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Digitalization Processes and Bridge Information Modeling for Existing Bridges

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Abstract. Bridges constant assessment, monitoring and retrofitting are key aspects to prevent inadequate damage situations. Considering the importance of these processes, a new official guideline for Bridge evaluation, classification and monitoring has been issued in Italy. The usage of BIM methodology comes as a logical solution to store and manage all information related to the bridge surveillance process and create a unique database. In the present work, HBIM methodologies are implemented for the creation of a damage database and new approaches are tested for the application of the guidelines directly on the BIM environment. Using the dismantled structures of Largo Grosseto bridge as a case study and damage information previously recovered as input data, HBIM models are created using two different methodologies: Parametric modelling and Mesh-to-BIM process. Moreover, the utility of the database created is expanded thanks to the usage of visual programming tools. The evaluation of the modelling processes highlights the effectiveness of BIM for infrastructure monitoring and classification. The results obtained demonstrate the way towards a new BIM monitoring standard procedure for infrastructure surveillance processes.

Keywords: HBIM, Bridge inspection, Structural Health Monitoring.

Introduction

The serviceability of long-time existing infrastructures produces great impacts in social and economic terms. Extended service life of infrastructure has led to great accumulation of damage and dangerous situations for its users. The quick identification, assessment and restoration of this damage has become one of the major challenges of civil engineering. As an answer to this challenge a new field of Structural Health Monitoring (SHM) is emerging in Civil engineering. This field embodies a large range of topics such as sensors arrangements, material studies and automatic detection and modelling of damage [1]. Nonetheless, as this is a developing field, its standardization and adoption are still a pending issue [2]. On an effort to

guarantee a correct risk management and a standardized classification process for existing bridges, the Italian Government has issued in 2020 an official guideline for Bridge evaluation, classification, and monitoring [3]. This guideline is a first approach to the SHM with the purpose of regulating the risk classification of existing bridges and provide a decision-making tool for maintenance works.

The new guideline introduces a multilevel approach for the risk classification process where six different levels of analysis can be performed. All bridges in the network are subjected to Level 0 (Census, documentation research and localization process), Level 1 (Direct visual inspections and topographic survey) and Level 2 (Bridge risk classification). However, the depth and level of detail of further analysis vary depending on this classification or "Attention Class" as it is called on the guideline.

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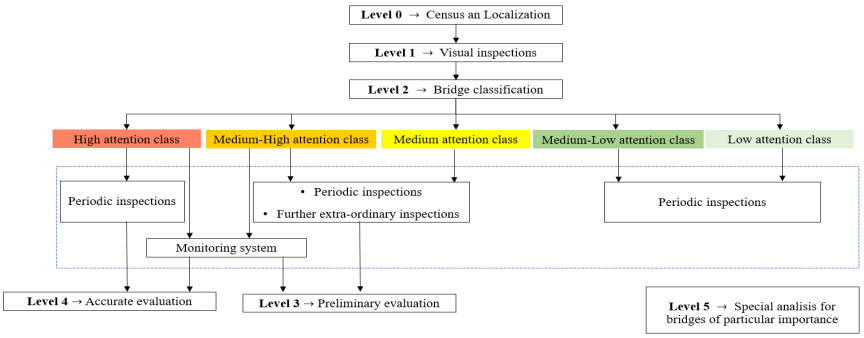


Fig. 1. Levels of analysis of new Italian guideline.

Considering that the type and quantity of information to be recovered differs depending on the Attention Class and that all information should be periodically updated as monitoring process continues, the complexity of data management emerges. A unique database would result helpful in order to digitalize the different inspection forms and store all data in a single model. On this sense, BIM methodology results helpful as it allows a digital representation of all project data in a single database, making it easier to store, manage and actualize according to the bridge service life [4].

HBIM: Concepts and methodologies

BIM methodology was initially intended for the design and management of new constructions during its life cycle. Subsequently, due to the upgrades in BIM platforms, a new concept of HBIM (Heritage or Historical BIM) was further developed [5]. These areas target to construct a reliable record of the facility in its current condition starting from a geometrical survey instead that from a project

idealization. Ordinary information for HBIM may include geometrical data, façade representation, MEP (Mechanical, Electrical and Plumbing) systems, damage survey, maintenance plans, etc. [6].

Input information for the model can be recovered with different methodologies. A direct topographic survey plus an historical investigation process, recompiling data from different descriptive documents, is the more traditional procedure [7]. However, thanks to technological advancements, the most used survey techniques in the field have become remote sensing technologies such as photogrammetry and laser scanner. This type of technology speeds up the survey process while also achieving high accuracy and precision [8]. The output of these surveys can be either a point cloud or a triangulated mesh. The methodology for importing this output into BIM environment can be consequently defined as Scan-To-BIM or Mesh-To-BIM [5].

The Scan-To-BIM methodology consists in importing the point cloud into BIM software and directly creating the geometry according to its shape. This process can be manual or semi-automatic [8]. Nevertheless, as the modelling process takes place inside the BIM software, the freeform and color of the modelled geometry is constrained to the usage of the software basic tools, hence, complex irregular forms and details are generally not replicable [5]. Instead, the use of the Mesh-To-BIM workflow allows the representation of all irregular shapes through the point cloud derived mesh. However, this modelling process is not as direct as the previous one because the mesh format is not, generally, compatible/manageable by BIM software [9]. Different workflows have been used in the Mesh-To-BIM methodology. Barazzetti et al. [10] developed a methodology to transform the mesh into primitive NURBS (Non-Uniform Rational Basis-Splines) geometries and import them into BIM environment. [5,10,11]. Santagati et al. [11] and Yang et al. [12] explored more straight-forward procedures importing directly the mesh using CAD formats and programming tools, respectively.

On the other hand, not many examples of HBIM methodologies for SHM purposes can be found in the literature. Some authors have explored the capability of BIM to manage data from sensor measurements of a SHM [13] while others have explored the possibility of a passage from HBIM models to FEM (Finite Element Method) maintaining the irregularities captured on the model [14,15]. Nonetheless only a few works have combined BIM methodology with damage inspection procedures or automatic damage recognition. Among all, an interesting methodology was developed by Zhao et al. [16] to create a BIM model and apply automatic damage detection inside the model using an image processing algorithm.

Objectives of present study and proposed methodology

The main purpose of this work is to test two different methodologies for the creation of HBIM models that include all damage information of the structure and provide a decision-making tool for maintenance works. Specifically, a parametric modelling process and a Mesh-to-BIM process are tested. The quantity and level of detail of information included into the model is determined by the official Italian guideline [3].

Furthermore, a new procedure for the implementation of the guideline directly inside the BIM model is applied. This novelty in the inspection procedure allows an operator to perform the visual inspection of the bridge directly on the BIM model.

The modelling procedures are applied to dismantled beams of an aged prestressed concrete bridge located in the city of Turin, Italy. The parametric modelling is performed using already recovered information from a complete survey/inspection of the bridge beams and creating different families that are nested together. The Mesh-to-BIM procedure is performed starting from the photogrammetric survey of two pier cap beams. A 3D model is created in specialized software and interoperability issues for the BIM modelling are overcome using an innovative methodology. Finally, visual programming tools are used for implementing the official guidelines directly in *Autodesk Revit* ® environment. Different families and scripts are created for this purpose and a complete inspection (based on level 0 and level 1 of the guideline) of the models is performed. Once the examination of the models has ended the results are exported into excel format replicating the inspection forms provided by the guideline.

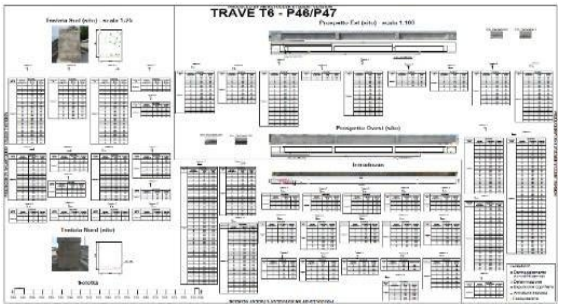
Experimental application

4.1 Case Study description

The Largo Grosseto overpass was an urban bridge in the city of Turin designed and constructed in the decade of 1960. With the purpose of building a new infrastructure system and considering that the overpass had already reached its lifetime, the bridge was demolished in 2019. In the context of the research project BRIGE|50 a group of 29 prestressed concrete deck beams and two pier caps were dismantled and moved to a storing site to be examined. The aim of the project is to obtain a variety of information about the structural elements at their long-term stage to support the safety assessment and residual lifetime evaluation of existing reinforced/prestressed concrete bridges.

An initial inspection analysis of the elements was performed generating a damage sheet for each element (Fig. 2b). The damage sheet included pictures of the structural elements and information about their dimensions and damage. A CAD relief of the damage as well as its quantitative description was also included. For each defect surveyed, identification ID, origin, length, dimension, and depth were provided.





(a) (b)

Fig. 2. (a) Beams on the inspection site. (b) Example of damage inspection sheet.

4.2 **Implementation of parametric BIM model**

Using the family editor in *Autodesk Revit* a new family model was created for a unique bridge beam. The modelling process started with the creation of several editable and fixed parameters. These parameters were assigned to geometric characteristics of the beam to speed up the editing process of the element and creating different element types. The created parameters correspond to the geometric measurements obtained during the survey of the beams. Only general parameters of the beam measurements could be created so other aspects such as irregularities, damage or textures are not considered directly in this family.

To consider the damage information, new families were created in *Revit* for all damage categories listed in the damage sheet. The applied hierarchic division is shown in Table 2a. On the basis of 2D CAD drawings, 3D modelling was performed in Revit considering crack width contained in the damage sheet and the model was enriched with the available non-graphical information, as well (Table 2b). To test the capacity of the model to be updated over time, some fictitious damage geometry was also created. For this fictious damage a different color and value for the parameter "*Data of Modelling*" was assigned.

Table 2. (a) Hierarchic organization of the families. (b) Damage family parameters.

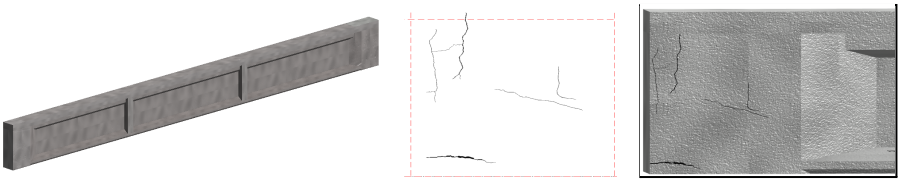
(a)

Division	Category	Family	Type
Beam Family	Structural Frame	I section beam/U section beam	Beam 46/Beam 47/..
Damage Family	Generic Mode	Cracks/Spalling /Corrosion/….	Crack1/Crack2/…

(b)

Parameter	Data of modelling	Operator ID	Damage ID	Damage Type	Length (cm)	depth (mm)	Opening (mm)	Origin
Type	Data	String	Integer	String	Double	Double	Double	Image

The beam family and the damage families were joined together creating a unique nested family (joining two families together to create a new one) that could be imported into a Revit project. On the project interface, a time scale was created using the phase filter tools. Three different phases (Corresponding to the present date and future dates) were created, and each phase was linked to the damage family parameter "Data of Modelling". Consequently, by changing the different phases on the project the visualization and damage information of the model actualizes.



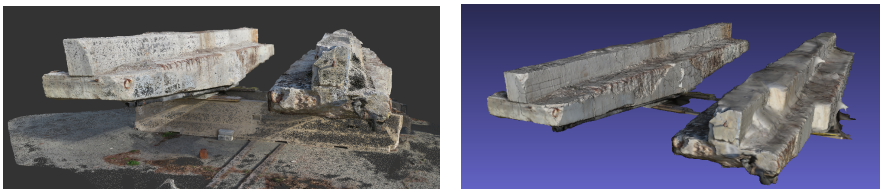
(a) (b) (c)

Fig. 3. (a) Beam family. (b) Damage family. (c) Both families showed/nested together.

4.3 **Implementation of mesh-to-BIM procedure**

The family creation using mesh-to-BIM methodology was applied to the two available pier-cap beams. This process started from the complete photographic survey of both elements. Normally, a survey for photogrammetric purposes is complemented by a topographic network to set the scale and orientation of the model, however, in this case all information about measurements was already recovered on the damage sheets so this step was skipped.

The pictures were processed in *Autodesk Recap* ® software to create a dense point cloud (.PTS format) and subsequently a triangulated mesh (.OBJ format). The mesh was created considering each point of the cloud as a vertex of an irregular polygon, transforming the point cloud into a solid polygonal model. Before the creation of the mesh a cleaning process was manually applied to the cloud using specific manual tools to remove the mistaken points or "digital noise". Once the model was cleaned the correct scale factor was set out using some reference measures and the triangulated mesh is created in order to have a proper accuracy of few centimeters. After this step, the "texture" of the geometric object was automatically generated thanks to the execution of orthographic projections using the RGB information assigned to the points.



(a) (b)

Fig. 4. (a) Pier caps point clouds. (b) Pier caps triangulated mesh.

The geometric model was passed into *MeshLab* ® software to apply several mesh-processing operations. Processes of dividing the model and fixing problematic details (filling surface voids, eliminating unconnected particles, etc.) are applied. Optimization and simplification processes are also applied to the mesh which implies a reduction of the model quality. This reduction in the model quality is necessary to make the triangulated meshes less complex and manageable by BIM software. To import the triangulated mesh into *Revit*, the CAD format was chosen as it allows a straight-forward passage without further converting the triangulated mesh. This procedure generates a non-editable solid block in the BIM software, however on this case this situation is not problematic, as it is only intended for a visualization purpose.

Using the .DXF format the mesh is uploaded into *Revit* as an "imported block" allowing all geometric details to be present inside the BIM software. Nonetheless, interoperability issues are found in the process, making the texture information to be lost, obtaining a no-colored model (Fig. 5a). A no-colored model represented a major problem for the inspection process as it is precisely the texture detail that allows the damage recognition on the elements. This problem was solved dividing the triangulated mesh into layers according to its planar faces prior of uploading it into BIM software. Once in *Revit*, the object was colored again assigning frontal images as material texture to each planar face. These frontal images came from photographs of each side of the beams that were previously edited to eliminate the background information, set the correct scale factor and produce an accurate ortho-photo (Fig. 5b).



(a) (b) (c)

Fig. 5. (a) Un-colored mesh in BIM environment. (b) Image editing process. (c) Mesh colored with the ortho-photos.

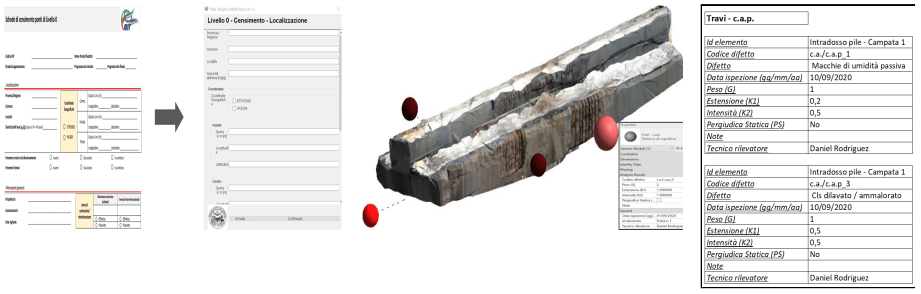
4.4 **Implementation of Italian guidelines in BIM environment**

Using visual programming tools such as *Dynamo*, *Revit* capability can be expanded to produce a user interface to edit a model. Thanks to this interface the damage inspection of the beams can be performed directly in the BIM environment instead of on-field as it is normally done. The level 0 and level 1 of the Italian guideline are reproduced on the BIM platform as these levels are the ones that report the necessary information to classify the bridge.

To create this user platform, different *Revit* families were created, and different *Dynamo* scripts were written. The information of Level 0 contained in the guideline sheets was reproduced by the creation of five information-only families corresponding to the principal categories of information. These families contained as parameters the data to be filled during the level 0 inspection. Then, different scripts were created in *Dynamo* to generate the user interface and fill the requested information. The user interface was created using the *Dynamo* package, *Data-Shapes*. The script allows an operator to import the information-family in the project and fill the parameters with either a list of predefined options or an open text, number or Boolean information. The interface consists in a set of windows that can be activated from the general *Revit* platform, so the operator does not need to enter the visual programming tool (Fig. 6a).

Then, to support with visual evidence the Level 1 of the guideline, a system of spherical labels was created. A total of 20 different label families and family types were created corresponding to the possible combinations of bridge elements and damage included in the guideline. A set of parameters was also created for all family types corresponding to the defect code, weight, risk, extension, and severity according to the guideline. The parameters were linked to the geometric characteristics of the label (radii and color), so a more severe defect would mean a bigger and more striking colored label. To import the labels in the project a user interface was created with a *Dynamo* script. The user interface allows an operator to choose what label to import according to the defect that is inspecting and fill its parameters. The script also asks the operator the position of the defect (with respect to the element origin) so the label can be correctly positioned. Single labels are imported for each defect of the beam as the inspection process continues, exhibiting from a global perspective the quantity and severity of damage in the beams (Fig. 6b).

After the scripts of Level 0 and Level 1 were performed and the inspection process is over, a final script was made and executed to export all the information included in the model into excel and produce inspection forms as intended in the official guidelines (Fig. 6c).



(a) (b) (c)

Fig. 6. (a) Level 0 sheets recreated on the BIM platform. (b) Beam family and damage label after inspection. (c) Damage sheets in Excel format.

Results, discussion and conclusions

In the present paper, two different methodologies were studied to reconstruct an HBIM model of dismantled prestressed concrete elements. Additionally, visual programming tools were used to recreate the official Italian guidelines for bridge monitoring inside the BIM platform and apply an inspection procedure.

The first modelling procedure, namely the parametric modelling based on traditional survey/previous documentation, was based on an inspection sheet containing all damage information. The quantity of present information allowed the modelling of not only the main features of the element but also its damage. The model could be updated over time thanks to the combined usage of parameters and time filters. This modelling process presented advantages of being the most straightforward and simple one. All elements are modeled directly inside the BIM software and controlled by parameters, so the output is fully and easily editable. The usage of parameters allows compiling all the damage information creating an updatable database. However, as the model is based on previously made inspections, the quantity of damage information can be limited as it depends on the quality of the inspections performed. Moreover, as the geometry modelled by this procedure is constrained to the usage of the software basic tools, complex irregular forms and details from defects or textures could be lost. Finally, the manual modelling of the elements can result into a time-consuming task that added to the time spent for the on-field inspection leads to a time-inefficient procedure.

The second modelling procedure used, namely the Mesh-To-BIM process with CAD format, worked through the photogrammetric survey of the elements, the creation of the point cloud and triangulated mesh, its data-processing and transfer to the BIM software. During the passage of information from the mesh-editing software to the BIM platform, interoperability issues made the texture information to be lost. This information was recovered dividing the mesh into layers and adjusting ortho-photos as texture to each planar face. The output produced from this methodology is considerably superior in terms of model detail than the one from the first modelling procedure. The model created maintained the actual surface details, color and shape consistency of the beam surveyed making the model more reliable.

Additionally, the photographic survey performed stands out for its time efficiency compared to manual survey techniques. Nonetheless, the non-editable solid block can produce limitations for further model updating plus the great quantity of manual operations for data processing/surpassing interoperability issues result time-consuming and costly in technological resources.

The final part of the research consisted in using programming tools to recreate two levels of the Italian guideline inside the BIM platform. The platform developed from this procedure is an effective representation of the inspection sheets, presented in a user-friendly interface. The interface allows an operator to perform the inspection directly on the model. The latter produces a series of advantages to the inspection process such as reducing the inspection accident risk, budget (less logistics and equipment) and disturbance to the bridge users, and increasing the bridge visibility. The label system created allows the user to quickly identify the most damaged areas of the bridge and keep them under a controlled monitoring process. However, as the inspection is performed directly inside the model, its precision depends on the quality of its images. Thus, the inspection with this methodology can only be performed in models that represent the reality in the best way.

The outcome of the present work proves the utility of BIM methodology for monitoring procedures in civil structures. Specifically, the model created with the Mesh-To-BIM procedure highlights such level of detail that allows the visibility of damage directly inside the model. The usage of BIM tools for updating the model over time plus the usage of visual programming tools to recover damage information convert the model into an adequate monitoring tool for surveillance procedures. Future efforts are needed to reduce the quantity of manual operations in the data processing and smooth the data flow from Mesh editing software to BIM software. A logical expansion to the outcome produced by this methodology can be the automatization of damage recognition inside the model, exploring possibilities of image processing and machine learning algorithms directly inside the BIM platform. Finally, for both the procedures studied it is possible to exploit the digitalization features implementing damage models to forecast future scenario and schedule ordinary or extraordinary maintenance operations.

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