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Infrastructure management integrating SHM and BIM procedures

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ABSTRACT: In view of using BIM procedures to support real-time lifecycle management of infrastructure, the paper explores the idea of integrating 6D digital models with SHM data bases, condition assessment algorithms and decision support systems for operation and maintenance. The main aspects involved in this integration, including optimal object breakdown, representation of the SHM sensory system, inclusion of damage sensitive features in the object properties and interoperability problems with SHM software are specifically addressed.

1 INTRODUCTION

The use of BIM (Building Information Modeling) procedures is becoming very popular and, in some cases even mandatory, for the design of building facilities and transportation infrastructure. According to these procedures, 3D digital models are constructed during the design phase, integrating automatically the different engineering disciplines involved (co-design phase) but they can also be produced from existing design documents originated from traditional design processes.

3D digital models form the basis for subsequent expansions and can be developed at different levels of development (LOD) depending on the design phase considered (preliminary, detailed, etc.). By adding to the relevant objects time data concerning the construction phase (4D Models), it is possible to perform the construction planning process and by adding cost data (5D Models) construction costs and cash-flow analyses can be performed. Facility management (FM) procedures can also be performed on the models enriched with pertinent data (6D Models) and sustainability evaluations can be conducted on subsequently expanded models (7D Models). All models can be developed at the design stage and updated during construction and operation to cope with field originated data. The scheme of the complete modeling process is depicted in Figure 1.

Although BIM procedures are nowadays reasonably well established up to 5th dimension, at least for buildings, the issue of extending the procedures to the facility management stage and especially to the infrastructure field, still involves several open problems. Despite of the very extensive literature on the argument of BIM and its applications, relatively few research papers have been published on the subject of facility management and almost none, at least in the Authors' knowledge, have treated the subject of the use of BIM in facility management of infrastructures.

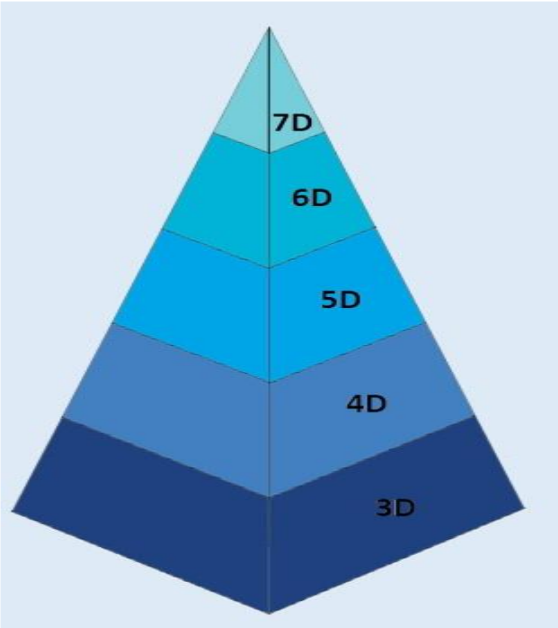

Figure 1. The dimensions of digital models.

To name a few among these papers, Becerik-Gerber et al. (2012), Mc Arthur (2015), Mohandes et al. (2014), Guillen et al. (2016) and the excellent review by Pärn et al. (2017) are just referenced here.

The subject of this paper is however related to the issue of complementing the digital models with the information gathered during the infrastructure lifecycle by means of a structural health monitoring (SHM) system and related procedures, in such a way to support FM decisions on the basis of the actual structural conditions and related risks. Such issue is relatively new and, in the Authors' knowledge, the bibliography is almost not existing, except Sternal et al. (2016) and Valinejadshoubi et al. (2016).

Basically, SHM techniques are aimed at identifying damage states eventually taking place in the structural system (diagnosis) and characterizing their evolution (prognosis), based on the analysis and interpretation of the data streams coming from a sensory network installed on the structure. The interpretation phase often requires a numerical model of the structural system to be available and the integrity condition may be represented by several alternative parameters.

The integration of the two procedures, BIM and SHM, is analyzed in the following paragraphs and some possible alternatives are explored in view of practical implementation. A simple example illustrating the complexities of the problem and the proposed solution approaches is also presented at the end of the paper.

2 CHARACTERIZATION OF THE PROCESSES

The two processes are synthetically represented in the flow chart of Figure 2, where the connections between them are outlined.

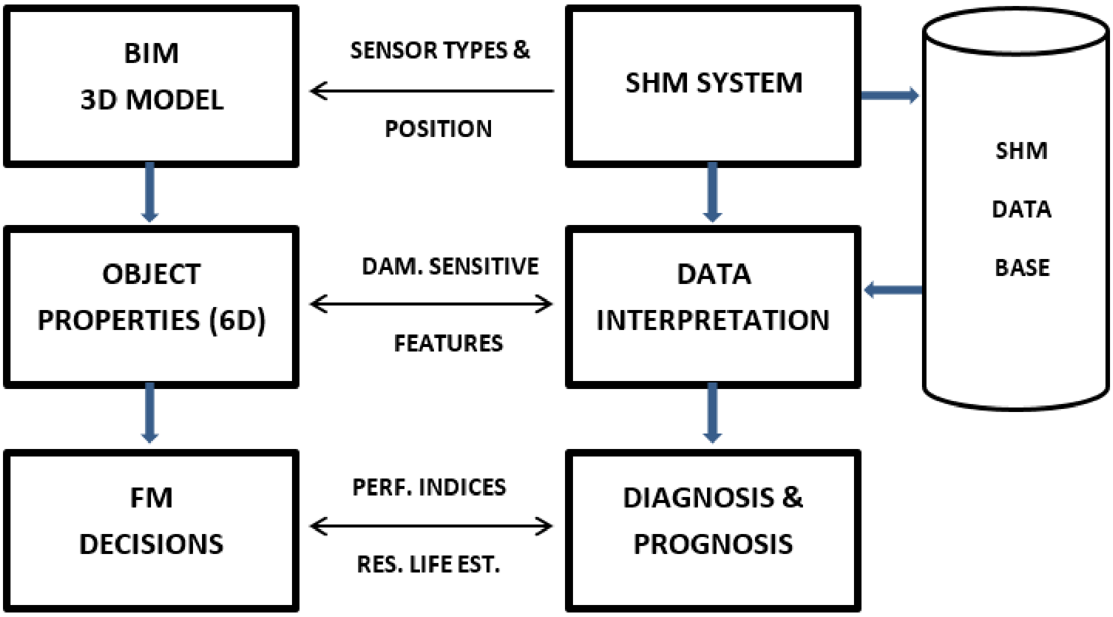

Figure 2. Complete process representation.

As indicated in Figure 2, the construction of the 3D model should be able to include sensor types and position and eventually provide access to the SHM data base to provide interactive representation of the measurements, and interaction among the other processing modules should also be provided.

Sensor representation has already been attempted by some Authors (Sternal et al., 2016) but, as mentioned in the previous paragraph, no other reference has been found on the other subjects. The main issues are related to the standard formats to be used for the data interchange and the functions to be implemented in the communication and data storage platform.

3 CURRENT WORKFLOW FOR THE REPRESENTATION OF THE SHM SYSTEM AND DATA EXCHANGE IN REVIT AND NAVISWORK

To enable the whole process described in the previous Section, the first issue to be solved is related to the representation of the SHM system and how to create the link between SHM and BIM to allow a, possibly, bi-directional data flow.

The Authors are presenting herein a solution to the issue at hand, considering the Autodesk suite as the working environment and, specifically, considering the case of a system identification and model updating of a bridge, modelled in Revit.

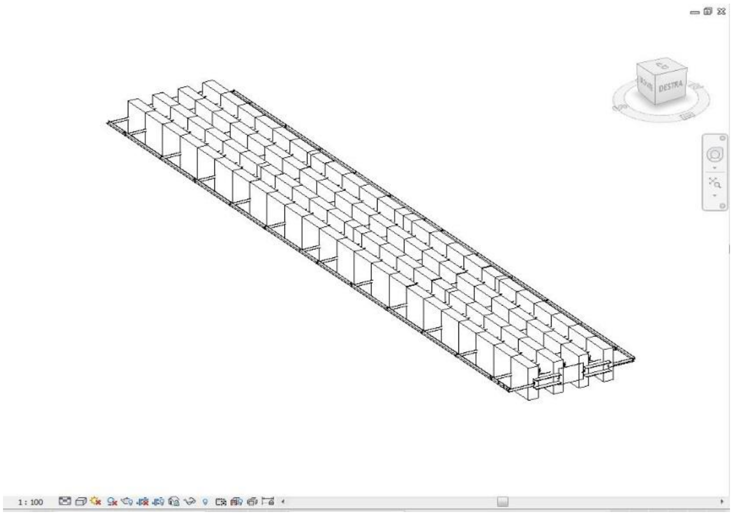

Figure 3. Bridge model in Revit (imported as IFC from Sap2000).

The steps below show how it is possible to create the sensor system (accelerometers chain) in Revit and associate to it the updated information coming from the measurements on field:

1. Creation of a family that will be used as pointer to indicate the location/orientation of the sensors. The pointer could be also linked to the sensor data sheet and will be used to collect variations of SHM measurements as explained in the next point.
2. Some shared parameters of type «instance» will be assigned to this family. Parameters must be shared to make them usable in schedules and should be of type «instance» to make them editable one-by-one once they are linked to an external data source (e.g. link to measurements from SHM via excel or other database)

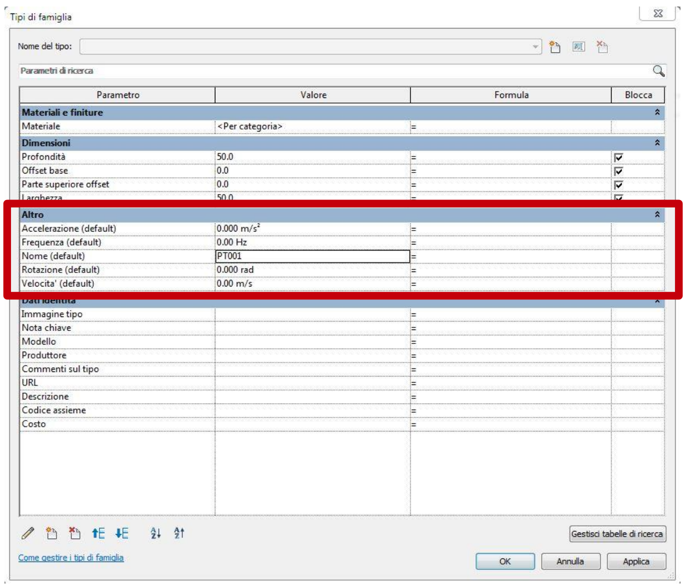

Figure 4. Family parameters in Revit.

3. creation of a schedule for the «sensors».
4. Using "BIM One", the schedule can then be exported from Revit in .xls format, and SHM measurements can be linked to it.

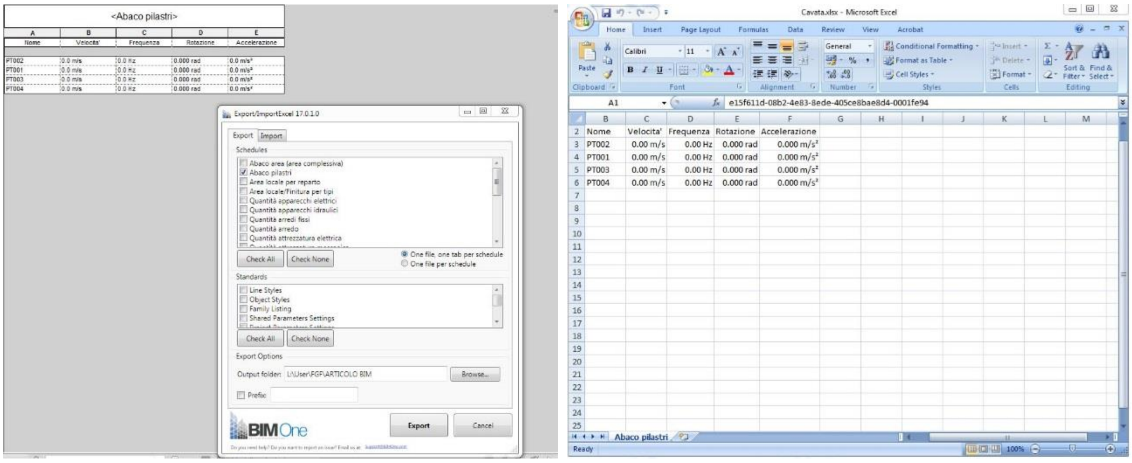

Figure 5. BIM One exporting/importing procedure.

5. Once the file is filled/updated with measurements, still using BIM One it is possible to import back the results in Revit and associate them to each sensor's representation (pointer) through the schedule.
6. In this case, the excel file is then becoming the interface between the BIM model in Revit and the source of data from SHM. By changing the data in the excel (i.e. writing the file with new measurements), the Revit model automatically updates.
7. In order to allow the visualization of the data, the best choice at present is to create a Naviswork model. In fact, this model can then be accessed from all involved stakeholders (e.g. infrastructure manager) by means of the free Naviswork 3D viewer.
8. To update the Naviswork model, an automatic routine based on the import/export of the .dwf file only can finally be adopted.

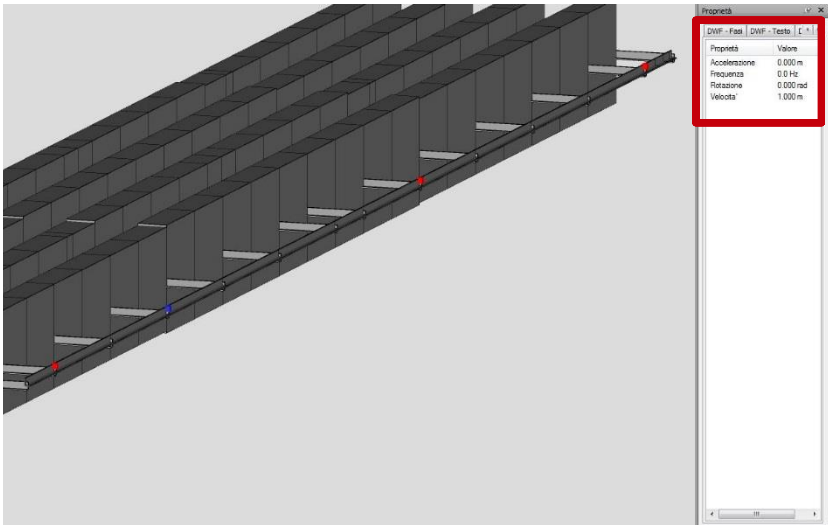

Figure 6. Visualization of sensors (red, blue points) and shared parameters values from Revit (red box).

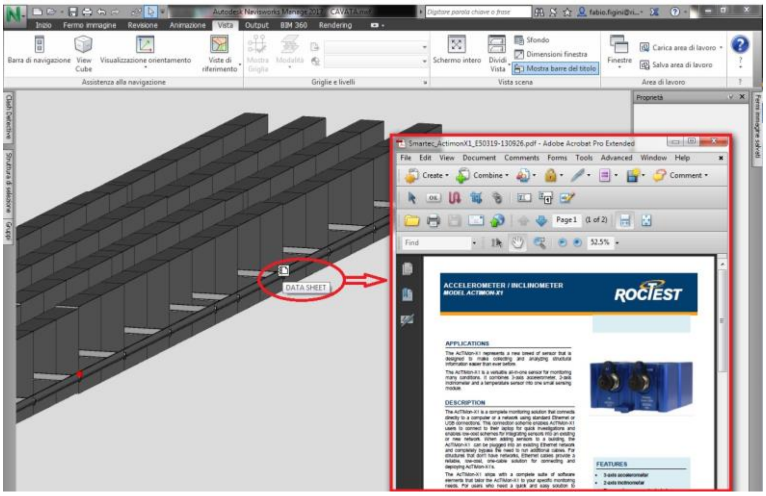

Figure 7. Visualization of sensor data sheet.

The illustrated workflow only allows to link data to sensors representations within the BIM model; however, the same creation of shared parameters and data exchange can be made to store information from interpreted SHM data, or even from more advanced diagnostics, directly in the BIM objects.

4 DISCUSSION

Following the list of steps reported in the previous Section it is possible to create an interface between SHM and BIM, but alternative methods can be also used (e.g. using Dynamo). More important, several limitations still exist along the workflow, both considering the specific steps illustrated here or thinking at a more general approach.

In the first case, it is not possible to visualize or manipulate time histories directly in Revit or Naviswork, nor to associate them to family parameters. The only way to have data like accelerations or velocities associated to sensor pointers is to define a link to an external source (e.g. via excel).

Aiming at a more general workflow, the main limits can be instead identified in the absence of a unique standard interface to describe all the infrastructure components (IFC4 does not support yet the specific semantic of the infrastructure components and other formats, such as .landXML, store complementary information) and the arbitrariness in management data from SHM.

5 CONCLUSIONS

The paper has briefly discussed the state of the art of the current considered and potential relationship between SHM and BIM. The topic is still little investigated: on one side the growing availability of extremely general procedures to access data inside BIM databases would suggest that the integration of SHM data within the flow of information related to a project is just a matter of time. On the other hand, the fragmented scenario of working environments (e.g. Autodesk devotes Revit to structures design, Civil 3D to infrastructures design, Naviswork to assembly, visualization and management) and heterogeneity in file formats depending on the scale of the project (.IFC, .landGML, etc.) poses some questions regarding the most effective approach in terms of interaction with the different software.

At present, there is not a preferred workflow to inform the BIM model with SHM and/or interpreted data regarding elements of the project. The absence of a unique common standard interface for the description of the infrastructure components and the absence for criteria for the inclusion of SHM related data are the main reasons behind this scenario.

It is feasible to make the connection, storage and update of SHM data within the BIM working environment by creating customized interfaces but this process is highly platform dependent. Further development are necessary to mitigate these issues and to enable the whole prognostic/diagnostic process to be expressed till to the system scale.

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