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## BIM-based structural survey design

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### Abstract

The study, which is part of the digitalization project of the public real estate portfolio of the City of Turin (TOBIM), explores the use of parametric structural models in organizing the knowledge and the data involved in the investigations and analysis on an existing building. The recommended approach exploits Building Information Modelling to set up a graphic and alphanumeric database of interoperable information that can be implemented throughout the building life cycle. Specifically, this paper promotes solutions focused on maximizing BIM data for structural survey design activities. The case study analyzed is a pavilion school complex of the 70s located in Turin.

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*Keywords:* BIM; Structural survey; Knowledge

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### 1. Introduction

In the “Industry 4.0” era the construction sector is going through a period of structural change to keep pace with the speed of the innovation process. Meeting the challenges of the digitalization process offers the opportunity to take advantage of engineering methods, tools, digital workflow and technologies already proven effective in other industrial sectors. The need for knowledge characterizes all the phases of the construction process and represents the common thread that connects the different actors involved in the project in various ways. In this context, BIM is intended both as a three-dimensional digital representation of the asset and as a working method to ensure better sharing of information throughout the building life cycle. The use of BIM in the structural field is a topic still being explored by professionals in the sector. In facts, while the representation of the asset in physical terms is a long-established practice in the architectural field, the calculation and verification of the structures is performed by the

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analytical representation of rods and nodes connections. Currently some researches are focused on the import of physical models made with modelling authoring software into calculation software (Beirnaert, Lippens, 2018; Crespi et al. 2015) and on the export of analytical models made with finite element software in non-proprietary open BIM format (Bazzarin, Rostagno, 2019; Toska, Zanchetta, 2018). In addition to the aspects related to interoperability among software, the possibility of automatic modelling and positioning of reinforcement after their calculation is addressed through Computational Design (Toska, Zanchetta, 2018). It is also worth mentioning the great potential for organizing and storing data useful for the punctual and updated knowledge of the state of the art about the buildings, in this way optimising the guidelines provided by the Ministerial Decree of 17 January 2018 (Repubblica Italiana, 2018) for the safety assessment of existing buildings and by the Circular of 11 February 2019 (Repubblica Italiana, 2019).

## 2. Case study

The tests described in this paper have been performed on a school complex of the 70s, located in Turin (Italy). This asset is part of the portfolio analyzed in the context of the TOBIM project (Osello, Ugliotti, 2017). The building consists of regular-shaped pavilions over two floors above ground separated by structural joints and covers an area of 2,858 square meters. The structure consists of a frame of reinforced concrete beams and pillars with concrete and masonry floors. The foundations are surface plinths isolated. The case study is representative as it considers at the same time the issues of digitalization of the public real estate portfolio and the raising of funding for energy refurbishment, increasingly related to structural checks. In the context of this paper, a structural BIM model with parametric objects has been developed to allow its use in a professional multidisciplinary context.

## 3. Methodology

The methodology investigated aims at enriching the assessment of the building as described by the Italian regulations. It achieves this by setting up an “as is” parametric digital model as a collector of structured information that are currently available and that can be implemented over time. The main objective is to provide a usable representation of the level of knowledge about the building, achieved through the system of information gathered in the archive and in the field (Muratore, Rizzo, 2018). For this purpose, the principal steps covered concern data collection, survey and modelling activities in architectural/physical and structural/analytical terms and the mechanical characterization of materials by on-site testing.

### 3.1. Data collection

The critical historical analysis was carried out by looking both at the materials used for the day-to-day management and at the documentation deposited at the School Building Archive of the City of Turin. Given the public relevance of the building and the large number of schools built in the period of interest, it was possible to reconstruct the building history and have part of the structural design drawings as well as typological details and sections. In order to start the progressive implementation of the digital building dossier of existing assets, the documentation retrieved had to be organized and archived within a common data environment (ACDat) to be available for further investigation, as recommended by the UNI 11337-5:2017 (Ente Italiano di Normazione, 2017). If digital models are available, it is advisable to start from their analysis before proceeding to the survey in order to optimize the activities.

### 3.2. Geometric survey and data output

The best way to consistently verify data is to set up a BIM model after the architectural survey to verify three-dimensional geometries and automatically map quantities. Even though the focus is structural, the first approach to modelling concerned the architectural part, as it is the one that could be checked in the field with the highest accuracy.

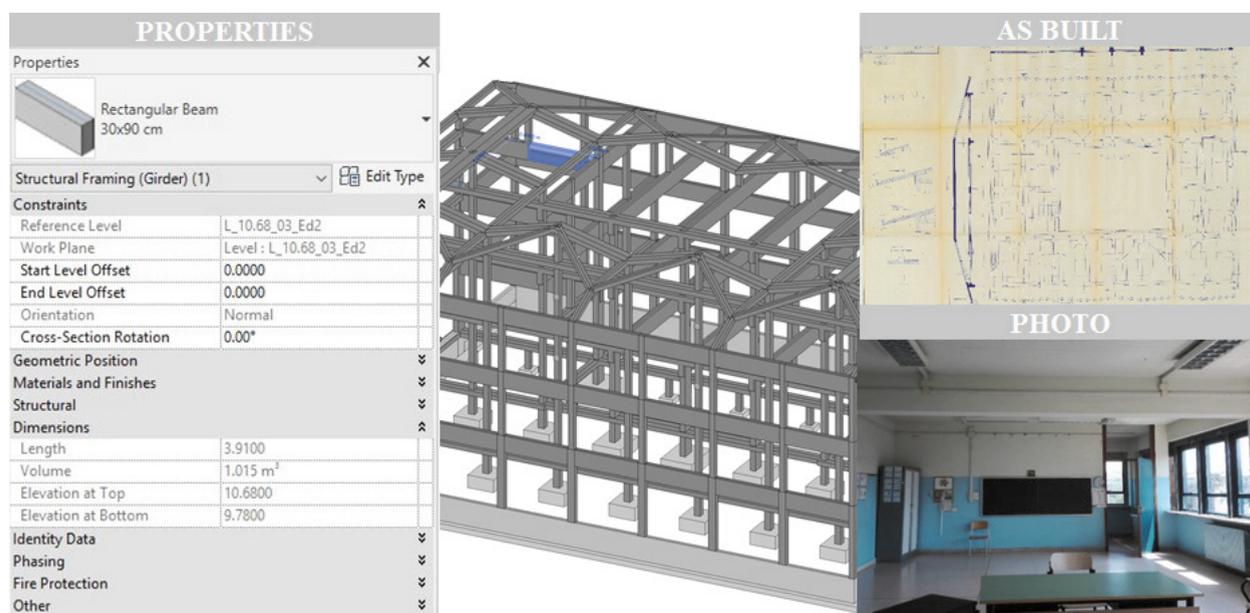


Fig. 1. BIM-based knowledge system.

The architectural model, even if simplified, is an indispensable element since it makes it possible to define a preliminary structural parametric model consistent with the actual state of the building by cross-referencing information with the structural project. Compared to the traditional process, parametric modelling certainly requires more initial time and effort, but it offers an integrated database with other disciplines and automatically returns an analytical model more in line with what has been realized. The way in which the structural components are created in the BIM environment plays an essential role in the subsequent calculation and verification activities in the finite element (FEM) software, where the physical representation is replaced by the analytical one. To ensure that the analytical definition is correct it is necessary to manage carefully the nodes connections between the various elements. To this end, modelling guidelines have been drafted from the experience information gained to facilitate interoperability in the next phases. In this work, Autodesk Revit 2018 has been used as BIM authoring platform, while Midas Midas Gen 2018 (Muratore, 2018) and Giatec Advance Design 2018 (Rizzo, 2018) for the analysis.

Independently from the specific objectives of simulation, setting up an investigation process that involves the use of the BIM methodology certainly has many advantages. First of all, the graphic and tabular correspondence characterizing BIM models makes it possible to automatically create a database of information on the objects. The mapping is organized according to the element type, size and position. Moreover, the parametric object modelling allows us to implement parameters according to specific purposes and link external documentation such as photos, monitoring-related information and previous assessment reports. In this way, it is possible to provide a real repository of data about the building which can be consulted in an integrated manner. This makes it possible to report and document any critical issues. For example, in the case of complex or non-compliant situations it is possible to document through photos and insert comments that may be useful during the synthesis processing of the structural model. It is also possible to create graphic thematization according to the objects' parameters - for example to highlight the structural components to be investigated or map the level of knowledge about the asset, as illustrated in the following paragraphs.

### 3.3. Investigation plan and structural survey

On the basis of the features outlined above, the BIM environment has then been exploited a step further for the design of the structural survey. It is focused on the mechanical characterization of the materials and the identification of the existing reinforcements through pacometric and sclerometric tests. Regarding the destructive tests, the results of investigations previously carried out by the Municipality were used.

The model is used to (i) set up an optimal survey plan depending on the components that can be investigated on-site, (ii) map pacometric and sclerometric tests, (iii) gather the data collected during the survey.

**Survey plan.** The overlap between the architectural and the structural model is an element of great operational value because it makes it easy to identify the elements which can be investigated. It is effective in assessing the individual faces that are in a favourable position with respect to the execution of the test, i.e. that are not covered with finishing elements or by fixed furniture. This allows to plan the structural survey in advance in a very realistic way, avoiding waste of time in the field. A second objective is connected to the graphic display of the survey plan. To do this, the objects have been characterized with parameters that identifies the type of test that can be performed, and filtering rules have been applied in three-dimensional views of the model. As the association is parametric, the objects are automatically highlighted with different colours according to the value of the implemented attribute. This method gives an immediate representation of the elements to be investigated, both graphically and in tabular form. In fact, it is possible to filter objects using the parameter introduced to extract a list of the elements of interest and their attributes.

**Tests mapping.** The parametric definition of objects has been used to obtain a mapping of the on-site tests in terms of number, type and position. For this purpose, two different surface-based families have been created to reference the data connected to the pacometric and sclerometric tests. In this way, the fictitious objects can be positioned perfectly adjacent to the faces of the structural component to be investigated, incorporating the host. The area of investigation is represented through a fictitious cube - shaped parametric object where the length and width parameters allow you to manage the dimensions while the height the elevation from the ground. These are instance parameters so they can be modified for each object in a timely and expeditious manner as shown in the figure below. The family types are used to differentiate the position of the fictitious object on the structural component, defining front/back and left/right (for columns) or top/bottom and left/right (for beams) to make the cases understandable already from their name. To obtain a more complete data set, it is necessary to cross-check the information associated with the fictitious objects representing the tests with those of the components on which they are placed.

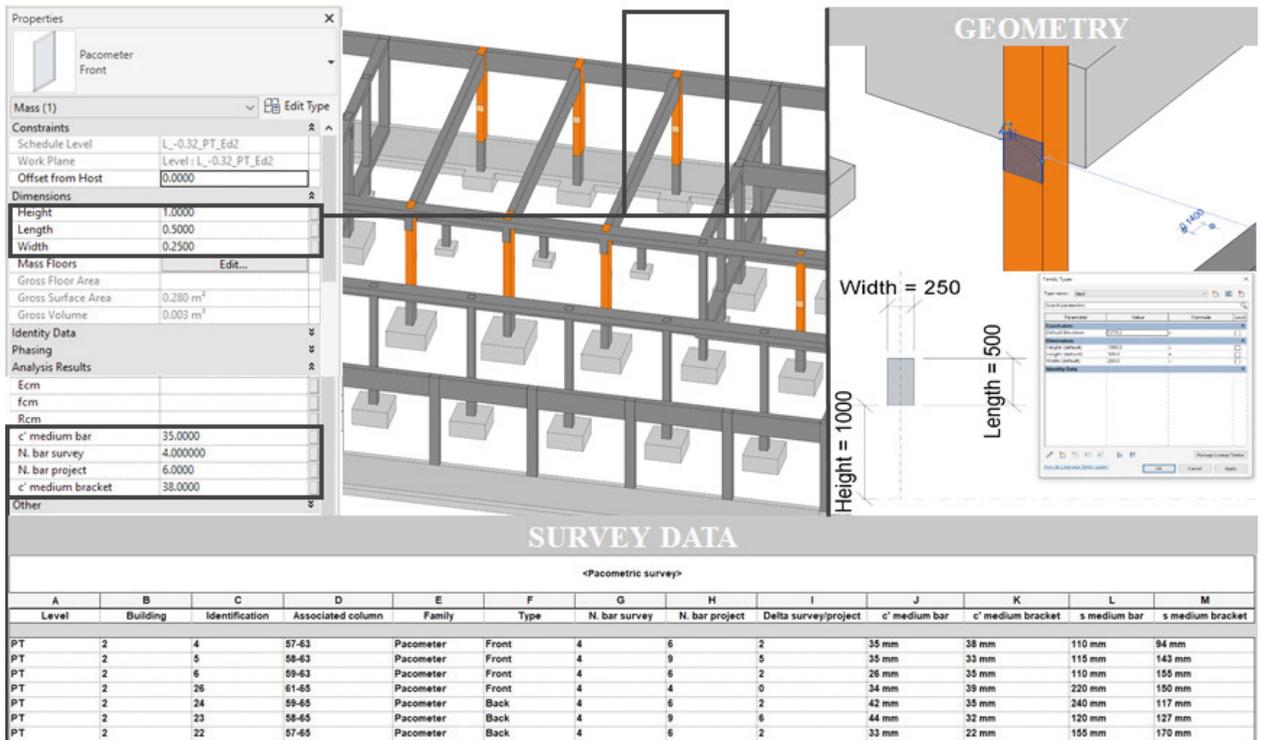


Fig. 2. Fictitious object representative of on-site testing.

This correlation is not automatically returned by the software because the host is identified only as a family and type of element and not through the identification of the single instance. For this purpose, a platform for Computational Design has been used to support the activities which has ensured the extension of data manipulation capabilities. The Dynamo script implemented aims at populating the identification code of the structural element investigated (i.e. the column location mark in the case of pillars) on the fictitious object. In this way a relationship among the elements is created and the associated information can be correlated. The script includes a series of functions and nodes aimed at the following operations:

- Detection of fictitious objects representative of on-site testing
- Filtering according to the test being carried out
- Extraction of the reference host to which the fictitious object is associated
- Extraction of the mark from the host object
- Population of a fictitious object-related attribute with the value of the mark of the associated structural element

If the surface-based family option is not used to represent the tests but another modelling mode, the script must consider the physical intersection between the structural component and the fictitious object to identify the association. Once created, the script is fully automated and can be run directly from the authoring software. Visual programming language makes it more intuitive to process complex functions without Python programming, reducing barriers to understanding the algorithm and thus enabling more users to understand it.

Structural survey outputs. The presence of the fictitious objects serves the dual purpose of giving immediate evidence of the type and position of the tests in a three-dimensional manner and to become collectors of data gathered in the field. The idea is to introduce in the BIM model the information characterizing the tests before executing them as attributes associated with the fictitious objects. In this way, it is possible to organize the measurements data in a structured way and populate them on-site by means of Excel sheet extraction. Once the file is reloaded into the model, the outputs of the tests can be made available over time through interrogations of the objects. Alternatively, it is possible to link an external document that summarizes the results.

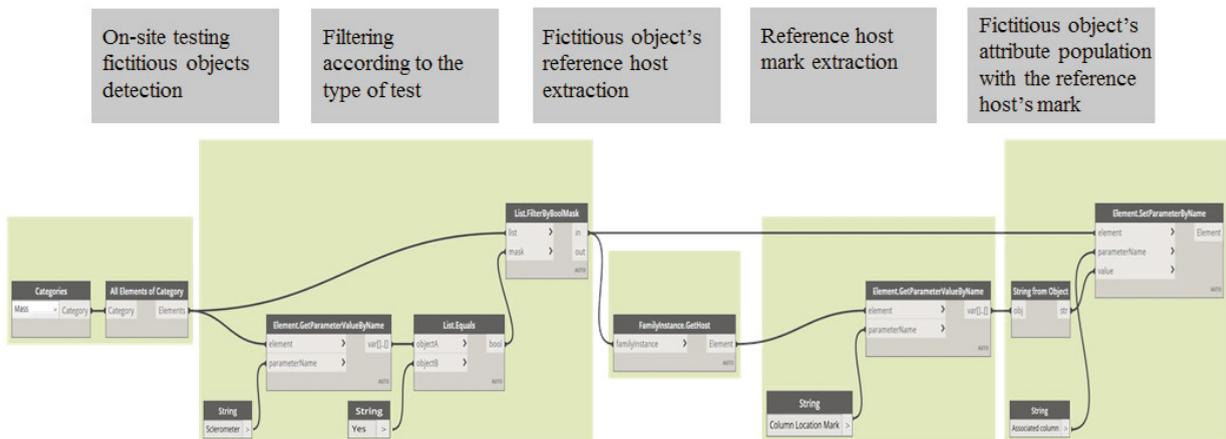


Fig. 3. Dynamo script to relate fictitious objects of tests with the investigated elements.

### 3.4. Analysis of the results

Aside from ensuring better planning of the structural survey, the model is also an optimal tool for carrying out data checks. As an example, the schedules of the fictitious objects have been used to compare the quantity of reinforcement foreseen by the project with that detected by on-site tests. Using the conditional formatting functionality, it is possible to set a cell colouring to verify the adequacy of a certain value.

<Pacometric survey>													
A	B	C	D	E	F	G	H	I	J	K	L	M	
Level	Building	Identification	Associated column	Family	Type	N. bar survey	N. bar project	Delta survey/project	c' medium bar	c' medium bracket	s medium bar	s medium bracket	
PT	2	4	57-63	Pacometer	Front	4	6	2	35 mm	38 mm	110 mm	94 mm	
PT	2	5	58-63	Pacometer	Front	4	9	5	35 mm	33 mm	115 mm	143 mm	
PT	2	6	59-63	Pacometer	Front	4	6	2	26 mm	35 mm	110 mm	155 mm	
PT	2	26	61-65	Pacometer	Front	4	4	0	34 mm	39 mm	220 mm	150 mm	
PT	2	24	59-65	Pacometer	Back	4	6	2	42 mm	35 mm	240 mm	117 mm	
PT	2	23	58-65	Pacometer	Back	4	9	6	44 mm	32 mm	120 mm	127 mm	
PT	2	22	57-65	Pacometer	Back	4	6	2	33 mm	22 mm	155 mm	170 mm	

Fig. 4. Data check through the conditional formatting functionality.

In the case shown in the figure, for example, a red highlight has been set when the amount of concrete cover detected in the field is less than the design. Once the amount of reinforcement present in the structure has been identified, it is possible to insert the data into the BIM model both through a graphic and alphanumeric representation. To insert the reinforcement geometrically there are several possibilities that take advantage of the functionality of the modeling software or external plug-in. It is also possible to generate them by means of visual programming. However, a complete representation of the reinforcement can weigh down the model making it difficult to manage. It is therefore advisable to conceptualize the information and map it at a typological level and not by instance. In this way, it is possible to have the constructive details of the nodes and of the relative schedules and to refer them to the typological mapping of the elements already present in the model.

Another added value of the study is the mapping of the overall knowledge about the building, allowed by the attribution, for each structural object, of a range of predefined values and the setting of thematic filters. Four values are possible: object known, medium-known, poorly known, unknown. The implemented functionality allows us to have a functional and usable overview of the building, particularly when it comes to effectively identifying the knowledge about an existing asset to then carry out assessments or interventions.

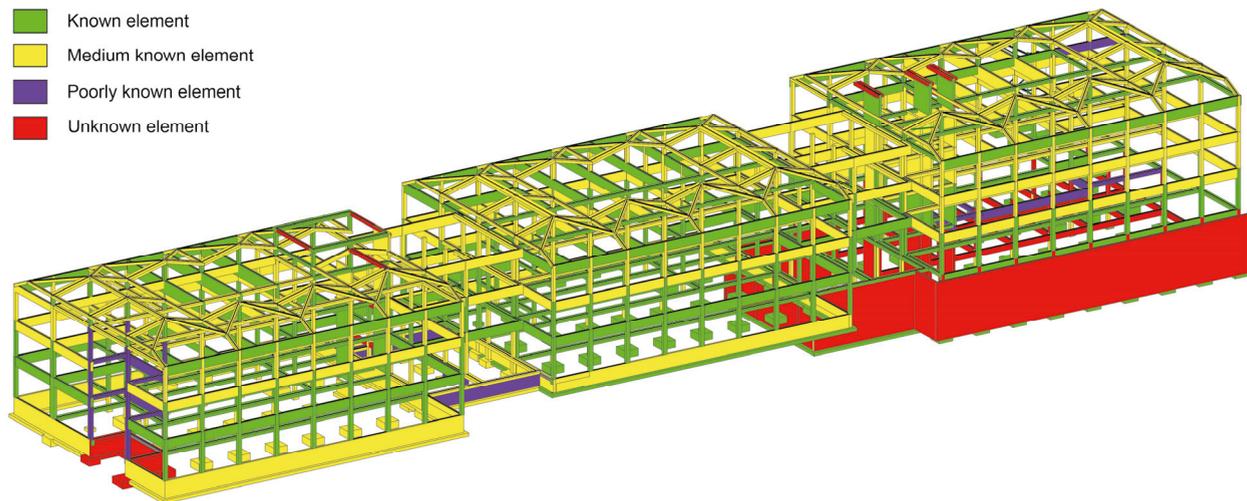


Fig. 5. Mapping of the overall knowledge of the building.

#### 4. Results and conclusion

The study carried out involves the use of the BIM methodology and tools to support the activities of investigation of an existing building, as well as to organize the knowledge about the building in a structured and integrated way. Starting from the on-site survey and the archival documents the “as is” BIM model of the school complex has been created putting together the geometric information and the diagnostic analysis. The implementation of the model, with a focus on the structural component, has seek an interdisciplinary process aimed at returning a database that

can be used by different types of users and for different purposes, not just for the design phase. The modelling of the components must be fit for purpose. In this sense, great attention is paid to the structural elements to find the best way to convert the BIM model into a finite element model. The modelling effort is however compensated by the benefits that can be obtained in having a more detailed and complex analytical representation to better understand the building behavior. The model can be fully exploited thanks to its parametric characteristic to govern and manage any type of information. Through a BIM-oriented approach, the structural survey activity, until now managed separately, has been planned and designed through a new integrated method, becoming part of the digital process. The advantages of the methodology and its potential lie in the implementation of the repository of the building through an accurate evaluation of the investigation plan by introducing and highlighting the positioning of the tests and the reference components. The critical analysis carried out by mapping the reliability of the data and of the information associated with the model elements represents a robust synthesis of the investigation process, which is understandable and usable in a collaborative manner during the building life cycle.

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