as the presence of fire extinguishing and signaling equipment by the proper setting of schedules. Besides the fire rating characterization of the building elements, fire compartments have been defined spatially through mass objects viewable in 3D, in which has been nested the symbols corresponding to installed systems. In this way, it is possible to select by a flag the fire systems present in each fire compartment and visualize them in a graphical way. Once the model is characterized by all the elements of fire strategy, some walkthrough path were created to simulate and to verify the escape route from different floors by the use of the two stairwells of the building.
Furthermore, the setting of the Fire load calculation is probably one of the most significant contributions of this study. The concept of ‘fire load’ indicates the quantity of heat liberated per unit area when a building and its contents are completely burnt. The calculation of the fire load is the basis to reach the classification of the occupancies for the fire grading of buildings. In this regard, the Italian legislation provides the following expressions *Eq. (1), Eq. (2)*.

$$\mathrm{qf,d} = \delta\mathrm{q1} \cdot \delta\mathrm{q2} \cdot \delta\mathrm{n} \cdot \delta\mathrm{qf} \tag{1}$$

where *δq1* is the factor that takes account of fire risk in relation to the size of compartment,
δq2 is the factor that takes account of fire risk in relation to the type of activities carried out in the compartment,
δn is the factor that takes account of the different protection measures,
qf is the nominal value of the specific fire load.

$$\mathrm{qf} = \frac{\sum gi \cdot Hi \cdot mi \cdot \psi i}{A} \tag{2}$$

where *gi* is the mass of the i-th combustible material [kg],
Hi is the lower calorific value of the i-th combustible material [MJ/kg],
mi is the combustion participation factor of the i-th combustible material,
ψi is the combustion participation limiting factor of the i-th combustible material,
A is the gross surface area of the compartment.

In particular, the factors of the *Eq. (2)* can be directly correlated to the model objects as characteristics of the individual components and their associated materials.

Fig. 3. Design offices layout of the new UnipolSai headquarter in Milan. Source: http://www.mcarchitects.it/project/centro-direzionale-unipolsai#

For this purpose, several shared parameters has been implemented to all the elements (families and materials) made up of combustible materials which have been organized in a materials schedule. Firstly both families and materials to be included in the Fire load calculation has been identified by a common parameter which works like a filter in the schedule in order to display only this type of information in the aggregate. In the case study, the offices floor plans and the auditorium have been analyzed. According to the offices layout project, as shown in *Fig. 3*, chairs and stools, desks and documents cabinets have to be taken into account as well as the elements delimiting the fire compartment such as ceiling, wall, suspended ceiling, which are characterized by a wooden surface finish. Depending on the elements types different data are required for calculation and additional shared parameters need to be associated to the Revit families to estimate the specific fire load as *Table 1*.

Table 1. Shared parameters associated to the Revit families according to their specific fire load calculation mode

Units of measure	Families	Parameters
[MJ/unit]	Chairs, stools	[MJ/unit] [mi] [yi]
[MJ/kg]	Desks, Ceiling, Wall, Suspended ceilings	[kg/m^3] [MJ/kg] [mi] [yi]
[MJ/ m^2]	Documents cabinets	[surface] [MJ/m^2] [mi] [yi]
[MJ/ m^3]	Documents paper	[MJ/m^3] [mi] [yi]

Then it has been possible to implement a calculation algorithm in the modeling software as stated in *Fig. 3*. In order to make compatible the units of measures within Revit, the part of qf calculation which contains Surfaces and Volumes, automatically generated by the software, have been divided by respective dimensional units (m^2, m^3).

$$qf = ([[MJ/unit]] \cdot mi \cdot yi) + (\frac{(Material:Volume \cdot [[kg/m^3]][[MJ/kg]] \cdot mi \cdot yi)}{1\,m^3} + \frac{(Surface \cdot [[MJ/m^2]] \cdot mi \cdot yi)}{1\,m^2} + \frac{(Material:Volume \cdot [[MJ/m^3]] \cdot mi \cdot yi)}{1\,m^3} \tag{3}$$

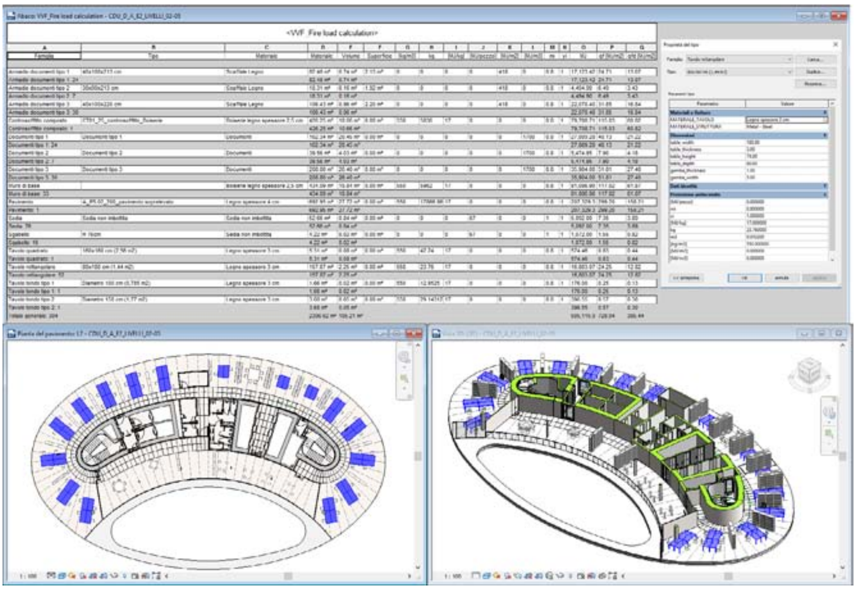

Fig. 4. Fire load calculation

The adopted method allows a dynamic update of the calculations in function of exhibit set-up or materials changes. In this way several scenario can be easily evaluated with limited effort during design, construction and management phases.
According to the building utilization and the occupant load of the site, the digital model becomes the environment to perform occupants egress simulation towards safe place and Fire rescue vehicles efficiency and approach. Considering this needs, the interoperability process guaranteed by the exchange formats allows to transfer the geometric model to specialized software, such as Pathfinder and PyroSim, to perform exodus simulation and computational fluid dynamic analysis (CFD) for the evaluation of fire scenario and phenomenon evolution. In this case study, specific CFD simulations has been performed to verify the actions on structures in case of fire and the natural fire curves from the structural calculation point of view. The building envelope is characterized by a double-skin facade that has been evaluated within the fire protection purposes with reference to the fire protection measures contained in the "*Requisiti di sicurezza antincendio delle facciate negli edifici civili*" national guideline. This provides an automatic fire extinguishing system for the protection of the building configuration examined. However the Fire strategy has been integrated in this project by the use of a water spray extinguishing system ie through a fire extinguishing system with respect to a containment system (i.e. sprinkler system). Moreover, the inner skin of the facade is used as a fire protection screen of structural steel elements to which floors as well as Diagrid structure are connected. Diagrid has the function of supporting structure on the external perimeter of the building as well as of the facade elements and glazing panels. To achieve this performance the inner skin has EW30 fire rating characteristics. In this complex scenario, the BIM model allow to design and verify effective alternative solutions in a virtual environment through a greater control of measures and constraints. Both technical parameters and results coming from the specialist software have been linked to the model objects implementing the database for the building lifecycle. For these reasons, the BIM model is also useful for the Emergency Management phase providing opportunities for rescuers to know in advance the spaces distribution, the fire extinguishing assets positioning and the fire scenarios through digital representations on mobile devices.

3 CONCLUSIONS

The use of BIM in the field of Fire safety engineering represents a significant implementation within the process, enabling better integration with other disciplines and allowing more advanced and more effective data processing. The case study developed shows that the results obtained are of great interest to both BIM level and fire prevention applications, as listed below.

- Graphic symbols describing the fire strategy are immediately computable and displayed in a structured way by quantities and materials schedules since they are modeled as three-dimensional parametric objects.
- According to the different phases, a continuous updating and implementation of the elements properties and characteristics is allowed within the same BIM model.
- By the setting of additional shared parameters and a calculation algorithm, the materials schedules is configured as a useful dynamic tool to assess the Fire load calculation and to monitor this value over time in function of possible layout or set-up configurations or materials changes.
- Walkthrough path can be easily set to check the escape route as well as the emergency procedures.
- Data exchange is pursued both among professionals and software, increasing the reliability of the information along the building life cycle and optimizing time and simulation accuracy.

Within this kind of approach supported by advanced modeling tools, new read modes of the Fire project are possible allowing a better understanding of the spatial and functional areas and consequently of the Fire strategy adopted. Likewise, new opportunities are established for firefighters and rescue workers that can examine beforehand the emergency process flows, the intervention strategies and the possible fire scenarios through augmented and virtual reality applications.

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