Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2023 Volume 29 Issue 2: 171–193
https://doi.org/10.3846/jcem.2023.18460

INTEGRATION OF STRUCTURAL INFORMATION WITHIN A BIM-BASED ENVIRONMENT FOR SEISMIC STRUCTURAL E-PERMITS

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Received 8 April 2022; accepted 5 October 2022

Abstract. The assessment of the structural safety of buildings, with the related outcomes and other structural information, is typically reported in un-structured sets of documents (tables, drawings, reports, etc.). This happens even if Building Information Modelling (BIM) workflows, platforms, and standards are adopted. Generally, the BIM database provides input data for the structural design, but most of the data produced by structural designers, according to the structural codes, do not fully integrate into the BIM database along with other context-related information. These data are not easily recorded, especially in openBIM standard file formats such as Industry Foundation Classes (IFC). In the context of digital procedures for permit applications pertaining to seismic structural engineering, the authors propose an openBIM approach for the integration of structural information to support the activities of building authorities' bodies (BABs). The proposed framework has led to the development of an Information Delivery Manual (IDM) and a Model View Definition (MVD), considering the IFC schema, for the integration and exchange of information within a BIM-based environment. Successively, the authors implemented the proposed IDM/MVD solution in a case study that provided an effective workflow for innovative future delivery of necessary information to building authorities to obtain seismic authorization permits.

Keywords: building e-permits, structural engineering permits, structural engineering, openBIM, IFC, IDM, MVD.

Introduction

Adoption of BIM methodologies in e-permitting procedures

Today, the BIM approach is the methodology of reference for digitization in the construction industry. As a result, the scientific community is increasingly focusing on the topic of digitizing e-permitting procedures using BIM methods and tools. Recently, the adoption of BIM and openBIM to support e-permitting procedures for both building and construction permits has attracted considerable attention from the international scientific community. Specifically, some studies (Eirinaki et al., 2018; Kim et al., 2020; Messaoudi & Nawari, 2020; Noardo et al., 2022; Ullah et al., 2020) have focused on identifying the potential that the BIM approach offers generally in reconceiving e-permitting procedures. Other authors (Ciotta et al., 2021; Muto, 2020; Noardo et al., 2020a, 2022) have focused principally on the potential offered by openBIM. In general, e-permitting procedures can be applied to both building permits (i.e., design permits) and construction permits (once the design phase has ended). Indeed, a recent study argues that the use of open model-based processes and automated code-checking tools could simplify and accelerate permit application practices considerably (Muto, 2020). Using BIM models for e-permitting procedures essentially means transferring information about the geometry of the asset to the officers; studies (Shahi et al., 2019; Noardo et al., 2020b), therefore focus on the possibility of integrating GIS systems into BIM-based e-permitting procedures. To date, research has identified two major obstacles to implementing the most advanced e-permitting scenarios in professional practice. The first relates to ensuring quantifiable and standardized information in BIM models, while the second considers the requirements for translating code into shared machine-readable rules. To overcome the first obstacle, the availability of appropriate information in BIM models can be achieved through: (i) defining clear rules for structuring BIM models in proprietary formats, as Singapore did with the .rvt format; (ii) using open formats, such as the IFC format. BuildingSMART International's Regulatory Room report (Muto, 2020) provides a

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recent snapshot of the trend in using IFC models for e-permitting. To overcome the second obstacle, it would be better, from now on, to opt for clear regulations that can be effectively translated into machine language (Li et al., 2021). This paper focuses on the first obstacle and proposes and proposes the adoption of IDM/MVD approach to use open formats for e-permitting in seismic structural engineering.

Brief overview on the development of IDMs and MVDs from the structural engineering perspective

The IDM/MVD approach is suggested for the development of openBIM solutions as proposed in this paper. In detail, the aim of an IDM (Information Delivery Manual) is to organise activities in a structured manner and describe the data exchanged within a specific BIM process (buildingSMART International, 2010). The IDM provides a framework for defining the considered exchange requirements, describing the information flows, and exchanging data between different types of applications for certain purposes. Information, organised and managed in this way, is useful to both users and software vendors for the development and subsequent implementation of an IT specification that "translates" it into an appropriate data schema. The considered data schema for information exchange is the IFC (Industry Foundation Classes). Therefore, what is defined in the IDM is necessary for the development of an IT specification, i.e., the MVD (Model View Definition), which can be implemented and supported by different types of software application (buildingSMART International, 2010). This mechanism allows IFC models to be exported in accordance with specific processes and exchanged information defined in the IDM, and properly constructed to satisfy predefined exchange requirements.

Specifically, the IFC is an international standard developed by buildingSMART which is able to represent building elements as BIM objects with associated relationships and properties. To date, one of the most widespread and common IFC versions is IFC2×3, which was released in early 2006 and subsequently became an international standard. In 2013, bSI released the IFC4 version and subsequently updated it with the IFC4 ADD2 TC1 version, officially published as an international standard ISO 16739-1:2018 (International Organization for Standardization [ISO], 2018). Regarding mainly the IFC2×3 version, one of the most popular MVDs implemented in BIM-authoring applications and other software is "Coordination View", which was developed with the aim of supporting the sharing of building models among different disciplines (architecture, structural engineering, MEP implants, etc.). Applications of the IDM/MVD approach may concern architectural design (Sanguinetti et al., 2012) or structural design, specifically for the assessment of interoperability in the structural domain (Muller et al., 2017). In the same context, some authors (e.g., Nawari, 2012a) identify the IDM/MVD approach as an integrated process for the management of processes and data related to the design of wooden structures. In the case of modular buildings, Ramaji et al. (2014) consider different MVDs in order to facilitate the use of a BIM model for different design disciplines (architecture, structural engineering, manufacturing, logistics, etc.). Instead, the research carried out by Nawari (2012b) analyses challenges and opportunities in the application of BIM standards to off-site constructions. Panushev et al. (2010) suggest the development of IDMs and MVDs to support the planning, design, construction and fabrication phases of PSC constructions. As regards the automatic control of information within BIM models to support structural analysis Ran and Jiansong (2019) propose a new method using Python and structural analysis software. Meanwhile, in the context of the collaborative and interdisciplinary design phase, and in regard to data exchange for structural engineering Lai et al. (2019) develop a specific method for the delivery of structural information.

In Italy, the Structural E-Permit (Str.E.Pe.) project is the first attempt to investigate the creation and use of integrated IFC models to modernise traditional processes for applications to building authorities for seismic structural engineering approvals and permits (Ciotta et al., 2021). In addition, MVD can also support checks and validation of the exchanged data. In order to ensure the integrity of the data and maintain a reliable data exchange environment, the authors of one study investigate the different types of rules for checking and validating data via MVD (Lee & Eastman, 2015; Lee et al., 2016, 2018, 2021).

In conclusion, the application of the IDM/MVD approach in the field of seismic structural engineering mainly concern the exchange of information between BIM-authoring software and tools for structural analyses and verifications. Unfortunately, there is a lack of proposals concerning the integration of information related to structural design outputs, such as the results of structural verifications and other structural information.

Problem statement

The exchange of information between BIM-authoring software and structural calculation software aims mainly to obtain the export of analytical model information, from the former, and successively imported, in the latter, for a specific phase of analysis and structural verification. Unfortunately, this process does not include a second export into IFC format, or subsequent import into the BIM environment of the structural calculation outcomes and other information. In addition, the adoption of an openBIM approach, for seismic structural e-permits, requires that this information be shared in open IFC format as well. Considering the procedures for permit applications pertaining to structural engineering, a need emerges to integrate structural information (derived from structural design outputs and other context-related information) into new digital means (e.g., BIM models) as well as to design new digital methods to support the activities of building authorities. Generally, the BIM database provides input data for the structural design, but most of the data produced by structural designers, according to the structural codes, do not fully integrate into the BIM database along with other context-related information. These data are not easily recorded, especially in openBIM standard file formats such as IFC. To date, no business software solutions (i.e., structural software), which organise the data in a synthetic and optimised manner for structural e-permit processes, are available. existing software does not allow the export of tailor-made IFC models for structural e-permitting processes. All outputs, which are produced by structural calculation software, are grouped together with other documentation and provided to the BABs' engineers usually via paper-based organisation yet. Based on this information, BAB engineers have to validate the related design solutions before the issue of the related seismic permit. As already highlighted in several studies (Ciotta et al., 2021; Muto, 2020; Shahi et al., 2019), different e-platforms have been developed worldwide, but their use is still limited along with the structural e-permit processes are not totally IFC-based yet. One of the reasons can be found in the lack of a specific MVD that enables the production of IFC models, as a mean of summarising structural data, e.g., required by the structural e-permitting context (e.g., PSets, IFC classes, etc.), and obtained downstream of structural design activities. Until now, in fact, the engineer had to select among the existing ones, available in the commercial software, even if they are related to other use cases and this involved a lack of information in the IFC export phase.

Research scope

In the context highlighted above, the authors propose an openBIM approach for the integration of structural information to support the activities of building authorities. Accordingly, a specific framework was developed, which led to the development of an IDM and related MVD, using the IFC schema, for the integration and exchange of the selected information within a BIM-based environment.

Although we today have software that allows us to carry out structural design activities and export related documents (reports, drawings, etc.), authors considered the openBIM approach for supporting the management and validation of the large amount of information, which traditionally involve very complex and time-consuming activities, though the adoption of open standards (e.g., IFC). The IDM/MVD approach, adopted by the authors, enabled the production of context-related IFC model, which represents a part of the delivered ICDD solution related to seismic permitting (Ciotta et al., 2021), allowing the design solutions to be transferred and validated more easily (e.g. via checks and validation carried out via the e-permit platform by the BAB technicians). In addition, the considered approach was also essential to provide specific instructions and data in order to perform automatic or semi-automatic code-checking along with the opportunity to reduce the deliverables required for seismic-authorisation applications via IFC format. In this manner, authors' proposal supports these activities based on specific IFC models compliant with the proposed MVD and the use case under investigation. In this regard, for the proposal development, the authors considered Edilus software, a structural business software that integrates a BIM environment, because it already included other model views, allowing to save time in the implementation of a completely new mechanism.

As a result, the authors applied the proposed framework on a case study that provided an effective solution for innovative delivery of necessary information to building authorities in order to secure the issue of seismic-authorization permits through these new digital processes. Accordingly, the full integration of the selected structural information into the IFC database enables an open and transparent workflow for the design and management of structural systems as well as the development of improved approval processes. This digital solution allows to archive knowledge on the building heritage (e.g., new built structures starting from the permit issue). Due to this new approach, it is possible to reduce the time required to issue permits compared with the traditional procedure in force in Italy so far. In conclusion, from a methodological point of view, this approach could be taken into account for any construction project (building, bridge, tunnel, etc.). However, the structures considered for the authors' proposal refer to new R.C. buildings. New developments will certainly consist in the extension of this approach to other building construction typologies (e.g., steel, masonry, etc.) by means of new additions related to the authors' proposal.

Structure of the paper

This paper is formed of three sections, In the Introduction the problem statement and research scope are described. It also contains a brief introduction and an overview on the IDM and MVD applications from the structural engineering perspective. Section 1 presents the development of IDM/MVD for integrating structural information into a BIM environment. Section 2 deals with the implementation of the proposed MVD in the structural software in question, in order to export IFC models for seismic structural e-permitting purposes. This was implemented as part of a structural renovation project of an existing school. Section 3 presents a discussion of the proposal. Final section gives our conclusions.

1. Development of IDM/MVD for integrating structural information into a BIM environment

The authors believe that a new digital approach is necessary to improve and expedite seismic permitting processes. With regard to the scenario under investigation, the authors consider an IDM/MVD approach, established by bSI, for the integration of specific information within an IFC model.

Before developing the specific solution (i.e., MVD) to be implemented in the structural software we consider (i.e., Edilus) that integrates a BIM environment, context-related information was established and a specific integration strategy was adopted. For the process we consider (seismic authorization permitting), there is a lack of usable "structural MVDs" to convey outputs and other kinds of information by means of IFC file format. The innovative content we present consists in the development of an MVD that, by means of its implementation in structural software, can enable the export of specific IFC models in accordance with the purposes of the structural e-permitting process. In this way, we can fill the gap that is highlighted in the Introduction. Thus, IFC models we produce can meet the information requirements defined by the process in question, in addition to recording and conveying all structural information obtained downstream of the design activities and other activities related to the general context. The IFC-based approach proposed by the authors, which was successively implemented on a real case (see Section 2), provides a new way that enables checking and validating the required information, thereby allowing users to save time and increase productivity with regard to BAB technicians' activities. The integrated IFC models produced by means of this MVD, implemented in the structural software, will be part of the delivery represented by the ICDD container, which is produced by the structural engineer in charge of the design activities of a new building. All this represents a new digital method, based on the openBIM approach, for managing and conceiving the whole structural e-permitting process (Ciotta et al., 2021). In accordance with these goals, our proposal was organized as shown in Figure 1; the next sections will explain in detail the development phases of the proposal.

This paper proposes the use of the IFC standard to convey and transfer information for the release of seismic-authorization permits. However, the authors are mindful that only a well-designed summary of project information should be transferred through IFC, along with the related documents that must be delivered for further investigation of a specific issue. Moreover, this approach does not eliminate technical drawings and plans, which will always be a fundamental reference for a detailed understanding of the design choices. At the same time, this approach aims to speed up the delivery of information to BABs, and their related verification, where the IFC format can be considered as a valid solution to optimise the seismic-authorisation process and synthetize large quantities of information, which are not only related to the structural context. For instance, 2D drawings could be replaced entirely by IFC models that achieve a sufficient level of development of BIM objects. Meanwhile, BAB civil engineers could use simple IFC viewers to explore the models in detail. Project documentation, such as reports and printouts, would then be consulted, if necessary, starting from synthetic information integrated into the IFC models. However, for the appropriate definition of the dataset related to the seismic-authorisation process, it is necessary to consider certain issues associated with the complexity and heterogeneity of the information that may be required by BABs. Accordingly, the requirement would be to develop an unambiguous and wide-ranging solution for information exchange. However, this is particularly difficult because the information is strictly related to three aspects: (i) the structural code of reference; (ii) the choice of structural and construction type; and (iii) the condition of the building, i.e., whether it is a new construction or existing building.

In detail, with regard to the first aspect, it should be noted that structural calculation must necessarily refer to specific structural codes which regulate, for instance, the methods and strategies of structural analysis or verification of a structure and its elements. Although there are international codes (e.g., Eurocodes), structural design activity must be compliant with relevant national codes and annexes, which are typical of each country where engineers work and design a given structure. These are characterised by numerous theoretical and practical approaches, and various ones can be considered. These are characterised by prescriptive or performance rules and specifications. The former specifies a series of requirements that must be observed step by step, both in the structural analysis and verification phases; the latter only constrain the verification result, i.e., the performance required of the structure or its components. Accordingly, the information produced in the structural verification

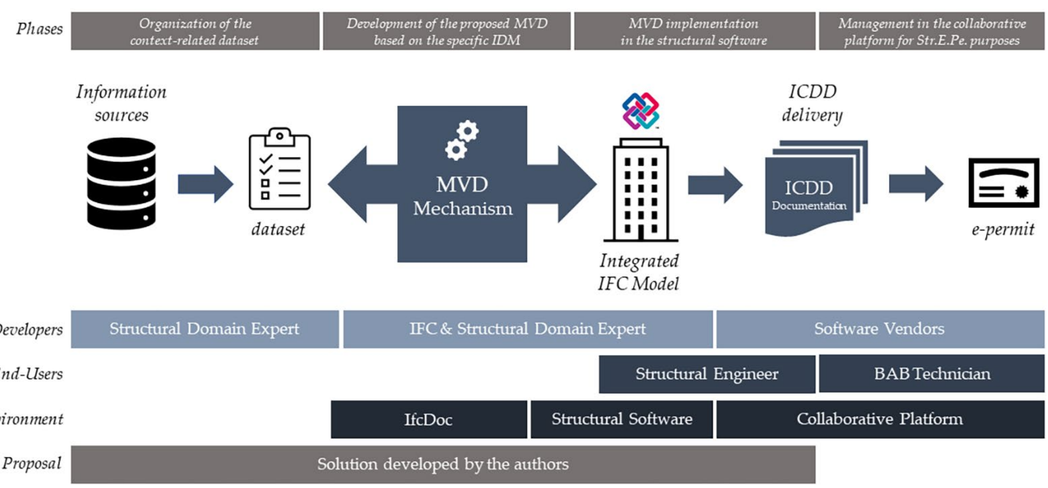


Figure 1. Adoption of IDM/MVD approach for integrating structural information in the context of seismic structural e-permitting

phase changes. Therefore, the information content to be conveyed through the IFC standard is strictly linked to the nature and type of structural codes that can be considered.

The second factor may influence the information that must be considered for the integration of IFC models, which consists of the structural materials and construction technologies adopted to build the structure. It is well known that the latter refer, for example, to prefabricated, cast-in-place or hybrid systems. At the same time, the materials with which the structural systems are built can also be different (concrete, wood, masonry, steel, mixed solutions and so on). Obviously, this involves the use of different structural verification procedures and methods depending on the material and type considered. This is addressed in an organised and systematic manner within the structural codes, with dedicated sections or chapters, also in the case of NTC. Indeed, they deal with the different verifications to be developed, with various approaches depending on the specific case to be considered (e.g., masonry, reinforced concrete, wood, steel and so on). Furthermore, for each scenario, with reference to the construction material (e.g., R.C. buildings), it is possible to have different structural configurations (e.g. frame, wall or mixed structures etc.) depending on the presence of specific structural elements (e.g. column or wall elements) with specific geometric and mechanical characteristics. Therefore, in this scenario too, the result is that different sets of information are considered each time.

To conclude, the third aspect is a building's condition, which refers to the difference that exists between new and existing buildings. The former is concerned with structural design work to identify both geometric and mechanical characteristics able to withstand design actions. The latter can be characterised by assessment operations (e.g., verification of the safety conditions of the building) or structural retrofits, when it is necessary to restore safety levels with interventions aimed at increasing performance in terms of strength and/or ductility. Depending on the condition, a number of checks and verifications may be performed according to different structural methods. In the case of a new building, the most commonly used analysis methods are linear (static or dynamic); in the case of an existing building, non-linear (static or dynamic) methods are mostly applied, since the structural capacity of the building has to be assessed. The dataset of information is therefore quite specific depending on the case in question, i.e., whether the structure is new or existing.

Accordingly, as regards the proposal dealt with by the authors, this refers to a specific context with the goal of formalising and subsequently implementing (as shown in the following sections) an operational solution concerning the export of IFC models integrated with information required by the process under analysis. In particular, the authors decided to consider new design buildings in reinforced concrete, according to the structural normative context in force in Italy. The methodological approach used for the paper's proposal is such that afterwards it could be used to cover other types of buildings (steel, wood, masonry, etc.) as well. Ultimately, the final aim is to support a new digital approach in information exchange for the seismic-authorisation process, thus improving the existing (mostly paper-based) approach mainly considered so far.

1.1. Organization of the context-related dataset

Before considering the possible strategies to integrate the selected information in the IFC format, it is important to specify the context-related dataset to be integrated into the BIM environment. This requires a specific organization of all the information related to the contest under investigation, as proposed in Figure 2, specifically in accordance with the considered use-case, namely the issue of a seismic-authorisation permit by the BABs (Ciotta et al., 2021).

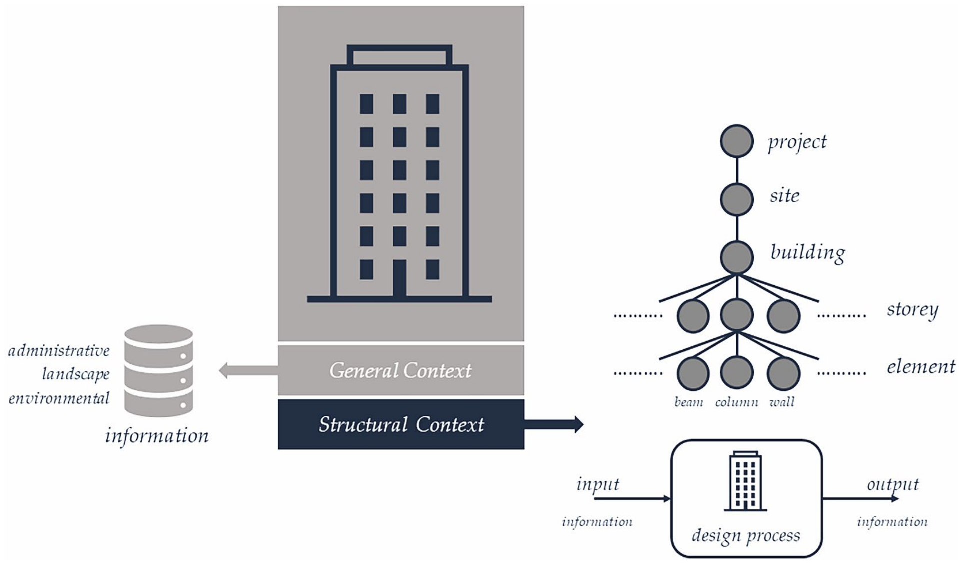


Figure 2. Setting of context-related information to support integration into the BIM environment

More specifically, the information can refer to two types of contexts: (i) the "structural context", in which the information is related to structural design; (ii) and the "general context", in which the information relates to an administrative, landscape and environmental setting. Specifically, the information related to the "structural context" is considered at the "level" of: project, site, global structure; storey; and structural element (i.e., beam, column, wall, foundation, etc.). Moreover, with reference to each of the aforementioned levels, the information can refer to two categories: "input information", which is necessary for structural analyses and the characterisation of the structure or of its elements (e.g., information concerning the structural typology of the building under consideration, the type of structural element, the materials used, and more); and "output information", which is obtained after the structural analyses and the structural verifications (e.g., through Safety Factors). For example, considering structural context, at the global structure level the output information can deal with the inter-storey displacements, P-Δ effects, in-plane and in-elevation regularity of the structure, and so on. On the other hand, remaining in the same context, at the structural element level, output information may be the safety factors (SFs) obtained as the ratio between capacity and demand related to the specific structural checks under consideration. In detail, SFs are the output information of structural verifications (e.g., regarding normal stress, bending, shear, etc.), and are considered for each load combination, since each combination determines a different stress demand (for different calculation sections, upper or lower section bounds, etc.). The SFs must be greater than or equal to one to comply with the code requirements, proving that the engineer has correctly designed the structural safety of the building. In addition, with reference to specific cases, they also take into account conditions expressed by the capacity design strategy (e.g., demand-capacity criteria, ductility requirements, etc.) and by specific limit states (e.g., conditions on global deformability of structure and local deformability of element). For this reason, among the items of information related to the structural context at the structural element level, the authors have decided for this proposal to convey SFs as output summary information. During the design activities, SFs are calculated by structural calculation software and are reported, as output of the structural verification phase, in information containers such as tables, tabulations and reports. However, it would be impossible to report in the IFC model all the SFs reported in these documents, and the authors have therefore decided to use as synthesis parameter, for each structural verification type, both at structural element and global structure level, the minimum SF related to all the considered combinations in the design process. If the minimum SF for a certain structural verification is greater than one, automatically all the others will also be greater than one. Therefore, this approach considers this kind of parameter (i.e., SF) because it summarizes and condenses information about the capacity and demand regarding a certain load combination. This can be used both with reference to the global structure and to the structural elements of which the building under consideration is composed. A detailed and in-depth investigation regarding the specific SF, with its information, can always be carried out starting from the available documentation (e.g., printouts, tables, reports, and other forms of output developed by structural engineers).

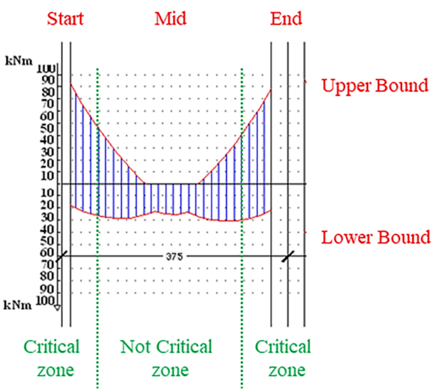
This type of approach therefore allows us: (i) to record a summary and easily checkable information; and (ii) to investigate, if necessary, the design choices made by the engineer in the detailed design document. In addition, the information conveyed through BIM models, which use open formats (e.g., IFC), can enable the use of quick checks, from the point of view of structural engineering, allowing the validation of the information content by means of sets of rules or conditions that could be easily implemented in validation software or other environments. Accordingly, the Str.E.Pe. project, presented in the introduction of this paper, also proposed a preliminary countercheck considering the information related to seismic authorization within the IFC models that had been produced. In this way, by implementing possible conditionalities arising from the structural context (e.g., NTC), and considering the authorization process for these models, along with related information, the timing involved in the whole process is optimised, both in the delivery of the information, which is carried out by the design engineer, and in its verification, which is done by the BAB engineer. The availability of a three-dimensional and parametric model facilitates understanding of the real complexity of the structure, and at the same time is a unique reference for the association of a series of items of information or documents to the objects and global structure (represented by means of BIM models and their objects), and therefore for the eventual in-depth investigation of specific situations. The setting of specific conditions ensures that the considered information is correctly recorded in the IFC models. This information, together with other information contained in the ICDD delivery, will then be validated by the BAB technicians for the release of seismic authorisation. Indeed, the availability of this kind of information (for instance with reference to minimum SF as numerical value and related to each load combination to be considered in reference to a specific limit state), allows technicians to verify in an expeditious way certain structural conditions (e.g., all SFs greater than the minimum SF and one as well), without the burden of checking them all on paper documents and number by number.

Identification of required structural information for the seismic-authorization process

The first step was to identify the most appropriate information to be conveyed through IFC models according to the information needs required by the (seismic) authorisation process. The authors chose to refer to the dataset developed within the Str.E.Pe. project (Ciotta et al., 2021). However, the chosen dataset refers to a specific use-case, namely the seismic-authorization request mainly for new reinforced concrete structures to be built. In respect to this, much of the information that forms the dataset (i.e., the SFs) is not currently covered by the IFC standard. In order to integrate the information related to the dataset into the IFC model, the authors have chosen the MVD mechanism, considered as an opportunity to standardise the information flow.

In particular, in addition to the choice of the IFC classes involved in the integration (e.g., IfcBeam, IfcBuilding, etc.), it was also necessary to define specific Property Sets for the association of the information content related to the dataset with the IFC classes involved in the integration. Hence, it was necessary to analyse in detail all the information in the referred dataset, which originates from several sources (i.e., simulations, structural models, printouts, reports, etc.) and refers to the structure at a global, storey and element level. It is possible to consider, for example, the case of structural beams belonging to the building structure. In the case of structural verifications, as already mentioned in the previous section, the SF synthesis parameter is used. In order to convey this information, however, it is necessary to take into account the way in which the verifications are carried out for the element. In the example reported above in the Figure 3, a generic beam, belonging to a certain building frame, is shown. For this, bending moment checks were carried out, considering its longitudinal direction (for start, mid and end sections) and section bounds (upper or lower bounds, for each section in question). For instance, with reference to shear verifications, the element was divided into three ideal zones corresponding to critical and not critical zones. In general, for all the verifications (bending, shear, torsion and other), the lowest values of the related SF were considered among all the load combinations taken into account during the design phase. Figure 3 shows an example in the specific case of a structural beam. This strategy was applied for each category of structural element considered in the proposal (beam, column, wall, foundation and others) in relation to its characteristics for the structural verification phases. Each element will be characterised by the corresponding IFC class that represents it within the IFC format. For each of the categories related to the structural elements, in addition to certain aspects (e.g., geometry, material, etc.), specific PSets were developed with the goal of conveying summary information in relation to the structural outputs, obtained downstream of the structural design activities (SF and others), and specific information required by the authorisation process.

For example, specific PSets were developed considering a single structural element (e.g., beam) with respect to the structural verifications for moment, shear, torsion and other aspects (e.g., ULSStructuralVerificationRCBeam), at the considered limit state (e.g., Ultimate Limit State), or with respect to other items of information related to the restrictions required for a given structural element (e.g., StructuralReinforcementRestrictions). With regard to the global structure, other PSets were defined for the information deriving from the general context (e.g., GeneralBuildingInformation) and with regard to the outputs related to the global structural verifications (e.g., StructuralBuildingInformation). As regards site information, for instance, with reference to the IfcSite class, the PSets SoilCondition and EnvironmentalAction were proposed. This was also done for IfcProject, and all other classes covered by the proposal. An example of the above is shown in Figure 4. For each IFC class considered by the proposal, the information was appropriately selected and organised in tabular form (see Figure 4). Starting from this organization, it was possible to associate certain PSets, characterized by a specific name, type and other specification (e.g., value and description), to the IFC entities considered for the integration and development of the MVD. These classes, with related information, will then be made available in an integrated IFC model, suitable for the seismic authorisation process, through the MVD mechanism proposed and integrated into the structural software. This will enable the information exchange necessary for the BABs to validate the information for the authorisation process.



Entity→ IfcBeam

PSet for Objects

PSet Name	Properties		
	Template	PropertyName	Value
ULSStructuralVerificationRCBeam	SingleValue	TypeOfBeam	IfcLabel
	SingleValue	BendingSFStartSectionUpperBound	IfcReal
	SingleValue	BendingSFStartSectionLowerBound	IfcReal
	SingleValue	BendingSFMidSectionUpperBound	IfcReal
	SingleValue	BendingSFMidSectionLowerBound	IfcReal
	SingleValue	BendingSFEndSectionUpperBound	IfcReal
	SingleValue	BendingSFEndSectionLowerBound	IfcReal
	SingleValue	ShearSFStartSectionCriticalZone	IfcReal
	SingleValue	ShearSFSectionNotCriticalZone	IfcReal
	SingleValue	ShearSFEndSectionCriticalZone	IfcReal
	SingleValue	CapacityDesignMS	IfcBoolean
	SingleValue	DuctilitySFStartSectionUpperBound	IfcReal
	SingleValue	DuctilitySFStartSectionLowerBound	IfcReal
	SingleValue	DuctilitySFEndSectionUpperBound	IfcReal
	SingleValue	DuctilitySFEndSectionLowerBound	IfcReal
	SingleValue	TorsionSFStartSection	IfcReal
	SingleValue	TorsionSFMidSection	IfcReal
	SingleValue	TorsionSFEndSection	IfcReal

Figure 3. Example of a structural beam and proposed properties set to support the data exchange

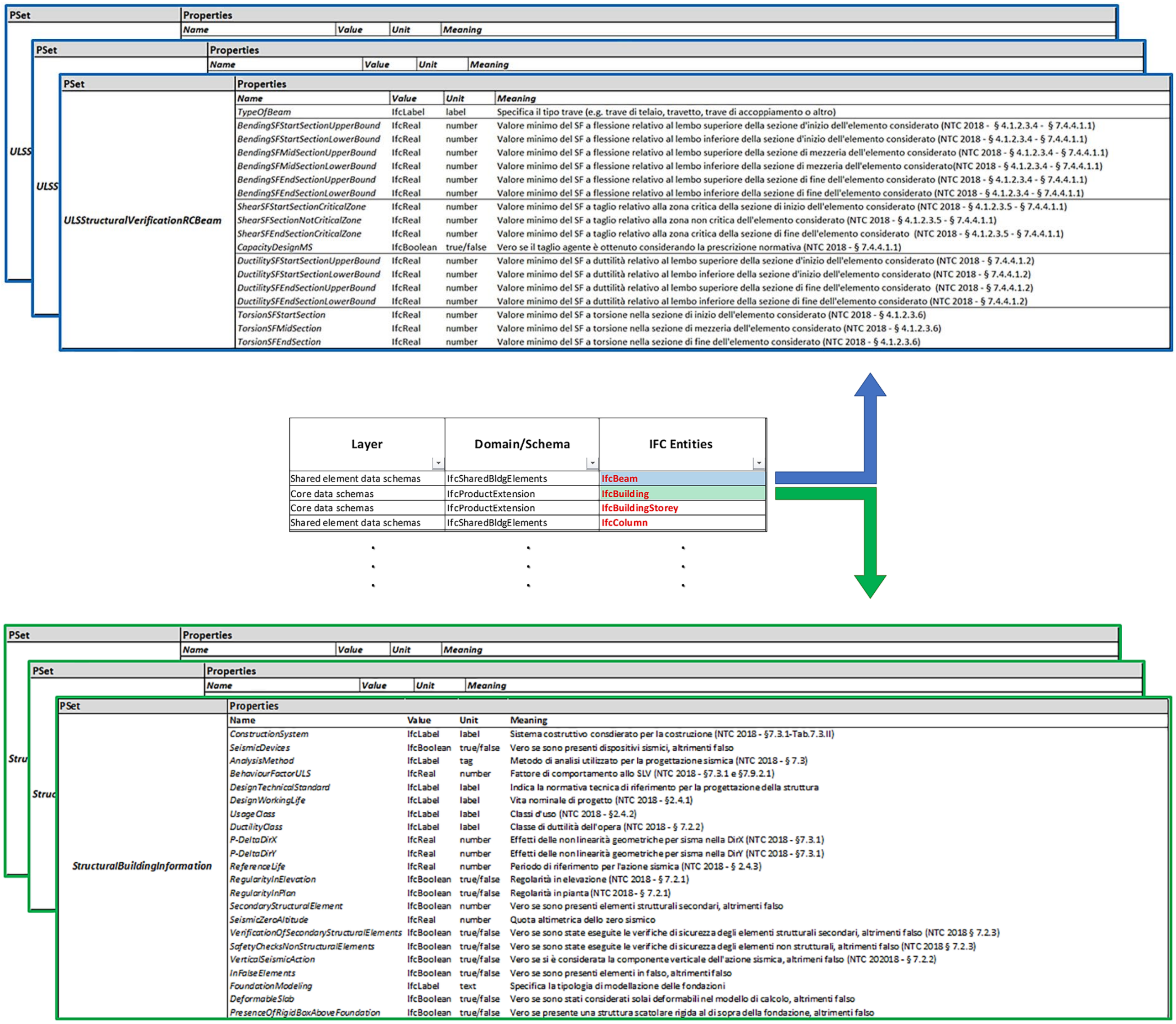


Figure 4. Examples of proposed Property Sets for IfcBuilding (in blue) and IfcBeam (in green)

1.2. Definition of an integration strategy in the BIM environment by means of the use of openBIM standards

In order to support the information flow identified by the Str.E.Pe. project (Ciotta et al., 2021), the authors consider that the best performing approach consists in the definition of an IDM and related MVD (as shown in the next section). Starting from the definition of the process and related requirements (ERs and others), a mechanism is proposed that can successively be implemented in all structural tools that integrate BIM-authoring environments, in order to allow the export of a specific IFC model with classes characterised by specific PSets useful for the purposes defined by the paper. In this structural scenario, as mentioned previously, in the bSI context there are MVDs (e.g., Structural Analysis View) aimed at exporting IFC models with specific information (e.g., geometry, material, constraints and other) useful for importing into structural software for structural analysis activities. As also highlighted in the Introduction, the process of exporting information, obtained downstream of the structural calculation, has not been discussed in detail so far. As regards information exchanges in the field of structural engineering, since the IFC2x3 version with related MVDs (e.g., Coordination View, Structural Analysis View, etc.) is so far one of the most popular and widely implemented versions in the software, and includes both BIM authoring and structural calculation tools, the proposal of this paper, based on the aforementioned IDM/MVD approach, considers the IFC2x3 schema. Unfortunately, the MVDs currently certified by buildingSMART and implemented in BIM-authoring software are not able to cover information related to structural calculation outputs (https://www.buildingsmart.org/compliance/software-certification/certified-software/). Furthermore, as already defined by the authors (Ciotta et al., 2021), in addition to what was stated in the Introduction, it has been shown that most of the information related to the integration context is not conveyed by the IFC standard. Therefore, the proposal covered by this paper deals with using and applying the IFC format in these types of processes (the issuing of seismic-authorization permits) as well. The proposal deals with the development of a new MVD related to the process purposes under analysis (in the context of the Str.E.Pe. project), and takes as its starting point a pre-existing and consolidated MVD, namely the Coordination View (https://technical.buildingsmart.org/standards/ifc/mvd/mvd-database/), which is widely used, and also considers this in relation to BIM methodologies applied to the workflows which involve structural discipline. This mechanism is very well implemented, workable, and tested with BIM-authoring software and BIM tools currently in use. Accordingly, for the development of the proposed MVD, since we started from this existing mechanism rather than creating a completely new one, time and resources were optimised. This development was also designed and successively implemented, as will be dealt with in Section 2, with the goal of showing the feasibility of an operational solution in support of process needs (related to the Str.E.Pe. project). The application of this openBIM approach (IDM/MVD), by means of IFC format, allowed a BIM integration of specific structural information in support of BAB activities. To do that, a specific software ecosystem was considered. Firstly, with regard to the technical development of MVDs, buildingSMART provided a free tool called IfcDoc (https://www.buildingsmart.org/standards/groups/ifcdoc/), which was used in this case. This tool enables the definition of the exchange requirements and the development of related MVDs. Using this tool, it is also possible to develop new proposals starting from MVDs that are already available, as happened in the case of the project presented in this paper. The Coordination View, in this case, was considered as a starting point for the work carried out by the authors. In the context of structural analysis, the authors of another paper (Ramaji & Memari, 2018) also consider this view to develop a specific mechanism for the conversion of the IFC information models obtained from the "Coordination View" into their equivalent IFC structural models, obtained from the "Structural Analysis View". Therefore, the wide sharing in the usage and implementation of this model view in the software considered by the structural context, i.e., both BIM-authoring and structural software, justify the choice of this starting point for the development of the proposed MVD. The adoption of an approach based on IDM/MVD will allow structural calculation software, which integrates BIM-authoring environments, to produce IFC models that are properly built and targeted for the purposes of the seismic-authorization process. Indeed, in the Str.E.Pe. process (see Figure 8), the exchange of information takes place by means of a structural BIM model (in IFC), with the related documentation (2D drawings, reports with technical specifications, and a summary form) delivered in a single data container known as "Information Container Data Drop" (ICDD), where the links between the model and documents are also registered and stored. Therefore, considering only the structural IFC concepts related to the construction of the building (classes, relationships and properties), we filter only the entities concerned by the proposal, both from the physical and spatial point of view, and thus not considering some domains that are not related to the structural context (e.g., HVAC, Electrical, Construction Mgmt, etc.). Figure 5 shows the data schema concerned by the proposal with reference to the IFC2x3 TC1 version.

After a detailed analysis of all these sources and definition of the necessary information (see Section 0) in relation to the authorisation process, these were organised in accordance with the logic and structure of the IFC format. Specifically, a series of information items referring to the project, site, building, storey, element and so on were collected. This information was subsequently organised into properties (i.e., PropertySet and Property concept) and associated with the reference classes of the standard (respectively IfcProject, IfcSite, IfcBuilding, IfcBuildingStorey, IfcElement and related subtypes). Obviously, the adopted mechanism was the MVD, considered as a subset of the IFC schema, which needs to be implemented in software. This allows us to filter only the information of interest in terms of classes, principally, and whatever is associated considering related attributes, relationships and properties. Consequently, user-defined Property Sets were defined. Specifically, for the related properties both the specific type and admissible values were established in order to set context-related rules subsequently to record proper information within IFC models. The dynamic approach offered by the development of specific properties (through Property Sets and Property concepts) can be considered an alternative to integration by means of the definition of additional IFC classes and their attributes (i.e., a static approach) (Borrmann et al., 2018). An IFC model integrated in this way, by means of such properties and obtained by an MVD that filters only the entities of interest, would enable not only an easier validation of the information content that is digitally available, but also permit improved accessibility and speedier workability of information for BAB engineers. An example of this aspect could involve the results of structural checks, historically resident in other information containers (as calculation reports, summary sheets, etc.). The proposed process, shown in Figure 6, will allow, through implementation of the new Structural MVD, the production of BIM models integrated with the information required by the seismic-authorisation process. To do this, the structural software should integrate a BIM-authoring environment in order to allow, through implementation of the MVD mechanism, the export of IFC models.

For the implementation of this proposal in a specific case, as shown in Section 2, the software considered for the integration of the proposed MVD was Edilus, structural software certified both for IFC import (with reference to the "CV 2.0" Exchange Requirement) and IFC export (with reference to the "CV2.0-Struct" Exchange Requirement), and taking into account the IFC 2x3 schema, as reported by buildingSMART (https://technical.buildingsmart.org/services/certification/ifc-certification-participants/).

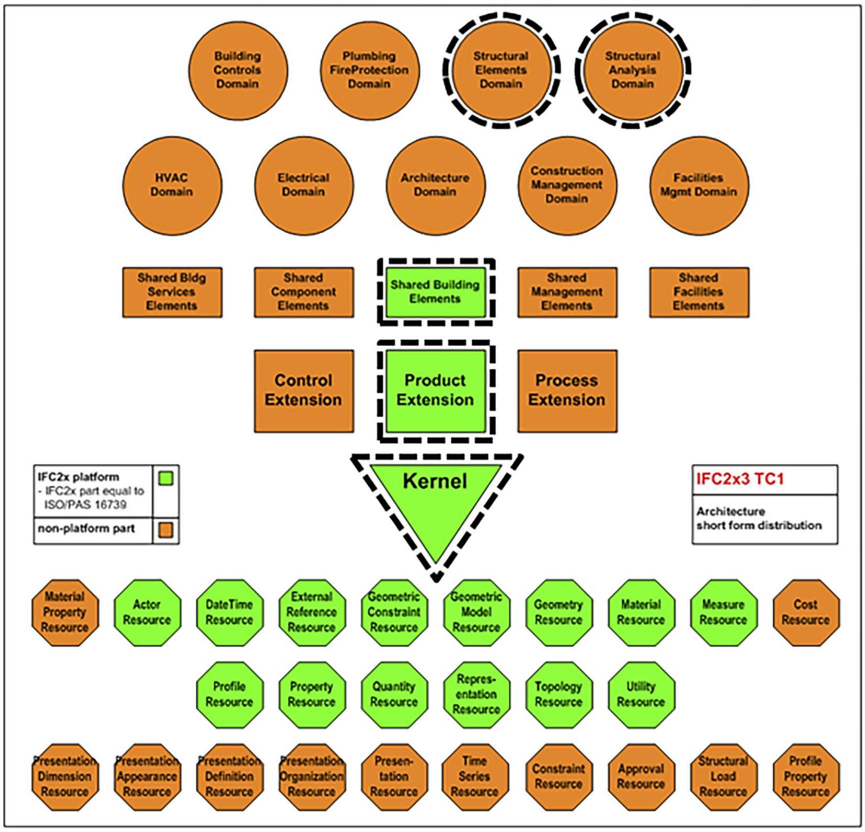


Figure 5. Main data schemas involved in the proposed MVD

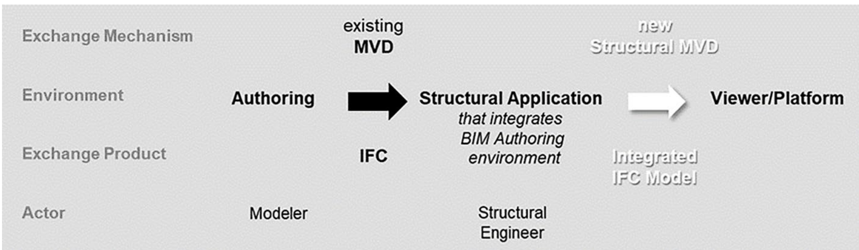


Figure 6. Proposed workflow with the availability of a new MVD, as suggested by the authors (Ciotta et al., 2021)

In collaboration with Acca Software, technical implementation and subsequent tests were carried out on a selected case study (Montemarano School). All this allowed us to enable the export of IFC models from Edilus software, in accordance with context-related exchange requirements that arose through the analysis of the seismic-authorization process and the implementation of a specific mechanism (i.e., the proposed MVD) in the software in question. To conclude, other activities were carried out in collaboration with the software provider, such as automatically writing the extracted values from structural outputs (tables, reports, etc.) in certain proposed properties.

1.3. Development of an IDM/MVD solution for information exchange using the IFC-schema

Starting from the analysis of information requirements, this paper proposes the development of an IDM and its computer formalization through the definition of the MVD and its documentation. By means of the implementation of this proposed IDM/MVD approach in structural software, the export of IFC models integrated with the structural information necessary for the seismic permitting process is enabled. In particular, the proposal is aligned within the workflow shown in Figure 7, where the integrated IFC models become an integral part of the ICDD container, successively delivered to the BABs, as presented in a previous paper (Ciotta et al., 2021), considering the digital process (see Figure 8) developed and proposed within the Structural E-Permit project. Among the objectives of IDM is providing specifications, in a structured and organised manner, to users who decide to use the IFC format for information exchange, and offering support to those responsible for developing a software solution, based on IFC, that implements what has been proposed and organised (buildingSMART International, 2010). The IDM is organised according to an architecture that involves interaction between specialists from the AEC and ICT sectors.

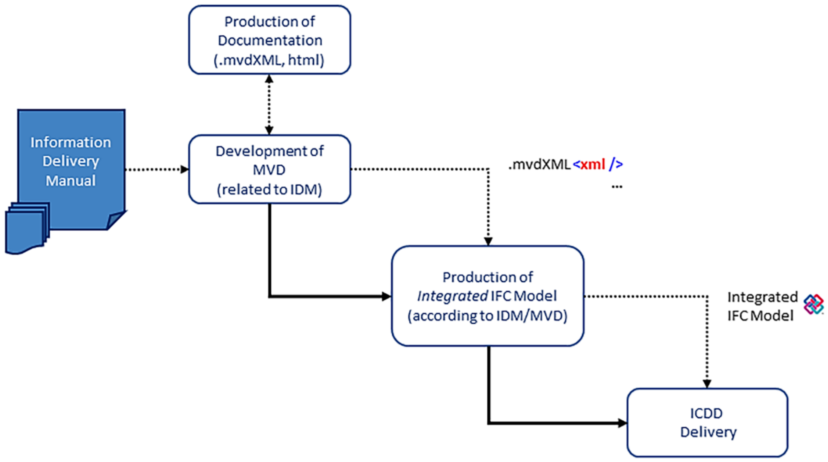


Figure 7. Project workflow to define an IDM/MVD solution

The organisation of an IDM as also defined by the related ISO standards ISO 29481-1 and ISO 29481-2 (ISO 2016a, 2016b), in this specific case defined to support the integration scenario in structural context under analysis, may be composed of the following components: (i) Process Map (PM); (ii) Exchange Requirements (ER); (iii) Functional Parts (FP); and (iv) Business Rules (BR). With reference to the integration context under analysis (Section 0), the involved IFC classes should convey the relevant structural information in order to be stored in the BIM model and its objects. The proposed solution, therefore, fills the gap that has been identified (for the integration of the necessary information), since to date existing software does not support the information exchange in question, or the production of a specific IFC model to convey the information obtained downstream of structural design activities. Therefore, the first step in the development of the proposal is the establishment of the process through which the various professionals will be involved in the information exchange aimed at release of seismic authorisation. In this regard, one of the IDM components is the Process Map (PM), which describes the information flow established among all the actors involved in the process (i.e., in this case, regarding the exchange of structural information for seismic authorization within a BIM project). In addition, the PM identifies the role and activities for each actor, and identifies the Exchange Requirements (ERs) required to support the analysed process. An ER reproduces the information exchanged between actors and processes in a given project phase. Once the ER has been clearly identified, in order to understand what information needs to be exchanged, the next step is to identify the information belonging to each ER. This will be necessary in order to define the Functional Parts and the relative Business Rules, considered as the technical in-depth knowledge of the IFC schema. It is known, in addition, that FPs can be used by different ERs and can also be decomposed into other FPs. As regards Business Rules, these are developed to satisfy the specific needs and conditions of a given process or activity. For the development of the above (PMs, ERs and FPs), the relevant international standards (ISO 29481 series), guidelines or specifications should be considered (buildingSMART International, 2010; IDM Technical Team – buildingSMART International, n.d.) as well as technical documents related to bSI standards (https://technical.buildingsmart.org/). Hence, in the PM shown in Figure 8, we offer a description of the considered process.

Figure 8 depicts the process map regarding the Str.E.Pe. procedure. This is characterized by two pools and three lanes: the first and third lanes describe the operations carried out by the two professionals involved in the process – respectively, the structural engineer in charge of drawing up the documentation to apply for a seismic-authorization permit, and the technician from the BAB who is involved until the permit is issued. The second lane refers to operations carried out within the Str.E.Pe. platform. Specifically, the exchange requirements envisaged by our process are: (1) an application in an editable PDF format or an online form; (2) an ICDD comprising an IFC model, which has been integrated with property sets (PSets) describing the structural project, drawings and technical specifications, as well as the connections between them; (3) an official approval document (i.e., a seismic-authorisation permit). As seen in the process map, a structural engineer draws up the documentation required to apply for a seismic-authorisation permit. Then, after the design phase, he/she accesses the Str.E.Pe. platform and delivers a form (first exchange requirement), applying for a permit for his/ her project and an ICDD (second exchange requirement) that includes: a structural information model in the IFC format, 2D drawings, and descriptions of the connections between them. The Str.E.Pe. platform can then initiate a preliminary automated code-checking process which, if it ends positively, enables the application to advance; if the end-result is negative, the system sends an email containing feedback to the structural engineer, who is asked to review the deliverables and resubmit the ICDD. If the preliminary code-check is positive, a civil engineering technician from the relevant BAB conducts his/her counter-checks. If this counter-check ends positively, the process advances and the technician uploads an official approval document (third exchange requirement) to the platform; if the result is negative, the technician sends an email containing feedback to the structural engineer, who is asked to review the deliverables and resubmit the ICDD. It is worth noting that the ICDD is standardized according to ISO 21597-1:2020 (ISO, 2020), which is a forthcoming specification for a multi-model container approach that allows the models to be interlinked and the data to be connected to external sources.

With regard to the ER, it may contain one or more FPs, which represent a set of technical concepts with their descriptions, associated entities and related Property Sets (IfcPropertySet). A scheme and organisation of the FPs, defined and useful for information exchange, by means of IFC models, is shown in the figure above (i.e., Figure 9). This information is mainly structured according to the IFC schema. In relation to each concept, several items of information are related with corresponding IFC entities, PSets and related properties, e.g., as shown in Table 1. Furthermore, for the purposes of information exchange, each information may be mandatory (MAN), recommended (REC), optional (OPT), or not specified (NOT).

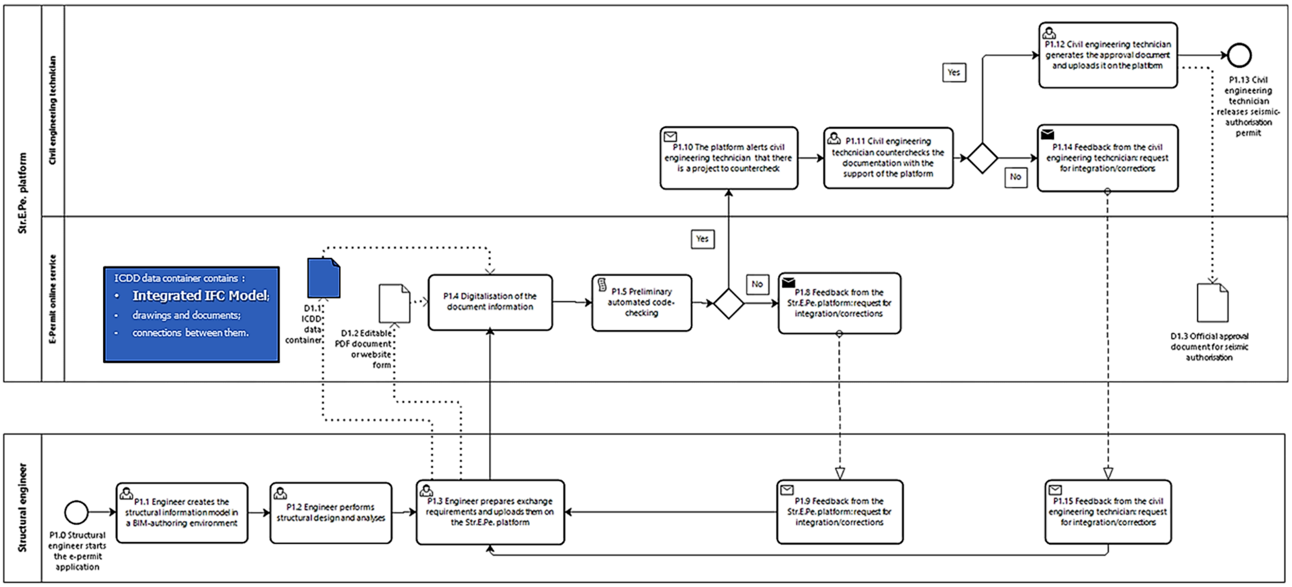


Figure 8. Highlighting the contribution of the proposed solution, provided by the authors, within the Process Map related to the Str.E.Pe. project (Ciotta et al., 2021)

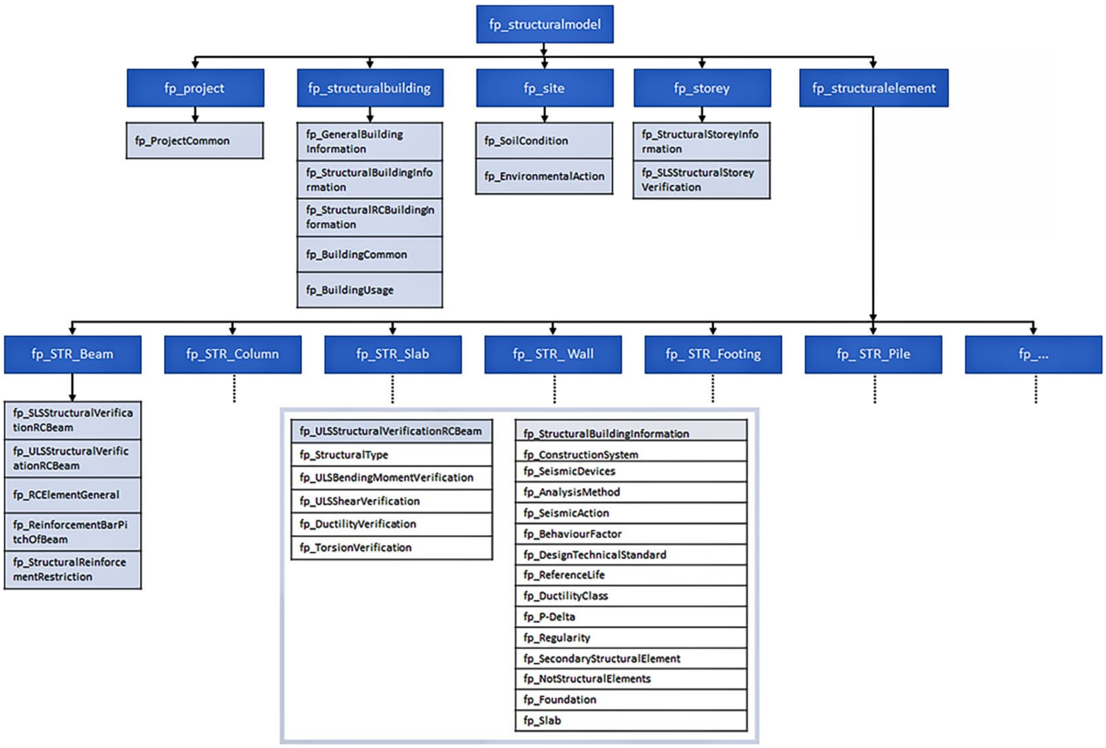


Figure 9. Organization of FPs required for integrating structural information

Table 1. Example of information exchanged by means of organization of specific functional parts considering the IFC schema (e.g., in reference to a structural beam for bending moment and shear verifications)

Information Needed	Pset.Property/Data Type/Entity/Functional Part	MAN, REC, OPT, NOT
Specify information about bending moment checks considering the ULS for structural beam *The property represents the minimum safety factor among selected load combinations, considering "start" section and "upper" bound of a structural element (beam), related to bending moment checks for the Ultimate Limit States (ULS).*	ULSStructuralVerificationRCBeam.BendingSFStartSectionUpper Bound→IfcReal Applicable entity: **IfcBeam** BendingSFStartSectionUpperBound→fp_ULSBendingMoment Verification	MAN
Specify information about bending moment checks considering the ULS for structural beam *The property represents the minimum safety factor among selected load combinations, considering "mid" section and "upper" bound of a structural element (beam), related to bending moment checks for the Ultimate Limit States (ULS).*	ULSStructuralVerificationRCBeam. BendingSFMidSectionUpperBound →IfcReal Applicable entity: **IfcBeam** BendingSFMidSectionUpperBound→fp_ULSBendingMoment Verification	MAN
Specify information about bending moment checks considering the ULS for structural beam *The property represents the minimum safety factor among selected load combinations, considering "end" section and "upper" bound of a structural element (beam), related to bending moment checks for the Ultimate Limit States (ULS).*	ULSStructuralVerificationRCBeam.BendingSFEndSectionUpper Bound→IfcReal Applicable entity: **IfcBeam** BendingSFEndSectionUpperBound→fp_ ULSBendingMomentVerification	MAN
Specify information about shear checks, for element with shear reinforcement, considering the ULS for structural beam *The property represents the minimum safety factor, considering the "critical" zone at the "start" of a structural element (beam), with shear reinforcement, related to shear checks for the Ultimate Limit States (ULS).*	ULSStructuralVerificationRCBeam.ShearSFStartSectionCritical Zone→IfcReal Applicable entity: **IfcBeam** ShearSFStartSectionCriticalZone→fp_ULSShearVerification	MAN
Specify information about shear checks, for element with shear reinforcement, considering the ULS for structural beam *The property represents the minimum safety factor, considering the "not critical" zone of a structural element (beam) with shear reinforcement, related to shear checks for the Ultimate Limit States (ULS).*	ULSStructuralVerificationRCBeam.ShearSFSectionNotCritical Zone→IfcReal Applicable entity: **IfcBeam** ShearSFSectionNotCriticalZone → fp_ULSShearVerification	MAN
Specify information about shear checks, for element with shear reinforcement, considering the ULS for structural beam *The property represents the minimum safety factor, considering the "critical" zone at the "end" of a structural element (beam), with shear reinforcement, related to shear checks for the Ultimate Limit States (ULS).*	ULSStructuralVerificationRCBeam.ShearSFEndSectionCritical Zone→IfcReal Applicable entity: **IfcBeam** ShearSFEndSectionCriticalZone→fp_ULSShearVerification	MAN

A PSet therefore includes several properties that can be associated with objects, materials and more. In relation to the development of the proposal (IDM/MVD), the authors noted that both the most recent IFC4 and the previous IFC2X3 schema contain only a few properties, which are not sufficient to support the whole information exchange investigated in a BIM environment.

In order to extend the use of IFC models also to this type of process (seismic authorization), the IFC schema would need certain information integrations with reference to the single object, the global structure, the site and so on. As regards the BRs, they will define the constraints, for entities and properties, according to the needs and requirements that arise from the process in question. An example of the proposed BRs is presented in Table 2, which shows an example of a specification concerning the rules for information within BIM objects.

In this case, the table shows an example of rules defined for a proposed PSet, namely "ULSStructuralVerificationRCColumn" for the IfcColumn class, where, for a specific rule, a specific name, PSet with related property, condition and value are set. This was also defined for all the information (entities and PSets) defined by the proposal.

Table 2. Example of specific BRs for information integration within a BIM object (e.g., ULSStructuralVerificationRCColumn for IfcColumn)

Rule ID	PSet.Property	Condition
StrEPe_RULE_01	*ULSStructuralVerificationRCColumn.CombinedMNSFStartSection*	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.CombinedMNSFEndSection	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.ShearSFStartCriticalZoneDirX	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.ShearSFEndCriticalZoneDirX	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.ShearSFNotCriticalZoneDirX	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.ShearSFStartCriticalZoneDirY	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.ShearSFEndCriticalZoneDirY	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.ShearSFNotCriticalZoneDirY	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.DuctilitySFStartSectionDirX	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.DuctilitySFStartSectionDirY	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.DuctilitySFEndSectionDirX	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.DuctilitySFEndSectionDirY	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.CapacityDesignM2S3	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.CapacityDesignM3S2	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.CapacityDesignDirX	"Exists" "AND" "≥1"
	ULSStructuralVerificationRCColumn.CapacityDesignDirY	"Exists" "AND" "≥1"

After dealing with the development of the IDM regarding the definition of the identified needs and processes, the next step was the development of the related MVD identified as the technical specification and computer formalisation of what is described in the IDM under consideration. Obviously, this work also involved software developers, who were mainly interested in the subsequent implementation in the software in question. For this purpose, the authors considered IfcDoc (buildingSMART International, n.d.), a free tool offered by buildingSMART, for the development of the MVD related to the specifications previously described regarding the information to be integrated as defined in the related IDM. This tool allows the production of the documentation concerning the MVD, which consists of schemes, diagrams, indexes and specifications defined by the user in accordance with the IFC schema. This tool also allows the export of the .mvdXML file for the validation of IFC data and supports software providers in the implementation of the proposed solution. The generated documentation (related to IFC entities, attributes, properties and other concepts that were specified for the information exchange in the context under analysis) will be necessary for software developers to create a tool that allows the export of IFC models, integrated accordingly, and in relation to the considered information. This is a solution for ensuring export operations in BIM applications, in accordance with information exchange requirements, to support the process considered here (seismic authorisation permitting).

In the IfcDoc tool, for the development of MVD-related documentation the user first has to load a "baseline" with reference to a specific version of the IFC standard. This file represents the complete IFC schema specification (with all related documentation) and a pre-selected set of reusable MVD concept definitions. The use of this tool, however, requires thorough knowledge of the IFC schema (regarding its ontology and semantics, principally). In an MVD, specific data requirements can be defined declaring which information, conveyed through IFC format, are necessary or not for the information exchange involved in the process. For instance, in the case of the concept Property Sets for Objects, it is possible to define properties and associated conditions in relation to their existence, or to the allowed values, and so on. Indeed, in the following figure (Figure 10) an example is shown in IfcDoc regarding the use of the Property Template, in the case of application to a generic beam (e.g. for the IfcBeam entity), and considering the proposed property sets (e.g., ULSStructuralVerificationRCBeam, ULSStructuralVerificationRCBeam, PSet_ConcreteElementGeneral).

The IfcDoc tool also allows users to define rules for specific entities and attributes, including the ability to define constraints and conditions of structures with respect to specific information represented through the IFC features. This process ensures that, in a specific exchange scenario, certain entities must have specific attributes, property sets and related specific values. This can also be considered for the production of IFC files, thus enabling the delivery of high-quality IFC files for the process purposes. This was also realized in this specific case, exporting .mvdXL file as one of the outputs generated by IfcDoc. With reference to the PSets, classes and attributes considered by the proposed MVD, specific conditions (see Table 2) were successively specified through MVD development.

Once the MVD settings were completed, IfcDoc generated the HTML documentation containing the subset of IFC entities, properties and concepts that were specified for the information exchange. In Figure 11 an example

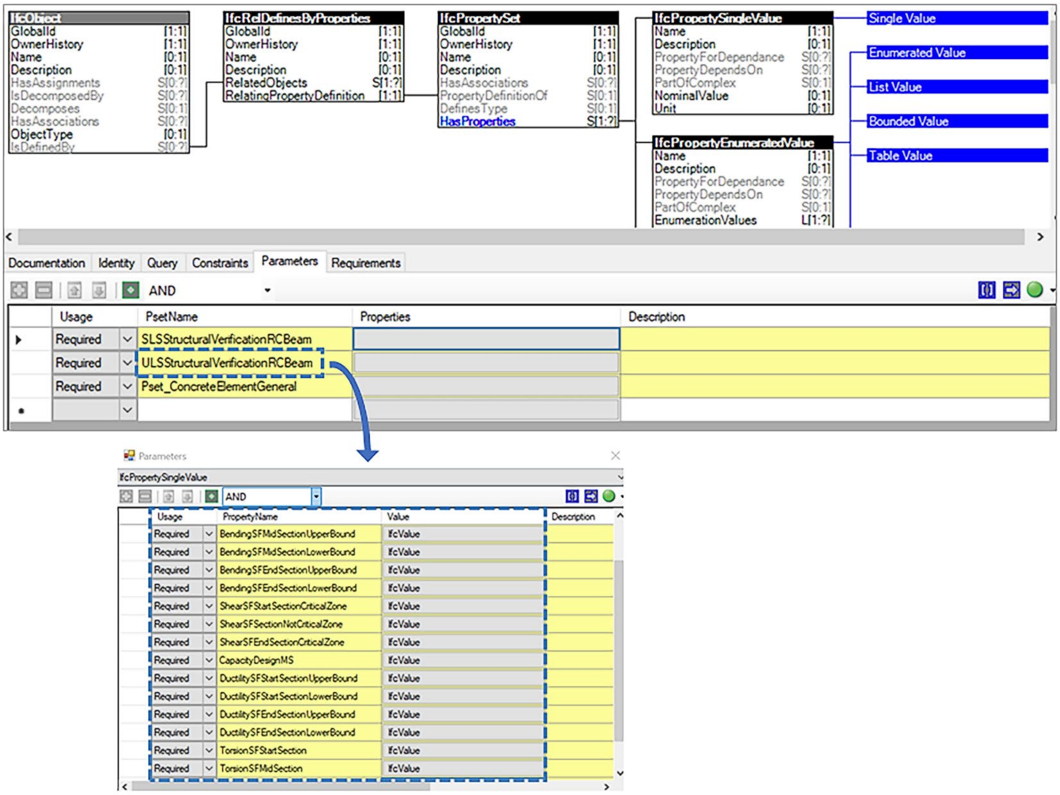


Figure 10. Setting of PSet and related properties in IfcDoc for a specific entity (e.g., ULSStructuralVerificationRCBeam for IfcBeam)

of HTML documentation is given, with reference to the PSets developed for a beam (IfcBeam entity) and structure (IfcBuilding entity).

If structural software implemented the developed MVD, the exported IFC files would contain only the exchange requirements considered for the context investigated here, i.e., seismic authorization. This approach, for the purposes of information exchange, establishes a series of benefits including the reduction of irrelevant information, the reduction of the time needed to acquire information from different sources, and the production of high-quality IFC models. As already mentioned, IfcDoc can generate various pieces of documentation, including .mvdXML files, which are useful for the development and implementation of the MVD (Chipman et al., 2016). Based on the requirements in question, and the information defined in the IDM (Section 0), the corresponding .mvdXML file was generated. This format allows us to set the exchange requirements with reference to IFC classes, attributes and more (Karlshøj et al., 2012). With the goal of also analysing, testing and validating what was produced with IfcDoc (mainly mvdXML files), XbimXplorer was used (https://docs.xbim.net/downloads/xbimxplorer.html, https://github.com/xBimTeam/XbimMvdXML). This is an open source IFC viewer that, by means of a specific plugin, allows us to upload an .mvdXML file. This software, given the possible links or relationships between IFC models and views, allows simultaneous reading of an IFC and .mvdXML file. With the use of this software, in this case the specific IFC model of the selected case study, the correctness of what was set and produced with IfcDoc was checked, as is shown in Figure 12.

The requirements and conditionalities set within IfcDoc and translated into mvdXML can be visualised through the use of coloured views in XBimXplorer. In order to do that, different values of a chosen property or the existence or non-existence of specific required information were considered in the same model. By using colour views, it was possible to check the functionality of such rule sets (e.g., implementation of BRs provided by IDM). Accordingly, it was possible to visualize the results obtained (IFC classes and relative properties) more easily, and the corresponding conditionalities were expressed through the formalization of BRs. All this was brought about starting from what was defined in the IDM and later formalised in the MVD. Figure 12 shows the formal and visual checking of certain conditions expressed in the proposed IDM/MVD approach for a specific IFC class (e.g., IfcBeam, IfcColumn, IfcSlab, etc.). For example, the element concerned by structural verification may be verified (green), not verified (red) or not have any requirements (blue). With reference, for instance, to the structural verification expressed by means of SF $\left(SF = \frac{C}{D} \geq 1\right)$, applying the definition, the generic structural verification will be satisfied if it is $C \geq D$. In the case studied in Figure 12, the BIM objects in red had an SF of less than one, while those in green were greater than one. With this logic, as described in the previous figure, a series of tests were carried out to validate the functionality of the implemented conditions.

a) **5.4.4.43 StructuralBuildingInformation**

Natural language names

Properties

buildingSMART Data Dictionary

PSD-XML

Name	Type	Description
ConstructionSystem	P_SINGLEVALUE / IfcLabel	Sistema costruttivo legato al materiale utilizzato per la costruzione (NTC 2018 - §7.3.1-Tab.7.3.II)
SeismicDevices	P_SINGLEVALUE / IfcBoolean	Vero se sono presenti dispositivi sismici, altrimenti falso
AnalysisMethod	P_SINGLEVALUE / IfcLabel	Metodo di analisi utilizzato per la progettazione sismica (NTC 2018 - § 7.3)
BehaviourFactorULS	P_SINGLEVALUE / IfcReal	Fattore di comportamento allo SLV (NTC 2018 - §7.3.1 e §7.9.2.1)
DesignTechnicalStandard	P_SINGLEVALUE / IfcText	Indica la normativa tecnica di riferimento [NTC, EC, ecc]
DesignWorkingLife	P_SINGLEVALUE / IfcLabel	Vita nominale di progetto (NTC 2018 - §2.4.1)
UsageClass	P_SINGLEVALUE / IfcLabel	Classi d'uso (NTC 2018 - §2.4.2)
DuctilityClass	P_SINGLEVALUE / IfcLabel	Classe di duttilità dell'opera (NTC 2018 - § 7.2.2)
P-DeltaDirX	P_SINGLEVALUE / IfcReal	Effetti delle non linearità geometriche per sisma nella DirX (NTC 2018 - §7.3.1)
P-DeltaDirY	P_SINGLEVALUE / IfcReal	Effetti delle non linearità geometriche per sisma nella DirY (NTC 2018 - §7.3.1)
ReferenceLife	P_SINGLEVALUE / IfcInteger	Periodo di riferimento per l'azione sismica (NTC 2018 - § 2.4.3)
RegularityInElevation	P_SINGLEVALUE / IfcBoolean	Regolarità in elevazione (NTC 2018 - § 7.2.1)
RegularityInPlan	P_SINGLEVALUE / IfcBoolean	Regolarità in pianta (NTC 2018 - § 7.2.1)
SecondaryStructuralElement	P_SINGLEVALUE / IfcBoolean	vero se sono presenti elementi strutturali secondari, altrimenti falso
SeismicZeroAltitude	P_SINGLEVALUE / IfcReal	Quota altimetrica dello zero sismico
VerificationOfSecondaryStructuralElements	P_SINGLEVALUE / IfcBoolean	Vero se sono state eseguite le verifiche di sicurezza degli elementi strutturali secondari, altrimenti falso (NTC 2018 § 7.2.3)
SafetyChecksNonStructuralElements	P_SINGLEVALUE / IfcBoolean	Vero se sono state eseguite le verifiche di sicurezza degli elementi non strutturali, altrimenti falso (NTC 2018 § 7.2.3)
VerticalSeismicAction	P_SINGLEVALUE / IfcBoolean	vero se si è considerata la componente verticale dell'azione sismica, altrimeni falso(NTC 202018 - § 7.2.2)
InFalseElements	P_SINGLEVALUE / IfcBoolean	Vero se sono presenti elementi in falso, altrimenti falso
FoundationModeling	P_SINGLEVALUE / IfcLabel	Specifica la tipologia di modellazione delle fondazioni
DeformableSlab	P_SINGLEVALUE / IfcBoolean	Vero se sono stati considerati solai deformabili nel modello di calcolo, altrimenti falso
PresenceOfRigidBoxAboveFoundation	P_SINGLEVALUE / IfcBoolean	Vero se presente una struttura scatolare rigida al disopra della fondazione, altrimenti falso

b) **6.1.5.22 ULSStructuralVerificationRCBeam**

/ IfcBeam

Natural language names

Properties

buildingSMART Data Dictionary

PSD-XML

Name	Type	Description
TypeOfBeam	P_SINGLEVALUE / IfcText	Specifica il tipo trave, ovvero: trave di telaio, travetto, trave scala o trave di accoppiamento.
BendingSFStartSectionUpperBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a flessione relativo al lembo superiore della sezione d'inizio dell'elemento (NTC 2018 - § 4.1.2.3.4 - § 7.4.4.1.1)
BendingSFStartSectionLowerBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a flessione relativo al lembo inferiore della sezione d'inizio dell'elemento (NTC 2018 - § 4.1.2.3.4 - § 7.4.4.1.1)
BendingSFMidSectionUpperBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a flessione relativo al lembo superiore della sezione di mezzeria dell'elemento (NTC 2018 - § 4.1.2.3.4 - § 7.4.4.1.1)
BendingSFMidSectionLowerBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a flessione relativo al lembo inferiore della sezione di mezzeria dell'elemento (NTC 2018 - § 4.1.2.3.4 - § 7.4.4.1.1)
BendingSFEndSectionUpperBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a flessione relativo al lembo superiore della sezione di fine dell'elemento (NTC 2018 - § 4.1.2.3.4 - § 7.4.4.1.1)
BendingSFEndSectionLowerBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a flessione relativo al lembo inferiore della sezione di fine dell'elemento (NTC 2018 - § 4.1.2.3.4 - § 7.4.4.1.1)
ShearSFStartSectionCriticalZone	P_SINGLEVALUE / IfcReal	valore minimo del SF a taglio relativo alla zona critica della sezione di inizio dell'elemento (NTC 2018 - § 4.1.2.3.5 - § 7.4.4.1.1)
ShearSFSectionNotCriticalZone	P_SINGLEVALUE / IfcReal	valore minimo del SF a taglio relativo alla zona non critica (NTC 2018 - § 4.1.2.3.5 - § 7.4.4.1.1)
ShearSFEndSectionCriticalZone	P_SINGLEVALUE / IfcReal	valore minimo del SF a taglio relativo alla zona critica della sezione di fine dell'elemento (NTC 2018 - § 4.1.2.3.5 - § 7.4.4.1.1)
CapacityDesignMS	P_SINGLEVALUE / IfcReal	vero se il taglio agente è ottenuto dalla prescrizione normativa (NTC 2018 - § 7.4.4.1.1)
DuctilitySFStartSectionUpperBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a duttilità relativo al lembo superiore della sezione d'inizio dell'elemento (NTC 2018 - § 7.4.4.1.2)
DuctilitySFStartSectionLowerBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a duttilità relativo al lembo inferiore della sezione d'inizio dell'elemento (NTC 2018 - § 7.4.4.1.2)
DuctilitySFEndSectionUpperBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a duttilità relativo al lembo superiore della sezione di fine dell'elemento (NTC 2018 - § 7.4.4.1.2)
DuctilitySFEndSectionLowerBound	P_SINGLEVALUE / IfcReal	valore minimo del SF a duttilità relativo al lembo inferiore della sezione di fine dell'elemento (NTC 2018 - § 7.4.4.1.2)
TorsionSFStartSection	P_SINGLEVALUE / IfcReal	valore minimo del SF a torsione nella sezione di inizio dell'elemento (NTC 2018 - § 4.1.2.3.6)
TorsionSFMidSection	P_SINGLEVALUE / IfcReal	valore minimo del SF a torsione nella sezione di mezzeria dell'elemento (NTC 2018 - § 4.1.2.3.6)
TorsionSFEndSection	P_SINGLEVALUE / IfcReal	valore minimo del SF a torsione nella sezione di fine dell'elemento (NTC 2018 - § 4.1.2.3.6)

Figure 11. Example of MVD-related documentation (HTML) regarding different property sets: a) for the IfcBuilding class; b) for the IfcBeam class

These were developed with the aim of checking, for example, the conformity within the proposed properties of the data that had been recorded, as well as verifying the existence of the properties or PSets to which they belong. Once these tests were carried out, we proceeded to the implementation of the MVD in the software, i.e., Edilus. For this purpose, the software developers considered the documentation that had been produced. In addition, several scripts and algorithms (generated by software developers) enabled, for example, the automatic recording of values extracted from the calculation outputs, obtained downstream of the structural calculation, into the proposed properties.

2. Implementation of the proposed MVD in structural software for exporting IFC models for seismic structural e-permitting purposes

In order to implement what had been proposed, a real case study was considered. The entire Str.E.Pe process was applied to a school renovation project in Montemarano, Italy. This project consisted of the deconstruction of an existing building and its replacement by a new reinforced concrete structure. Figure 13 shows architectural BIM models for the design of the new school.

For the development of the BIM structural model (see Figure 14), Edilus software was used, while Edificius was

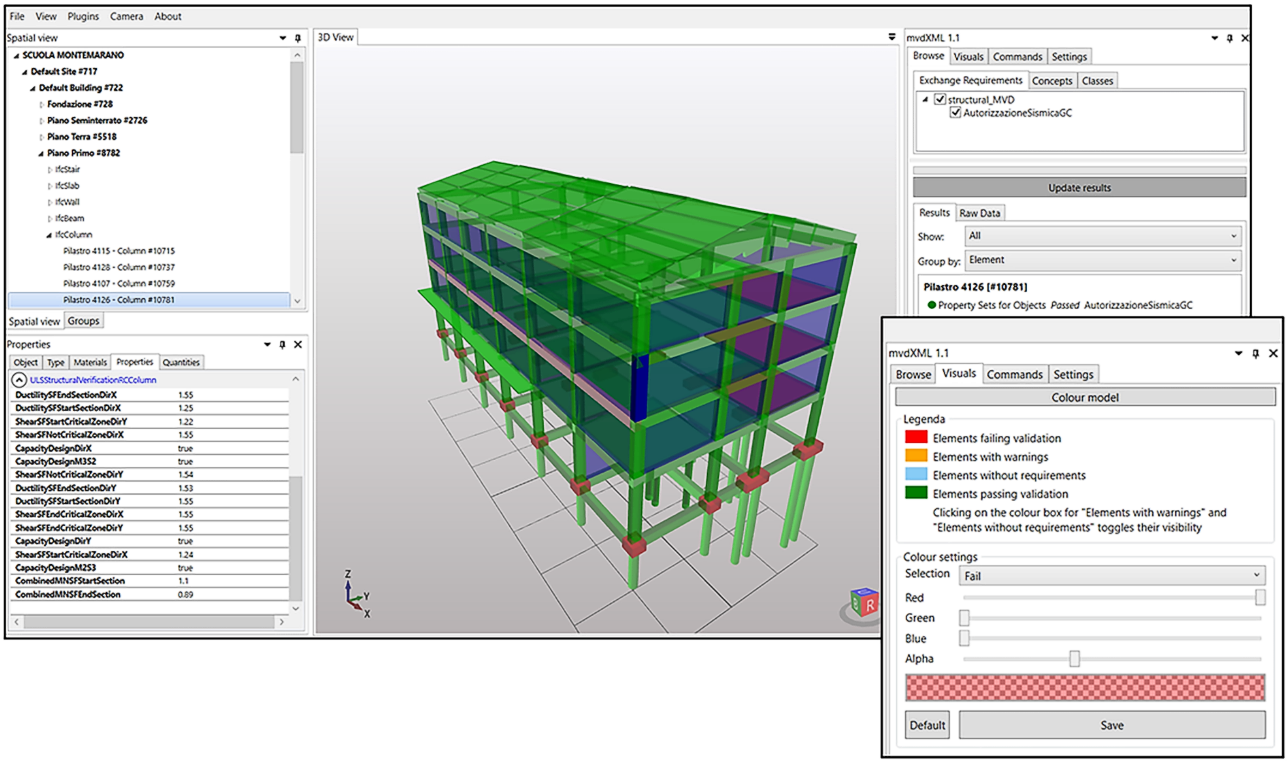


Figure 12. Using XbimXplorer to check an IFC model against the developed .mvdXML file

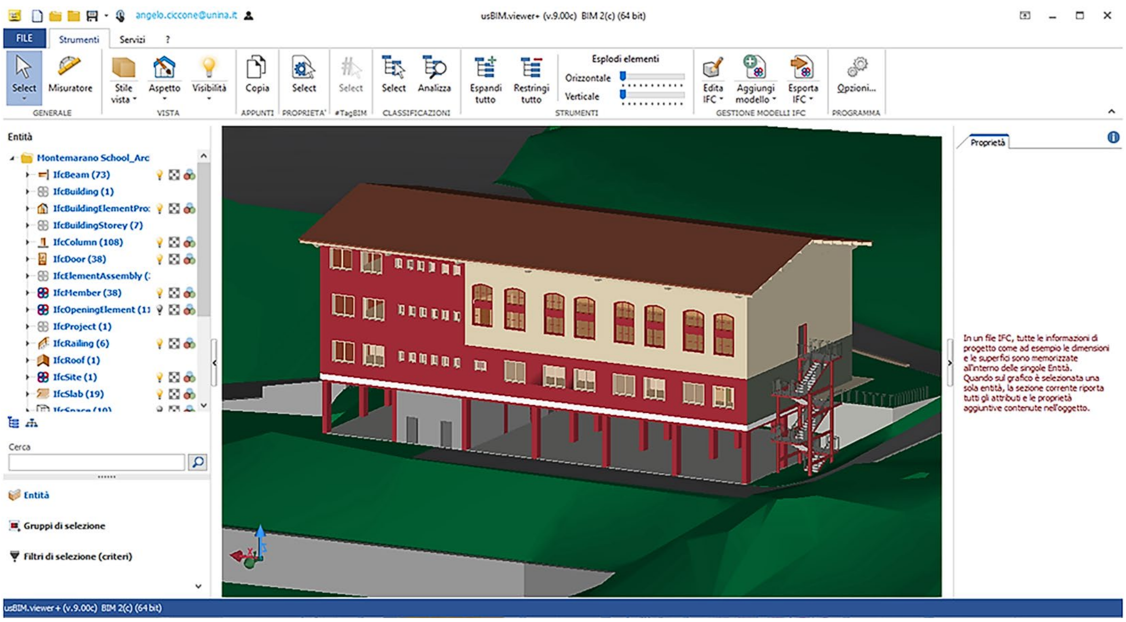


Figure 13. Architectural model of Montemarano School

used to create the architectural model. Both pieces of software are produced by ACCA Software®.

Hence, in collaboration with ACCA Software, the developed MVD was implemented in the structural software (i.e., Edilus) with the aim of enabling the export of IFC models (integrated with the information in question). This model will then be part of the final delivery to the BAB via ICDD, before it is loaded into the collaborative platform. For the implementation of the proposed solution, the software vendor relied on all the documentation produced for the proposed MVD, obtained (mvdXML, html, etc.) by the authors by means of IfcDoc and related IDMs. The structural model related to the case study, produced in Edilus, is shown in Figure 14. Afterwards, the required information was developed according to the current structural codes (e.g., Norme Tecniche per le Costruzioni) and other standards considered for the seismic authorisation process. After analytical modelling, design and verification of the structure, Figure 15 shows structural outputs obtained downstream of these operations.

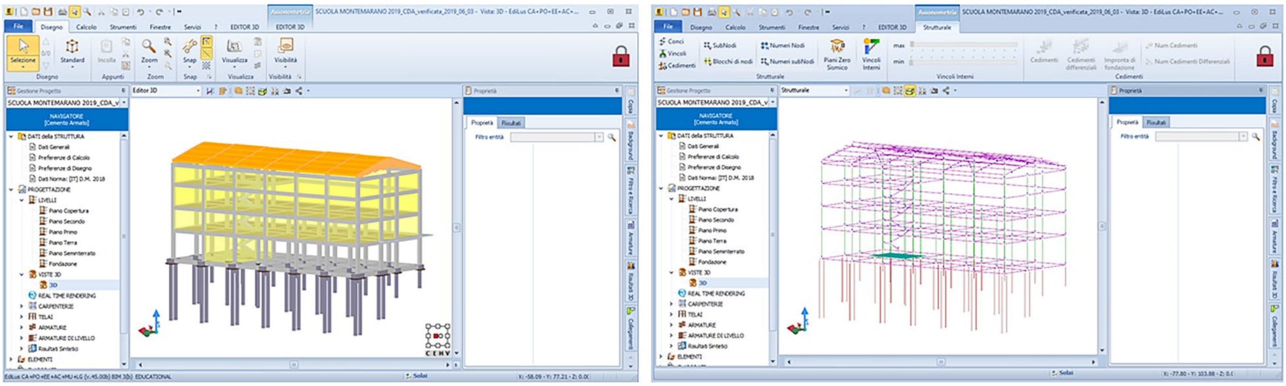


Figure 14. BIM structural model (left) and structural analytical model (right) related to the case study

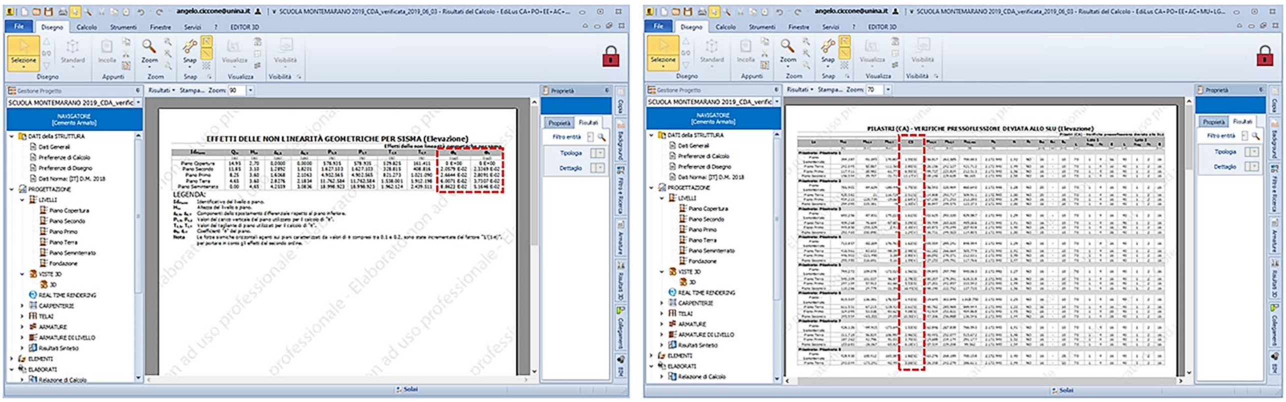


Figure 15. On the left, structural checks related to global structure (e.g., P-Δ Effects) and, on the right, structural checks related to a generic column (e.g., combined bending and compression from axial force)

In the above figure, some examples of results, obtained with reference both to the global level for the building (e.g., P-Δ Effects) and to the local level for instances considering a structural column (e.g., combined bending and compression from axial force), are shown. In the images, the results by means of synthetic parameters (e.g., SF) are also shown. Such information will then be necessary for enriching the IFC model for export. By means of scripts elaborated by the software providers, this information will be processed (e.g., considering for each verification the minimum value of the SF for all combinations) and the related values will be automatically written in the identified properties. The software developers accordingly implemented what had been proposed by the authors for exporting the integrated IFC model with the information required by the process in question.

This implementation also made it possible to set everything automatically through the management of the IFC concepts required by the information exchange, and the organisation of the proposed PSets (associated to the IFC classes concerned by integration) with related values obtained from the outputs (e.g., printouts or technical reports) exported by the structural software. Through the export procedure in Edilus, as shown in the previous Figure 16, it will then be possible to generate the required PSets, with the corresponding properties valorised, with reference to the IFC classes. Thus, Figure 17 shows the available selection of the implemented MVD in the software used for experimentation, i.e., Edilus, among existing available MVDs.

In addition, it should be noted that before implementation of the proposed MVD not all the required information, whether upstream or downstream of the structural calculations, were available in the IFC models exported by Edilus. In order to overcome these limitations too, the authors proposed to software developers to integrate into Edilus (e.g., though definition of additional windows in existing sections in Edilus) context- and process-related information that had previously been unavailable. This allowed the integration in the exported IFC model of all the necessary information (defined in Section 0) according to the exchange requirements (described and formalised in the IDM/MVD proposal for the authorisation process).

The availability of a three-dimensional model in open format (IFC), integrated with the information required for seismic permitting, allows BABs technicians to avoid time-consuming verification and control activities of the information content previously performed manually, mainly through paper-based documents. The IFC model will be part of the delivery via ICDD (Information Container Data Drop), resulting in a structured reference with smart links to other file types such as technical drawings and design reports. Therefore, the solution proposed by the authors considers the platform developed within the

```
........
#794 = IFCPROPERTYSET('1gYhLwyEj2pu93yEhD$dz1', #1, 'StructuralBuildingInformation', 'Informazioni strutturali', (#795, #796, #797, #798, #799,
#800, #801, #802, #803, #804, #805, #806, #807));
#795 = IFCPROPERTYSINGLEVALUE('ConstructionSystem', $, IFCTEXT('Cemento Armato'), $);
#796 = IFCPROPERTYSINGLEVALUE('AnalysisMethod', $, IFCTEXT('Analisi dinamica modale'), $);
#797 = IFCPROPERTYSINGLEVALUE('BehaviourFactorULS', $, IFCREAL(4.68), $);
#798 = IFCPROPERTYSINGLEVALUE('DesignTechnicalStandard', $, IFCTEXT('D.M. 17/01/2018'), $);
#799 = IFCPROPERTYSINGLEVALUE('DesignWorkingLife', $, IFCTEXT('50'), $);
#800 = IFCPROPERTYSINGLEVALUE('UsageClass', $, IFCTEXT('3'), $);
#801 = IFCPROPERTYSINGLEVALUE('DuctilityClass', $, IFCTEXT('A'), $);
#802 = IFCPROPERTYSINGLEVALUE('P-DeltaDirX', $, IFCREAL(0.), $);
#803 = IFCPROPERTYSINGLEVALUE('P-DeltaDirY', $, IFCREAL(0.), $);
#804 = IFCPROPERTYSINGLEVALUE('ReferenceLife', $, IFCREAL(75.), $);
#805 = IFCPROPERTYSINGLEVALUE('RegularityInElevation', $, IFCBOOLEAN(.F.), $);
#806 = IFCPROPERTYSINGLEVALUE('RegularityInPlan', $, IFCBOOLEAN(.F.), $);
#807 = IFCPROPERTYSINGLEVALUE('VerticalSeismicAction', $, IFCBOOLEAN(.F.), $);
#808 = IFCRELDEFINESBYPROPERTIES('103EbYs5H9Ngz2hkWHlsHv', #1, 'Object to Properties', 'Object to Properties Relation', (#731), #794);
#809 = IFCPROPERTYSET('28_R0rx_n7Mg7vP6RLy4VQ', #1, 'StructuralRCBuildingInformation', 'Informazioni strutturali Cemento Armato', (#810, #811));
#810 = IFCPROPERTYSINGLEVALUE('StructuralTypeDirX', $, IFCTEXT('A telaio, miste equivalenti a telaio'), $);
#811 = IFCPROPERTYSINGLEVALUE('StructuralTypeDirY', $, IFCTEXT('A telaio, miste equivalenti a telaio'), $);
#812 = IFCRELDEFINESBYPROPERTIES('093CKc4pz05xYYVMasAoOH', #1, 'Object to Properties', 'Object to Properties Relation', (#731), #809);
#813 = IFCLOCALPLACEMENT(#727, #816);
........
```

Figure 16. Extract of IFC file related to case study, with PSets for the IfcBuilding class

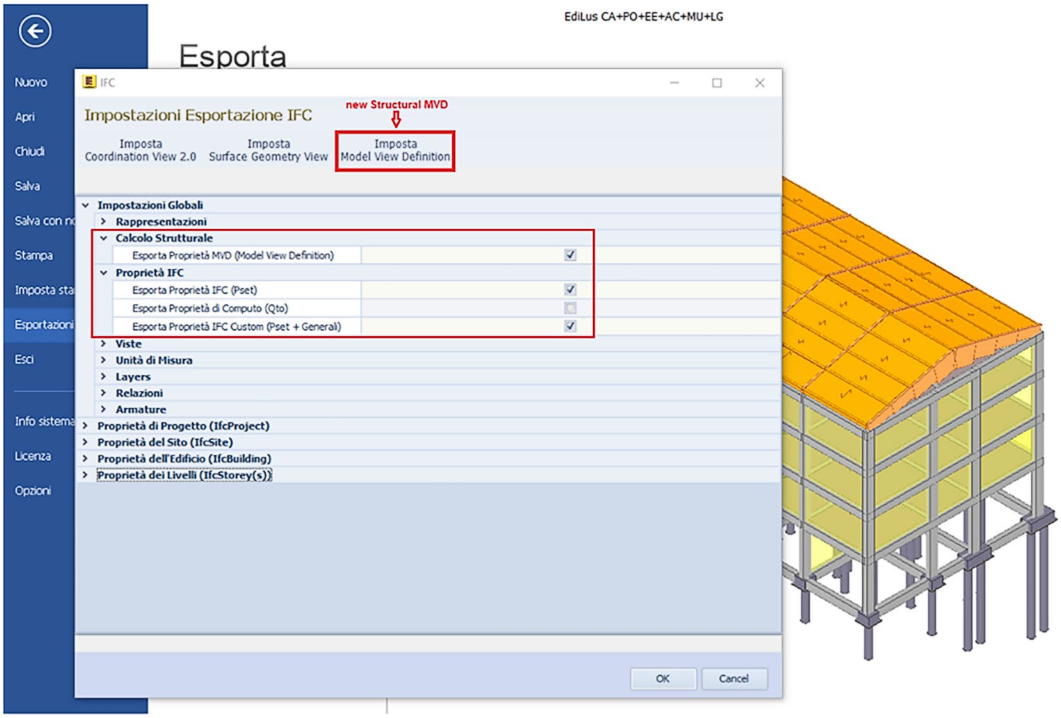


Figure 17. Selection of a new structural MVD to export IFC files with specifications about the proposed PSets

Structural e-Permit project to support the exchange of structural engineering information, in IFC format, for the issuing of seismic permits (see Figure 18). The platform thus has supported the digitisation of the seismic authorisation process in the field of structural engineering, addressing the need for a specific solution. In addition, the IDM/MVD approach provided the opportunity to build IFC models tailored to the purposes of the process in question.

Finally, among the various advantages that come with adoption of the IDM/MVD approach proposed in this paper, there are the following: the possibility of visualizing and managing information in other BIM environments or tools as well; the possibility of using a single environment (collaborative platform) on which to organize information exchange with BABs technicians; and the availability of an IFC model as a reference for the control and checking activities related to information content.

3. Discussion

The proposal to adopt an IDM/MVD approach for seismic authorization permitting enables, within a process based on BIM methodologies and tools, information exchange between the structural engineer (who requires the permit for the building) and the BABs technicians (who release the seismic permit), based on IFC models adequately integrated with process-related information. Given what has been analysed in the previous sections of this paper, in addition to what was already defined in a previous work (Ciotta et al., 2021), the authors consider that the principal information required by the seismic permitting process is significantly lacking within the IFC format. This limits the application of the IFC format to these types of process. Accordingly, the authors would like to see an improvement to the existing IFC schema so that it can provide more support for processes involving structural engineering.

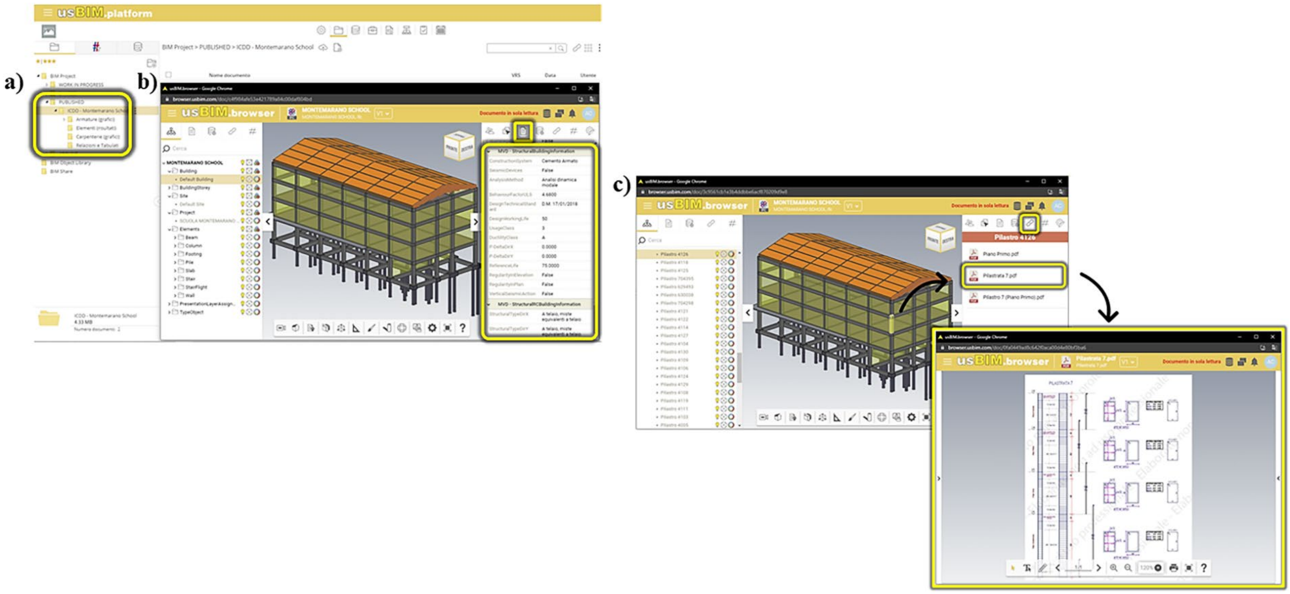


Figure 18. a) ICDD file in CDE environment; b) Integrated IFC model, based on a proposed new structural MVD, belonging to the ICDD container with other files and links; c) Linking of object-related documents (structural drawings, reports, etc.)

The adoption of an IDM/MVD approach favours and promotes the use of IFC models for seismic-authorization processes as well. However, given the current gaps in the IFC standard in relation to the structural domain, an integration of the specific information content for seismic permitting was necessary. Specifically, information was defined at the project, site, structure, storey and element levels. These are referred both to requirements provided by the codes (in this case NTC 2018) and to the specific purpose of structural seismic e-permitting. This information, especially when referring to structural verifications, is synthetic and for this reason representative of the worst conditions (minimum safety factor, SFmin) among all possible combinations of actions provided by the structural codes. In addition, the fully digital approach proposed here allows us to acquire detailed information easily, which the engineer can investigate if necessary. Indeed, the use of ICDD allows us to deliver IFC models to which are linked the technical documentation, consisting of reports, tables and drawings, so that, for example, the technician will find the specific details of the load combination from which the SF originates in the design report, or he will find detailed information relating to the reinforcements in the technical drawings. Therefore, in order to convey the information, we arranged about 200 properties according to the sources mentioned in Section 0. The selected information is associated at each level of the spatial organisation, starting from the context of the project (IfcProject), site (IfcSite), structure (IfcBuilding), storey (IfcBuildingStorey), and element (IfcBuildingElement considered as a supertype of some entities such as IfcBeam, IfcColumn, IfcWall, IfcFooting, etc.). The benefit of adopting the IDM/MVD approach for seismic permit applications and implementing the related MVD in structural software that integrates a BIM environment, consists, mainly, of making information available to BABs technicians through a parametric three-dimensional model in IFC open format. This enables the use of e-permitting platforms that integrate simple IFC viewers, and thus independent of proprietary formats. Moreover, among the potential e-permitting platform functionalities we may also consider the validation of the delivered information content and, consequently, the availability of reliable information from a geographic point of view as well. In fact, once the BABs operators have validated the information content regarding the IFC models, the latter can represent an information archive which can be considered as a reference for further updates (for instance related to structural retrofit interventions or other structural assessments). The proposal developed by the authors also addresses preliminary validation, in a BIM environment, of the IFC models delivered to the BABs for seismic permit applications. Moreover, the MVD also gives us the opportunity to standardize the information flow related to the seismic permit application, and allows us to produce tailored IFC models for the process purposes. At the same time, it should be specified that, in an MVD-based approach, implementation of the proposed MVD in the software we consider is necessary. As shown in Section 0, with reference to the case study we carry out, the proposed MVD was subsequently implemented in Edilus through collaboration of the software vendor ACCA Software. The integration of different skills and knowledge was fundamental in order to establish and organize an operational information flow that was stable and in accordance with the purposes defined by Str.E.Pe. Over time, the application of the MVD-based approach led to different MVDs that were not interoperable with each other. This has caused several scenarios in which, for example, the software that supported a certain MVD could not automatically ensure the support of another MVD.

In addition, to implement a generic MVD, software vendors have to spend resources to update or extend the computer codes within their software tools. Due to these issues, buildingSMART has recently begun to define a new approach where there will be several MVDs, each used for multiple use cases. This will be done with reference to the new IFC standard specification (e.g., IFC4x3 or IFC5).

Hence, the main challenges, regarding the implementation of the proposed IDM/MVD approach, concerned: (i) the development of specific information requirements (e.g., for the building structural types under consideration) in relation to the proposal (e.g., PSets and their properties); (ii) the development of the components of the IDM along with the implementation in IfcDoc for obtaining the MVD documentation; (iii) the technical implementation of the MVD, e.g. through .mvdXL files, in the specific software (this enabled to export from the software considered, i.e. Edilus, the IFC models consistent with the identified use case); (iv) testing phases regarding the validity of the exportation of IFC models relevant for the seismic authorisation; (v) testing phases for the simulation of considered processes in the proposed str.e.pe. platform; education and training, on the proposed openBIM processes, for all the actors involved in the seismic structural e-permit (e.g., BAB technicians and civil engineers).

In conclusion, the adoption of openBIM led, through the use of open formats (e.g., IFC), to save management costs of software licences; to prevent information from being obsolete or ineffective, producing durable projects with a standardised language and exchange of information; a better compliance with deadlines in relation to the information exchanged; and to avoid workflow fragmentation, thus improving collaboration and communication among all actors involved in the process therefore providing the right information at the right time to the right people.

Conclusions

This paper proposes the use of the IDM/MVD approach for the management of information, in the context of structural engineering, pertaining to the results of building design activities and structural e-permitting processes, in order to allow the automatic export of information, mainly through IFC models (via ICDD), supporting seismic permitting processes. The authors found that the integration of investigated structural information, in the IFC format, is a topic that is not well addressed in research. Therefore, this paper first suggests a detailed analysis of the information to be integrated within BIM models. The authors have provided an integration framework through the selected information, which has provided for the definition of about 200 properties, in addition to those already existing in the considered IFC schema, useful for the purposes of the proposal in the analysed context. The proposed IDM/MVD approach enables the information exchange required for seismic permitting in a BIM environment. It provides useful implementation insights for software vendors to develop a BIM tool capable of exporting an IFC model for the specific purpose of seismic permitting. At the same time, the implementation of the IDM/MVD approach will allow the exchange of structural information, possibly among applications or tools developed by different software companies. Accordingly, this will extend the use of openBIM to seismic-authorisation processes. The collaboration with ACCA Software allowed us to produce a first implementation of the proposed solution, demonstrating its full feasibility. For the authors, the main benefits of this approach were: the availability of information directly from the open format IFC model; accordingly, the use of information independent of the software being used; and a new manner of reading, checking and validating information digitally to support BABs activities.

In conclusion, the authors are among the first to propose, in a research setting, the adoption of an IFC-based solution for the seismic permitting process, and in support of this provide an example of implementation. However, the proposed solution refers only to new designs of reinforced concrete buildings. Future developments will certainly extend the IDM/MVD approach to other structural typologies involving other construction materials (masonry, wood, steel, etc.). This operation, in the authors' opinion, will require only a quantitative effort for the extension of the proposed framework to other IFC classes and relative PSets. At the same time, as regards buildingSMART, the development of new standards such as the buildingSMART Data Dictionary (bSDD, https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/) and Information Delivery Specification (IDS, https://technical.buildingsmart.org/projects/information-delivery-specification-ids/) will have to be considered. Indeed, to overcome the limitations of the MVD-based approach, buildingSMART is working on the development of the IDS, closely connected to the IFC standard, for the definition of interpretable computer exchange requirements depending on specific use cases. This standard, intended as a possible computer interpretable specification, defines the exchange requirements related to the exchange information model (in IFC format). These new opportunities (bSDD, IDS) can provide further updates and extensions for the proposal presented in this paper, allowing further developments in the openBIM scenario. The authors are working on this technological development and evolution in order to improve further what has been proposed so far with respect to the new openBIM standards mentioned above. In this regard, the solution seems to be interesting, given that it considers, for instance, the future contribution of bSDD; this could be a chance to standardise the information content (e.g., properties) conveyed through the use of the information model. Finally, the integrated IFC model, which is obtained through the implementation of the proposal (IDM/MVD), could be useful to other "structural use-cases" under consideration, besides that related to the process considered here, i.e., seismic authorisation. At the same time, this proposed solution will allow BABs to avoid time-consuming activities and optimise resources due to this new opportunity for digital management and use of information through the application of openBIM in the context of structural engineering.

Acknowledgements

The Str.E.Pe. research project won a buildingSMART® International Award in 2019. The Authors would like to thank Antonio Cianciulli, Guido Cianciulli and ACCA Software development team for their support regarding the implementation of the solution we propose in the Edilus software and in the Str.E.Pe. platform.

Author contributions

People who contributed to the work are listed in this section along with their contributions: DA conceived the study and were responsible for the design and development of the project. AC, VC and DA were responsible for data collection and analysis. AC and DA was responsible for the development and implementation of the proposal, as well as the testing of the solution. AC wrote the first draft of the article.

Disclosure statement

Authors have not any competing financial, professional, or personal interests from other parties.

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