DEVELOPMENT OF AN AUTOMATED WORKFLOW IN THE FIELD OF FIRE PREVENTION USING BUILDING INFORMATION MODELING

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ABSTRACT: *The research focuses on an approach for the development of an automated workflow in the field of fire prevention for the validation of BIM models regarding "Subjected Activities" (according to Italian law - Presidential Decree 151/2011), with reference to the contents of the Horizontal Technical Regulation of the Fire Prevention Code. In fact, since 2019, the Italian Fire Department, through the Fire Digital Check project, is seeking to digitize the Fire Prevention Code in order to allow professionals to integrate their BIM models with the objectives required by the fire regulations. The workflow proposed involves three distinct processes, integrating them within a single workflow: study of the technical regulations and transposition into the digital environment using proven methods such as RASE, Tx3 and TIO, information modelling of a case study and implementation of validation algorithms using Solibri software. One of the main points of the proposed process is to use an open and interoperable format such as that offered by the IFC schema for the information exchange between the different software involved.*

KEYWORDS: *fire prevention, BIM, validation, code checking, digitization*

1. INTRODUCTION

With the Industry 4.0 approach, the construction sector has been involved in the development of systematic digitization processes (Daniotti et al., 2022) and its progressive transformation into a data-driven production sector appears to be irreversibly (Mêda et al., 2021). Furthermore, in recent years the introduction of information management with Building Information Modeling (BIM) tools and methodologies in public supply, service and works contracts has highlighted the need to define structured and planned data flows and information exchange between the various phases of the construction process. This text is intended as an in-depth study on the subject of digitization within the technical-administrative processes concerning public administrations with a thematic focus on fire safety in Italy. In particular, it describes and presents an application of a workflow aimed at checking BIM models to be submitted to algorithms for automatic validation and verification of the contents of the Fire Prevention Code D.M. 03-08-2015.

The following software was selected for the application of the workflow, which met the requirements that emerged in terms of flexibility in model creation, data export and control: Autodesk Revit, as BIM authoring software, and Solibrì Model Checker, as BIM model checking software. The proposed structure, however, want to be more general, in fact it does not require the use of specific software and exchange formats, and for its implementation reference was made to proven methodologies for the translation of normative code such as TIO, Tx3, RASE. The exchange of data between proprietary software was also carried out using the IFC (Industry Foundation Classes) format, which is an open standard, developed by buildingSMART, capable of describing the ontology of the building and the different specialisations related to a generic building process, through the use of entities, properties and relationships. In addition, the use of such data schema has become mandatory for any BIM services in the public sector in Italy.

The application of the workflow presented in this paper refers to "subjected activities" to the controls of the the National Fire and Rescue Service in accordance with D.P.R. 151/2011, without a Vertical Technical Rule, within the project evaluation procedure. This is limited to the automatic validation and verification of the contents of the Fire Prevention Code D.M. 03-08-2015 at *Section S.1 - Reaction to fire*. The starting point and main reference of this work was the Fire Digital Check project, born from the will of the Department of Fire, Public Rescue and Civil Defence to undertake the necessary digitisation process of the fire prevention procedures provided by D.P.R. 151/2011.

2. STATE OF ART

BIM modelling of new or existing buildings guarantees a homogeneous database capable of transmitting

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information not only regarding the geometric component of an object but also its informative and documentary characterisation. The model assumes in this context not only the meaning of a geometric representation of building components but rather becomes a database where all the information produced in the different phases of the building process can be collected (C. M. Eastman, 2011). This methodology can be applied for new buildings as well as for existing buildings (Volk et al., 2014), and in particular much research is being developed on HBIM field (Murphy et al., 2013) for the digitisation of historical heritage (Biagini et al., 2022). The digitisation of all this assets must, however, be followed at the same time by a digitisation also of the national and international regulations so that it becomes possible to apply automated or semi-automated methodologies for the verification of these rules and the issuing of authorisations in the design phases of an asset. The concepts of clash detection and code checking, defined in the UNI 11337 standard as 'analysis of possible geometric interferences between objects, models and drawings', and 'information inconsistencies of objects', respectively, become important in this context. The automation of these checks with different tools during the design phases (C. Eastman et al., 2009) has led to many experiments over the years in different areas around the construction process, such as the verification of health and safety requirements in the design of the site layout (Getuli et al., 2017). The Singapore government has been a forerunner in this discipline through the CORENET e-PlanCheck project, developed by a collaboration between the Ministry of National Development and the Construction and Real Estate Network, which proposed the automatic checking of BIM models in the open IFC format. In general, code checking can be set up as a multi-domain framework based on a set of parametric rules (Solihin & Eastman, 2016; Zhang et al., 2013) that can be generated on the basis of quantitative specifications derived from a text.

The objective of this study is to understand which parts of a specific regulation are most easily digitised and how to translate these into verifiable entities or parameters within a BIM model through a combination of different methods (Solihin & Eastman, 2015). A reproducible workflow for the digitisation of a regulation using proven methods, such as TIO, Tx3, RASE, is then proposed for analysis (Hjelseth & Nisbet, 2011).

RASE (*Requirement - Applies - Select - Exception*), is a methodology aimed at identifying key points within the regulatory text. The latter are selected, classified and organised schematically with the aim of simplifying the elaboration of rules that can be implemented through programming languages. These operations are generally carried out by highlighting the text using coloured mark-ups that correspond to precise types of content within it. The portions of text that can be defined as necessary or requested requirements are highlighted In blue (*requirements*), the portions that define the scope of applicability of the requests or necessary requirements are highlighted in green (*applies),* the portions of text that contain the object or reference to the request or necessary prerequisite are highlighted), in red (*select*), and finally the portions of text that refer to an exception or that otherwise restrict the scope of applicability of the requested requirements are highlighted in yellow (*exception*).

Tx3 (*Transcribe - Transform - Transfer*), is a method aimed at expressing the degree of translatability of regulatory text into digital language. This is a very important assessment to make, since this translation process is not always advantageous and it may happen that the result obtained does not justify the time taken to achieve it. Basically, the method involves the classification of standards into three different categories: *transcribe*, i.e. those parts of normative texts that can be easily translated into digital language, usually prescriptive norms fall into this category; *transform*, parts of normative texts that can be rewritten while retaining their implementation purpose, but which often require the introduction of constraints such as qualitatively defined benchmarks but from which it is still possible to translate the requirements quantitatively; *transfer*, instructions that cannot be implemented due to the imprecise way in which they are expressed within the reference text, such as benchmarks that are not defined quantitatively but only qualitatively.

TIO (*Test Indicator Objectives*), has the objective of bridging the gap between qualitative and quantitative requirements in such a way as to be able to increase the degree of digitisation for the former, thus allowing them to be incorporated into the process. This is a very important step as the most difficult requirements to translate are often qualitative ones, because they cannot always be correlated to quantitative parameters or measurable quantities.

In order to verify the applicability of these procedures, it was decided to take as a reference the Fire Prevention Code, for which a discussion table on its possible digitisation has already been started in Italy at the beginning of 2019 as part of the BIM-FDC (Fire Digital Check) project, aimed at automating the validation of Fire Prevention projects drawn up with the code, limited to compliant solutions. A combination of the above methods was then used to digitise the regulatory text, limited to section S.1 of the code.

The TIO method, aimed at translating the requirements expressed in qualitative terms, and at identifying parameters that allow their verification and control, allowed the results of the risk analysis to be parameterised, and to correlate parameters such as R_{Vita}, R_{Beni}, $R_{Ambiente}$ that characterise an activity (or compartment) to specific requirements. The Tx3 method, on the other hand, was used to verify only the compliant solutions foreseen by the Fire Prevention Code. Given the high specificity of the alternative solutions, which do not generally have a prescriptive character, these must eventually be treated in a specific way for each case study and are not suitable for verification within a general automatic validation methodology. Finally, by means of the RASE methodology, the object to which the regulatory prescriptions of Section S.1 refer is identified: in this specific case we refer to the scope of the subjected activities, defined by the code in section G. In addition, a distinction has been made between the areas that constitute "escape routes" of the activity (or compartment) and areas that constitute "other spaces" of the activity, since different levels of performance are generally required of these, depending on the *Life Risk* attributed to the activity (or compartment).

3. METHODOLOGY

The workflow presented within this paper is based on the application of the BIM methodology in the field of fire risk management and the validation of the related regulatory features. Specifically, the objective is the automatic validation of BIM models concerning subjected activities (according to D.P.R. 151/2011), with reference to the contents of the Horizontal Technical Regulation of the Fire Prevention Code. Three distinct areas can therefore be found in the process: technical regulations, BIM modelling and validation algorithms. Each of these areas must relate to the others, and for each of these relationships objectives and criteria for their achievement must be defined.

Technical Standard - BIM Modelling. Technical regulations contribute substantially to determining level of development of BIM models. Operationally, therefore, it determines what is to be modelled.

Technical Standard - Validation Algorithms. Technical standard provides the basic parameters, criteria and logic for the implementation of validation algorithms.

BIM Modelling - Validation Algorithms. The data structures of BIM models must be organised according to predefined criteria, so that the necessary information is available for the application of validation algorithms. At this juncture, a standard must be defined for the databases on which the logic of the algorithms can be developed.

3.1 Preliminary study of legislation and information exchange

Annex I of the Fire Prevention Code 'Technical Regulations for Fire Prevention' consists of the following Sections: G (Generalities), S (Fire Strategy), V (Vertical Technical Rules) and M (Methods). From the study of the relative contents of the Sections, with reference to the scope of application and the objectives set, it was possible to define a workflow for the digitisation of the Code as shown in the figure (fig. 1).

The following methodology is based on the following principles:

1 - validation is performed on BIM models inherent to a specific subject activity (pursuant to D.P.R. 151/2011);

2 - risk analysis, the definition of design goals and safety objectives, and risk assessment, are steps that must necessarily precede the entire workflow from the creation of the BIM model to its validation. These steps need a specific assessment by a fire safety professional. From here, we arrive at the quantitative definition of the R_{Vita}, R_{Beni}, $R_{Ambiente}$ parameters for each compartment of the subject activity, which represent input data for the project;

3 - on the basis of the R_{Vita}, R_{Beni}, $R_{Ambiente}$ parameters, the minimum required performance levels are identified within the chapters of section S of the Fire Prevention Code, and for these, through the digitisation of the regulatory text, the parameters that determine compliance with the relative solutions are identified;

4 - when creating the BIM model inherent to the subject activity, geometric and alphanumeric data are defined by the fire protection professional responsible for the project;

5 - the achievement of these performance levels is verified through the application of the compliant solutions set out in the code, which, in general, are prescriptive in nature. Verification must take place by means of automatic validation procedures, using a library of algorithms specifically created for this purpose, which is applicable to each subject activity without a Vertical Technical Rule. This library of algorithms must also be scalable and reusable for more complex projects;

6 - the workflow does not provide for the application of alternative solutions to achieve the minimum performance levels.

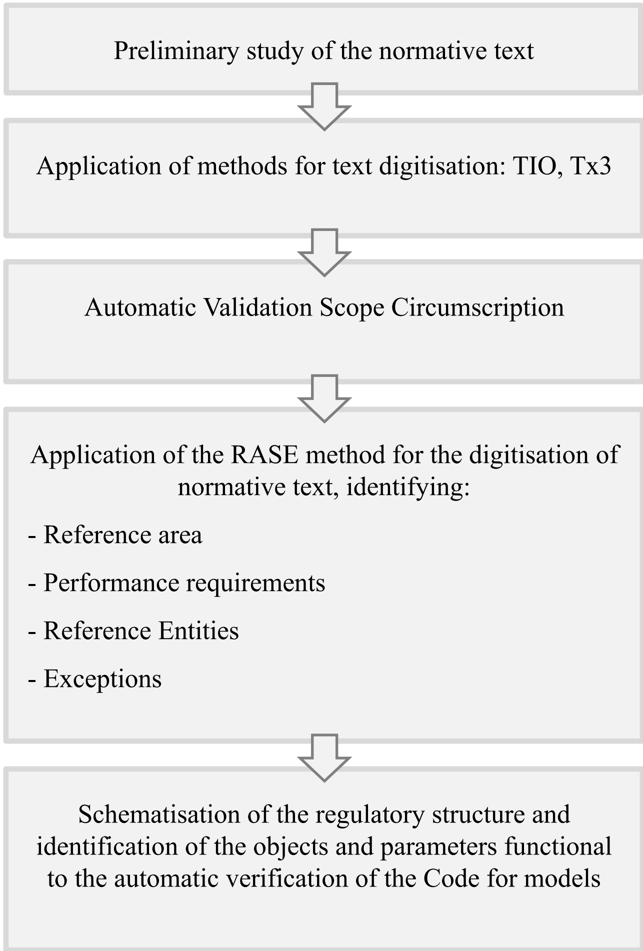

Fig. 1: Workflow for digital translation and parameterisation of normative text.

Based on these assumptions, three main work packages were then set up: the analysis of the regulatory text and its digitisation, the BIM modelling of the activity subject to regulatory control, and the application of algorithms for the validation of the BIM model. The first phase involved the definition of information requirements, in the form of alphanumeric parameters and geometric characteristics, which were to be included in the model and subsequently subjected to verification. The second phase involved the modelling of the considered activity, including not only the geometry, but also the design parameters that need to be. The last phase, on the other hand, led to the application of validation algorithms of the BIM model with reference to the contents of the Fire Prevention Code in order to verify the achievement of the minimum performance levels required for a generic subject activity.

Whereas the objectives and the actors involved in this information exchange process, each with its own tools and software, it is necessary to answer to two needs: to provide BIM authoring and code checking software capable of managing open and interoperable exchange formats, and to define a standard for the data structures to be exchanged, so that the information content within the model can be correctly analysed by the automatic validation algorithms used by the Fire and Rescue Service. Autodesk Revit BIM authoring software was then used to create the geometric model and assign the required parameters, then its information content was exported in IFC format. Once exported in IFC, it is possible to open this model within any model checker software, in our case the Solibri Model Checker software (Office version) was used, and to perform the validation operations on several levels.

The image below (fig. 2) shows the schematisation of which entities were involved in the verification algorithms. In particular, it shows the hierarchy of the spaces within the entire activity subject to inspection and where the areas for which specific performance levels are to be verified are located.

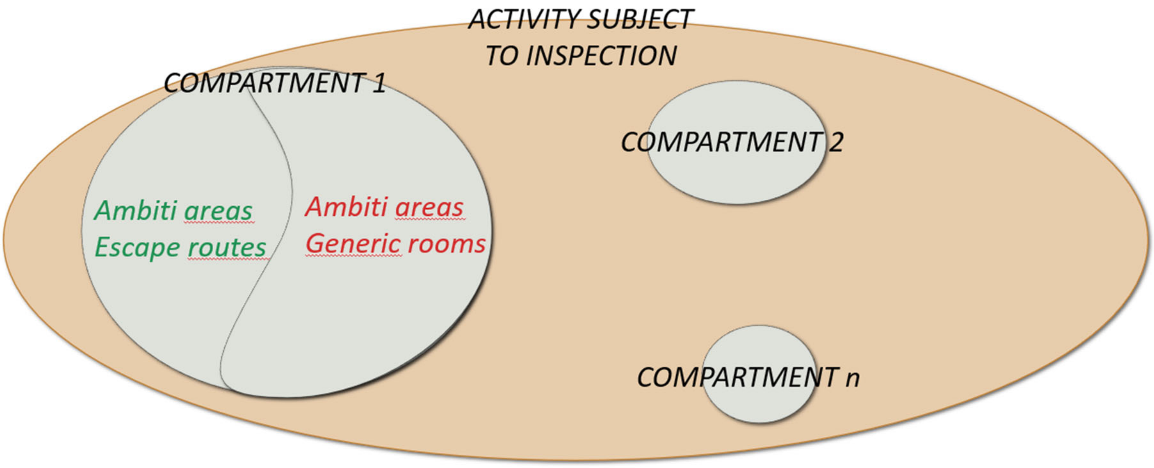

Fig. 2: Outline of the functional structure for digitising the code - Section S.1.

To achieve the required performance levels, some of the objects in the areas will have to have certain fire characteristics. The diagram below (fig. 3) shows what was modelled in the workflow application.

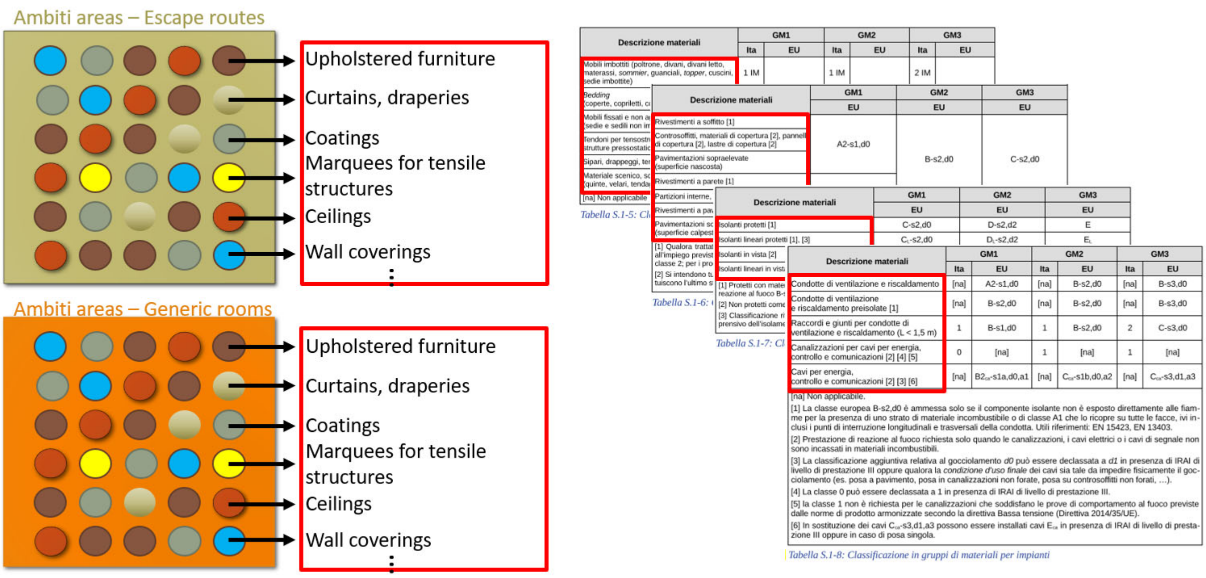

Fig. 3: Identification of the entities subject to verification within the schematic structure for code digitisation purposes.

3.2 P_set definition

The process of rule interpretation and digitisation of the normative reference text necessarily entails the definition of specific parameters that will subsequently be used in the verification process. Furthermore, in order to efficiently organise the data structure contained in the model, it is necessary for parameters to be grouped into specific Property Sets. This will make it easier to retrieve the necessary data to be analysed at a later stage. As part of the digitisation of section S.1 on the achievement of *Fire Reaction Performance Levels*, with reference to the normative structure outlined in the previous chapter, the elements to be modelled and the parameters to be assigned to them are defined.

Two entities were modelled within the BIM authoring software: activity scope and material. The tables below show the parameters associated with these two entities.

Table 1: List of parameters associated with the Ambiti areas of activity.

Property name	Property type	Description
NomeCompartimento	IfcLabel	Its value makes it possible to define to which compartment a given domain belongs, so that all domains belonging to a given compartment can be filtered in the validation processes
RVita	IfcLabel	Its value corresponds to the Life Risk determined during the risk assessment for a given compartment. By assigning the Life-Risk of the relevant compartment to each area, the performance level required for the Fire Reaction characteristics can be easily linked to it.
ViaDiEsodo	IfcBoolean	Its value makes it possible to determine the type of scope, as this contributes to determining the required minimum performance levels.

Table 2: List of parameters associated with materials.

Property name	Property type	Description
ClassificatoReazioneAlFuoco	IfcBoolean	Its value is used to determine whether an object representing the Material entity within the model falls within those listed in Tables S.1-5, S.1-6, S.1-7, S.1-8.
GruppoReazioneAlFuoco	IfcLabel	Its value, assigned with reference to the provisions of Ministerial Decree 26/6/1984 and Ministerial Decree 10/3/2005 by the fire protection designer, frames the fire reaction characteristics of a material, which, as can be seen in the normative text, are closely related to the minimum performance levels indicated by the law.

4. CASE STUDY

Modelling inside the BIM authoring software Autodesk Revit, within the scope of application of this methodology, is carried out for a simplified case study characterised by the structure shown in the table.

Table 3: Pilot model structure.

ACTIVITY SUBJECT TO FIRE BRIGADE INSPECTIONS			
COMPARTMENT 01		COMPARTMENT 02	
R_{vita} = D1 – R_{beni} = 1 Rambiente = NC		R_{vita} = B2 – R_{beni} = 1 Rambiente = NC	
Ambito 01	Escape Route	Ambito 02	Escape Route
		Ambito 03	Generic Room

Each *Ambito* (area of activity) within the Revit software was modelled as space, then exported as IfcSpace class within the IFC scheme. Regarding the modelling of the construction and furnishing elements that are covered in the tables of the Fire Prevention Code (S.1-5, S.1-6, S.1-7, S.1-8), and subject to verification in the validation process, the objects in the table below were modelled.

Table 4: Identification of the entities subject to verification within the pilot model structure.

[Compartment 01]	**Ambito 01**	n.3 Upholstered furniture [Category: Furniture]
		n.1 Floor covering [Category: Floor]
		n.1 Suspended ceiling [Category: Ceiling]
		n.1 Protected insulation [Category: Wall]
	Ambito 02	n.3 Upholstered furniture [Category: Furniture]
		n.1 Floor covering [Category: Floor]]

		n.1 Suspended ceiling [Category: Ceiling]
[Compartment 02]		n.1 Protected insulation [Category: Wall]
		n.3 Upholstered furniture [Category: Furniture]
	Ambito 03	n.1 Floor covering [Category: Floor]]
		n.1 Suspended ceiling [Category: Ceiling]
		n.1 Protected insulation [Category: Wall]

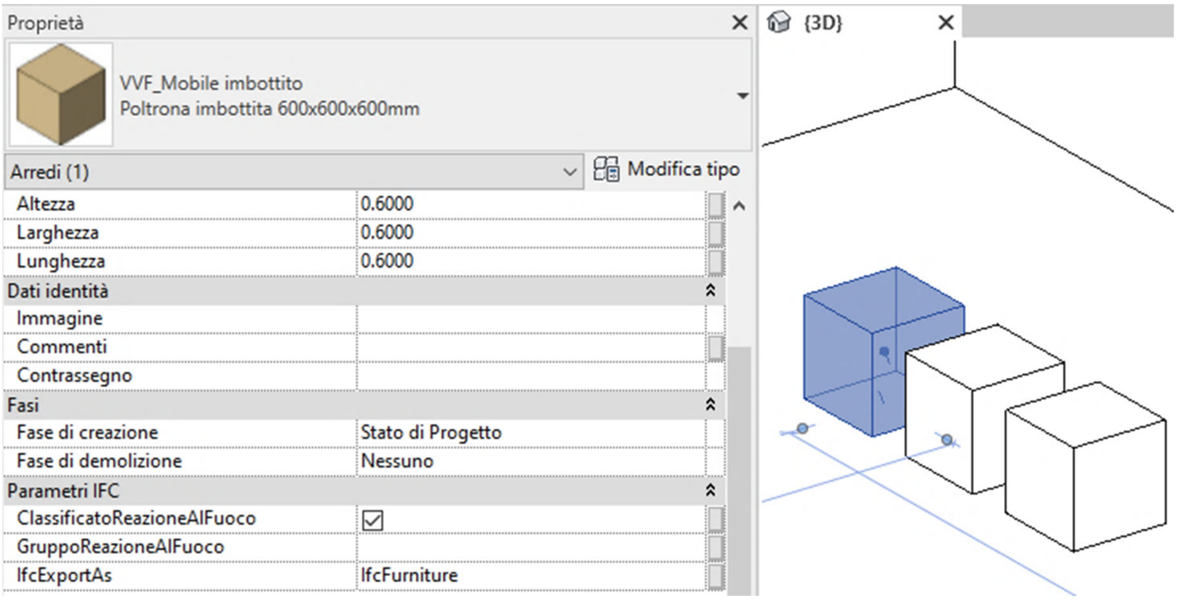

Fig. 4: Functional parameterisation for automatic validation of entities within the model.

To reach the level of information contained in the model and to implement the subsequent automatic validation process, it is necessary to enter the parameters foreseen during the digitisation of the normative text by assigning them to the modelled entities. These parameters were created as shared parameters, organising them in an external text file and therefore reusable in other models. Once the parameters had been assigned to the categories of the modelled objects, the data subject to verification were entered (fig. 4). The data assigned to the parameter GruppoReazioneAlFuoco did not in all cases reflect the requirements of the Code for achieving the minimum performance level required of the area belonging to a particular Compartment. This was an intentional error in order to show any issues that may result from the analysis.

The next step involved exporting the model created in the BIM authoring software in the open IFC format. The operation was carried out by first checking the settings of Revit's IfcExporter, analysing that the correct IFC classes corresponded to the different entity categories present in the model. Should it prove useful to further specify the IFC export class for a single instance, it is possible to exploit the shared parameters collected in the specially provided PSet_IFC_Exporter Property Set. As far as the export of parameters within the IFC format is concerned, these were organised in specific custom P_sets, through the structuring of a special file in .txt format subsequently called up in the Revit software export settings. Once the model was exported in the IFC schema, it was possible to open the latter within the model checking software. The image below shows how the imported model, displayed in the three-dimensional view, is represented by an organised data structure characterised by the hierarchy defined during the model creation phase (fig. 5).

At this point, within the model checking software we proceed to set up the groups of validation algorithms for the BIM model. Referring to what emerged from the study of the structure of the Fire Prevention Code, for the complete realisation of a library of verification algorithms, a library of Rulesets organised as shown in the table 5 is envisaged.

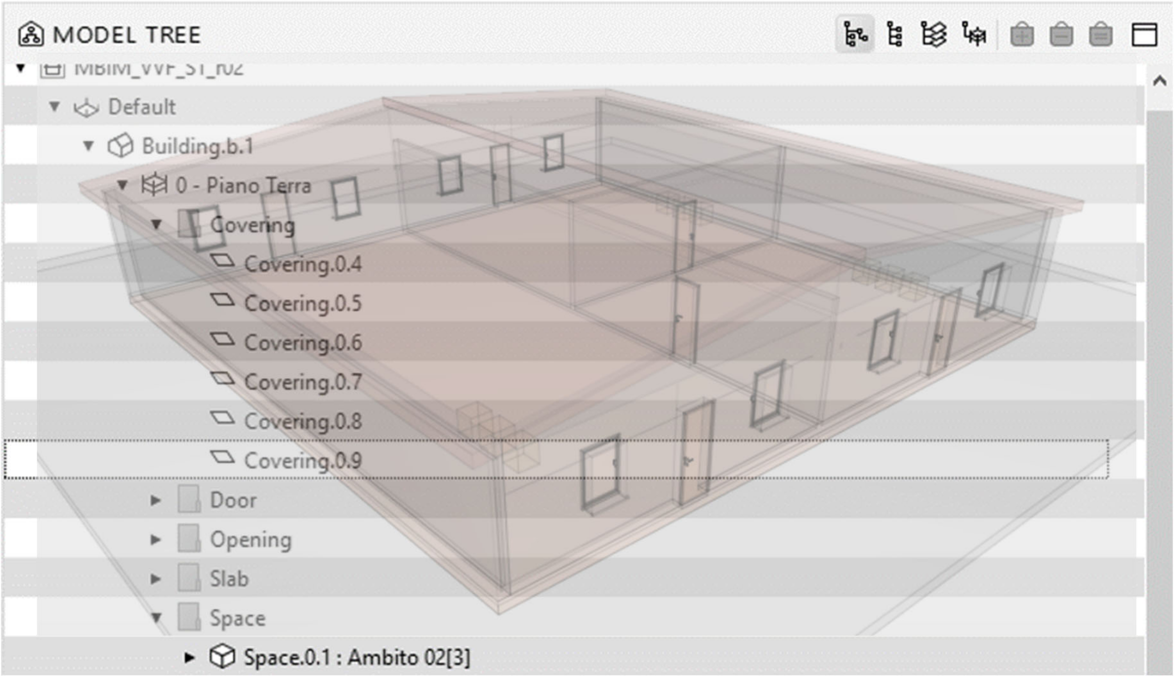

Fig. 5: Representation of the BIM model within the automatic validation software.

Table 5: General ruleset structure for the automatic validation of the fire prevention code

RULESETS	
Ruleset Name	Function
VVF_S.1_ReazioneAlFuoco	Verification of conforming solutions
VVF_S.2_ResistenzaAlFuoco	Verification of conforming solutions
VVF_S.3_Compartimentazione	Verification of conforming solutions
VVF_S.4_Esodo	Verification of conforming solutions
VVF_S.5_GSA	Verification of conforming solutions
VVF_S.6_ControlloIncendio	Verification of conforming solutions
VVF_S.7_RivelazioneAllarme	Verification of conforming solutions
VVF_S.8_ControlloFumiCalore	Verification of conforming solutions
VVF_S.9_OperativitàAntincendio	Verification of conforming solutions
VVF_S.10_SicurezzaImpiantiTecnologiciServizio	Verification of conforming solutions
VVF_G _AnalisiDelRischio	Data compilation check
VVF_Altro	Data compilation check

Each of the rulesets listed above will contain specific validation algorithms for the BIM model built with reference to the Code conforming solutions set out in the ten Chapters of Section S of the Fire Strategy. Two further rulesets are also foreseen: VVF_G _AnalisiDelRischio, dedicated to the control of the correct compilation of the parameters relative to the risk analysis, and VVF_Altro, dedicated to the control of parameters not directly referable to the contents of sections G and S of the regulations, but necessary to define the more complex validation algorithms.

Accordingly, for the purpose of validating the contents of Section S.1 of the Code, the structuring of the internal subgroups of the Ruleset VVF_S.1_ReazioneAlFuoco is given.

Table 6: Ruleset structure for the verification of reaction to fire performance for a compartment characterised by a generic risk profile.

RULESET - VVF_S.1_ReazioneAlFuoco	
Subgroups of validation algorithms	Function
VVF_S.1_ReazioneAlFuoco_Controllo	Verification of correct compilation of validation parameters
VVF_S.1_ReazioneAlFuoco_A1	Verification of Conforming Solutions by Activity or Compartment R_{vita} A1
VVF_S.1_ReazioneAlFuoco_A2	Verification of Conforming Solutions by Activity or Compartment R_{vita} A2
VVF_S.1_ReazioneAlFuoco_A3	Verification of Conforming Solutions by Activity or Compartment R_{vita} A3
VVF_S.1_ReazioneAlFuoco_A4	Verification of Conforming Solutions by Activity or Compartment R_{vita} A4
VVF_S.1_ReazioneAlFuoco_B1	Verification of Conforming Solutions by Activity or Compartment R_{vita} B1
VVF_S.1_ReazioneAlFuoco_B2	Verification of Conforming Solutions by Activity or Compartment R_{vita} B2
VVF_S.1_ReazioneAlFuoco_B3	Verification of Conforming Solutions by Activity or Compartment R_{vita} B3
VVF_S.1_ReazioneAlFuoco_C1	Verification of Conforming Solutions by Activity or Compartment R_{vita} C1
VVF_S.1_ReazioneAlFuoco_C2	Verification of Conforming Solutions by Activity or Compartment R_{vita} C2
VVF_S.1_ReazioneAlFuoco_C3	Verification of Conforming Solutions by Activity or Compartment R_{vita} C3
VVF_S.1_ReazioneAlFuoco_Ci1	Verification of Conforming Solutions by Activity or Compartment R_{vita} Ci1
VVF_S.1_ReazioneAlFuoco_Ci2	Verification of Conforming Solutions by Activity or Compartment R_{vita} Ci2
VVF_S.1_ReazioneAlFuoco_Ci3	Verification of Conforming Solutions by Activity or Compartment R_{vita} Ci3
VVF_S.1_ReazioneAlFuoco_Cii1	Verification of Conforming Solutions by Activity or Compartment R_{vita} Cii1
VVF_S.1_ReazioneAlFuoco_Cii2	Verification of Conforming Solutions by Activity or Compartment R_{vita} Cii2
VVF_S.1_ReazioneAlFuoco_Cii3	Verification of Conforming Solutions by Activity or Compartment R_{vita} Cii3
VVF_S.1_ReazioneAlFuoco_Ciii1	Verification of Conforming Solutions by Activity or Compartment R_{vita} Ciii1
VVF_S.1_ReazioneAlFuoco_Ciii2	Verification of Conforming Solutions by Activity or Compartment R_{vita} Ciii2
VVF_S.1_ReazioneAlFuoco_Ciii3	Verification of Conforming Solutions by Activity or Compartment R_{vita} Ciii3
VVF_S.1_ReazioneAlFuoco_D1	Verification of Conforming Solutions by Activity or Compartment R_{vita} D1
VVF_S.1_ReazioneAlFuoco_D2	Verification of Conforming Solutions by Activity or Compartment R_{vita} D2
VVF_S.1_ReazioneAlFuoco_E1	Verification of Conforming Solutions by Activity or Compartment R_{vita} E1
VVF_S.1_ReazioneAlFuoco_E2	Verification of Conforming Solutions by Activity or Compartment R_{vita} E2
VVF_S.1_ReazioneAlFuoco_E3	Verification of Conforming Solutions by Activity or Compartment R_{vita} E3

As can be seen from the list above, net of the group of rules necessary to control the parameters strictly related to the verification for section S.1, within the Ruleset VVF_S.1_ReazioneAlFuoco there are subgroups of validation algorithms which refer to the specific R_{Vita} attributed to each compartment of the activity, defined in the risk assessment phase. Each subgroup of the ruleset VVF_S.1_ReactionAlFuoco will be the container of validation algorithms necessary to filter the objects to be verified and which in general belong to different types of areas. It may be noted that this type of organisation of the structure for the verification algorithms allows the application of the Ruleset VVF_S.1_ReactionAlFuoco to a BIM model of any activity, even a complex one, and made up of compartments to which different risk assessment parameters are attributed.

It should be noted that the verification algorithms were created from the library contained in the Solibri Model Checker software, which provides a very extensive archive of basic rules, with which even complex validation algorithms can be created. We take the validation algorithms contained in the Ruleset VVF_S.1_ReazioneAlFuoco as an example, highlighting the following subgroups: VVF_S.1_ReazioneAlFuoco_Controllo and

VVF_S.1_ReactionAlFuoco_B2.

The subgroup VVF_S.1_ReazioneAlFuoco_Controllo (fig. 6) provides two control algorithms that verify the presence of the parameters and the correct input of the relative values for the purposes of subsequent Code checks. The first check verifies that all the elements requiring a Fire Reaction classification, and therefore referable to Tables S.1-5 S.1-6 S.1-7 S.1-8 contained in Section S.1 of the Fire Prevention Code, have a plausible value assigned [GM0, GM1, GM2, GM3, GM4] to the GroupFireReaction parameter. The second check verifies the presence of the parameters NomeCompartimento, Rvita, ViaDiEsodo and their compilation with plausible values.

▾ VVF_S.1_ReazioneAlFuoco_Controllo		
§ Controllo 01_DefinizioneParametro_GruppoReazioneAlFuoco	SOL/203/2.4	
§ Controllo 02_DefinizioneParametriAmbitiAttivià	SOL/203/2.4	

Fig. 6: Structure of the control ruleset for the correct compilation of parameters

The subgroup VVF_S.1_ReazioneAlFuoco_B2 (fig. 7) has been divided into two further subgroups whose function is to check the two types of Ambiti areas identified by the Code in Section S.1, namely Vie d'Esodo [VE] and Altri locali [AL]. The rule Ambiti Vie d'esodo_Rvita=B2 has the purpose of filtering all the entities within the model which must comply with Fire Reaction requirements, and which belong, specifically, to Activity Ambiti areas which are Exit Routes and which belong to compartments to which an Rvita=B2 has been attributed during the risk assessment phase. The Fire Reaction characteristics of all objects belonging to these areas will be specifically verified by the following algorithms. The image below shows by way of example one of the verification algorithms which hierarchically follow the rule Ambiti Vie d'esodo_Rvita=B2.

▾ VVF_S.1_ReazioneAlFuoco_B2		
▾ VVF_S.1_B2_VE		
▾ § Ambiti Vie d'esodo_Rvita=B2	SOL/1/5.0	
§ GruppoReazioneAlFuoco_Arredi	SOL/9/3.1	
§ GruppoReazioneAlFuoco_Pavimenti	SOL/9/3.1	
§ GruppoReazioneAlFuoco_Controsoffitti	SOL/9/3.1	
§ GruppoReazioneAlFuoco_Isolanti	SOL/9/3.1	

Fig. 7: Ruleset structure for the identification and verification of performance for the reaction to fire of compartments.

In particular, the tab below refers to the rule GruppoReazioneAlFuoco_Arredi (fig. 8). This takes into account all the elements filtered by the previous algorithm classified as Furniture, for which specific reaction-to-fire characteristics are specified.

Component	Property	Allowed Value
Furniture	PSet_VVF_ReazioneAlFuoco.GruppoReazioneAlFuoco	GM2
Furniture	PSet_VVF_ReazioneAlFuoco.GruppoReazioneAlFuoco	GM1
Furniture	PSet_VVF_ReazioneAlFuoco.GruppoReazioneAlFuoco	GM0

Fig. 8: Definition of possible values for the parameters under verification.

The possible values of the property GruppoReazioneAlFuoco, in this specific case described, are GM2, GM1, GM0. The operation of the remaining rules underlying the rule Ambiti d'esodo_Rvita=B2 is entirely similar and should be defined for each of the materials defined in Tables 5 S.1-6 S.1-7 S.1-8 contained in Section S.1 of the Fire Prevention Code.

Two types of errors found during Code Checking are given as examples:

- Failure to compile the parameters (algorithm for checking the formal correctness of the information model). For some instances, the GruppoReazioneAlFuoco parameter is not filled in, although the objects they represent must necessarily respect precise reaction to fire characteristics to reach the minimum performance level required by the Standard.

- Reaction to fire of materials not suitable for the Rvita value of the compartment (algorithm for checking the technical correctness of the information model). Some instances do not have suitable fire reaction characteristics with respect to the area and compartment in which they are located. The value assigned to the parameter

GruppoReazioneAlFuoco, which are not among those covered by the validation algorithm.

At the end of the validation procedure, the Solibri Model Checking software can generate a report of the issues that emerged during the analysis phase that can be exported in various formats, including the open BCF format, allowing further possibilities for the development of the data flow considered in the methodology presented.

5. CONCLUSION

In the methodology just shown it was possible to observe how automated verification procedures can be implemented for the verification of the Fire Prevention Code, at least regarding the compartment of prescriptive measures given by the conforming solutions reported in the different sections of the RTO of the fire prevention strategy. Although the work presented focuses only on the contents of section S.1, given the RTO's structure and potential, as well as the flexible interoperability between Revit and Solibri software, there appears to be ample scope for the development of Code Checking of the other sections.

In any case, it is necessary to emphasise the importance of developing a standard for BIM modelling, and in particular for the structure of IFC models that, in view of the digitalisation of fire prevention procedures, will have to undergo automatic validation by the Technical Office of the Fire Service. In fact, the same organizaton will implement the code checking phase and it will define the data structure of the IFC model that can then be linked to its set of automatic validation algorithms. Validation algorithms are an information verification tool that needs databases structured according to a declared standard to function properly.

Regarding the necessary characteristics of the BIM authoring software useful for the application of the workflow described in this text, a high degree of flexibility in the export of data in IFC format is considered of fundamental importance, which means having both the possibility of creating user-defined P_sets and the possibility of assigning user-defined properties to the objects in the model. These features will allow the creation of the data structure in IFC format, as required by the validator.

REFERENCES

Biagini, C., Bongini, A., & Verdiani, G. (2022). From Geospatial Data to HBIM of Romanic Churches in Sardinia: Modelling, Check and Validation. In M. A. Ródenas-López, J. Calvo-López, & M. Salcedo-Galera (Eds.), *Architectural Graphics* (Vol. 22, pp. 368–378). Springer International Publishing. https://doi.org/10.1007/978-3-031-04703-9_37

Daniotti, B., Pavan, A., Bolognesi, C., Mirarchi, C., & Signorini, M. (2022). Digital Transformation in the Construction Sector: From BIM to Digital Twin. In A. Petrillo, F. De Felice, M. Violeta Achim, & N. Mirza (Eds.), *Digital Transformation—Towards New Frontiers and Business Opportunities*. IntechOpen. https://doi.org/10.5772/intechopen.103726

Eastman, C., Lee, J., Jeong, Y., & Lee, J. (2009). Automatic rule-based checking of building designs. *Automation in Construction*, *18*(8), 1011–1033. https://doi.org/10.1016/j.autcon.2009.07.002

Eastman, C. M. (Ed.). (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors* (2. ed). Wiley.

Getuli, V., Ventura, S. M., Capone, P., & Ciribini, A. L. C. (2017). BIM-based Code Checking for Construction Health and Safety. *Procedia Engineering*, *196*, 454–461. https://doi.org/10.1016/j.proeng.2017.07.224

Hjelseth, E., & Nisbet, N. (2011). *CAPTURING NORMATIVE CONSTRAINTS BY USE OF THE SEMANTIC MARK-UP RASE METHODOLOGY*.

Mêda, P., Calvetti, D., Hjelseth, E., & Sousa, H. (2021). Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction. *Buildings*, *11*(11), Article 11. https://doi.org/10.3390/buildings11110554

Murphy, M., McGovern, E., & Pavia, S. (2013). Historic Building Information Modelling – Adding intelligence to laser and image based surveys of European classical architecture. *ISPRS Journal of Photogrammetry and Remote Sensing*, *76*, 89–102. https://doi.org/10.1016/j.isprsjprs.2012.11.006

Solihin, W., & Eastman, C. (2015). Classification of rules for automated BIM rule checking development.

Automation in Construction, *53*, 69–82. https://doi.org/10.1016/j.autcon.2015.03.003

Solihin, W., & Eastman, C. (2016). A KNOWLEDGE REPRESENTATION APPROACH IN BIM RULE REQUIREMENT ANALYSIS USING THE CONCEPTUAL GRAPH. *J. Inf. Technol. Constr.*, *21*, 370–401.

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction*, *38*, 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Zhang, S., Teizer, J., Lee, J.-K., Eastman, C. M., & Venugopal, M. (2013). Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Automation in Construction*, *29*, 183–195. https://doi.org/10.1016/j.autcon.2012.05.006