Towards Building Information Modelling for diagnosis, assessment and rehabilitation automation for existing buildings

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Abstract. While building information modelling (BIM) developed for new buildings, the majority of existing buildings needs to be maintained, rehabilitated or reconstructed. The promising benefits of BIM motivate the researchers to extend the BIM functionalities for existing buildings. This paper presents a BIM-based computer application that we have developed for diagnosis of concrete structural elements based on a knowledge base acquired from multiple references and the opportunities of BIM technology.

1. Introduction

Increased number of buildings that have exceeded their design life, natural disasters, man-made disasters such as design errors and wars and other reasons urge the competent authorities to find the best solution to deal with this problem. Resource scarcity, sustainability challenges and stricter decrees for recycling and resource efficiency in buildings [1] motivate the Architecture, Engineering, Construction, Facility Management (FM) and Deconstruction communities to manage resources efficiently [2]. other wise to make the building life cycle longer shifting the construction process to building modification, rehabilitation, retrofit and recycle the waste of deconstruction.

The BIM was developed on the basic concept of developing integrated analysis tools and object-based parametric modeling by the contribution of another industries like pilot. In the last decade there had been a growing interest of the construction sector in using Building Information Models (BIM) due to many benefits and resource savings during design, planning, and construction of new buildings.

The differences between buildings and structures in types of use (e.g. residential, commercial, municipal, infrastructural), in age (e.g. new, existing, heritage) influence the application of BIM, its level of details (LoD) due to the aims of implementation of BIM and required functionalities regarding design, construction, maintenance and deconstruction processes due to stakeholders' requirements.
2. BIM for existing buildings

2.1. BIM definition

Building (Construction) Information Model (BIM) is defined by international standards as “shared digital representation of physical and functional characteristics of any built object […] which forms a reliable basis for decisions” [3]. With BIM technology, one or more accurate virtual models of a building are constructed digitally. They support all the phases of design, allowing better analysis and control than manual processes. When completed, these computer models contain precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realized, operated, and maintained [4].

2.2. BIM application in existing building

As mentioned above the original BIM’s application is in new construction, functionalities concentrate on design and visualization, collaboration and coordination, manufacturing, quantity takeoff, scheduling or cost calculation and construction management rather than on commissioning, facility management or deconstruction. But the multiple advantages of using BIM had aroused the interest of researchers to take the benefit of BIM applications in existing buildings. since that BIM many potential functionalities had discovered depending on the project and the owner requirements. The major examples of expert functionalities applied in practice and examined in research can be determined as demonstrated in [5]:

- Clash detection, spatial program validation, BIM quality assessment Construction progress tracking
- Cost calculation or cash flow modeling (5D)
- Daylight simulation
- Deconstruction, rubble management
- Deviation analysis, quality control, defect detection
- Documentation, data management and visualization
- Energy/thermal analysis and control, carbon foot printing
- Localization of building components, indoor navigation
- Life cycle assessment (LCA), sustainability
- Monitoring, performance measurement (through sensors)
- Operations and maintenance (O&M), facility management (FM)
- Quantity takeoff (3D)
- Retrofit/refurbishment/renovation planning and execution
- Risk scenario planning
- Safety, jobsite safety, emergency management
- Scheduling (4D)
- Space management
- Structural analysis
- Subcontractor and supplier integration, prefabrication
  (e.g. of steel, precast components, fenestration, glass fabrication)

2.3. BIM model creation process

Regardless that the different expert functionalities require different set of information on objects, the BIM model have to provide relevant information, facilitate data exchange and avoid ambiguity. This means that the information embedded in the BIM model directly depend on the functionality to be performed from the BIM model. As BIM modeled to fulfill required functionalities (e.g. for deconstruction and rubble management when the information about construction materials and their
volume is needed, but the information about the design of door isn't), the technical specifications of data capture, processing and BIM model creation are determined by the functionality-related LoD.

In the BIM creation process can be determined three different cases as shown in Figure 1. Case 1: the BIM creation for the new building is done in an interactive, iterative process to create "as-planned BIM", which can be updated to "as-built BIM". For the existing building the process takes a different cases, case 2: when the existing building has insufficient preexisting BIM, in this case the BIM needs to be updated, in case 3: when the existing building doesn't have any existing BIM model the process is performed to capture and model actual building conditions to create an "as-built BIM" from scratch (points-to-BIM).

![Figure 1. BIM model creation processes in new or existing buildings depending on available, pre-existing BIM and LC stages with their related requirements [5]](image)

3. Information acquisition

The main objective of this study is to automate the process of decision making on procedures for repair and rehabilitation or deconstruction of concrete structures, but in order to make this decision, diagnosing distresses in the structures and assessment of their conditions need to be performed.

An overview of the developed expert functionality as a computer application to be coupled with BIM software in this case with Autodesk Revit 2017 for this purpose is discussed in the chapter 4.

In this chapter the techniques of information sources and acquisition and the way information is structured are discussed.

3.1. Information sources

In order to ensure accurate decision-making, it is necessary to carefully select sources of information, for this purpose, information was collected from what is considered to be the best source based on
previous experience in this field, considering the use of multiple sources. Information has been obtained from literature searches, codes of practice, manuals, textbooks, Journals and conference proceedings. Most of the knowledge is directly taken from [6] and [7] Including the following sources:

- American Concrete Institute (ACI, 1996)
- British Standard Institution (BSI, 1997)
- American Standard Testing for Materials (ASTM, 1980)
- International Concrete Repair Institute (ICRI, 1992; 1996)
- RILEM Draft Recommendation (RILEM, 1994)
- The Concrete Society (2000)
- U.S. Army Corps of Engineers (USACE, 1995)
- Federation Internationale de la Precontrainte (FIP, 1991)
- Strategic Highway Research Program (SHRP, 1994)

3.2. Information construction

Since the purpose of collecting information is to automate the diagnosis of concrete elements, special attention has been paid to the structure of the information acquired from the selected references so that there is no confusion or inconsistency in the diagnostic process. To meet the required purpose, it has been considered that the hierarchically structured information is an appropriate structure, which makes the process of automation possible. Taking into account the specificity of the different concrete elements (slab, beam or column ...) in terms of loads to which they are exposed and in terms of operation conditions on the other hand, the symptoms that can appear on the structural elements have been classified based on the nature of the concrete element.

During the analysis of the selected references to acquire information, it was noticed that most of the concrete element distresses associated with the appearance of one of three symptoms category (cracking in concrete, surfaces distresses and miscellaneous distresses).

Cracking in concrete differs in terms of cracking pattern and direction (Longitudinal, transverse, diagonal, pattern or map...), also differs in terms of cracking location (over reinforcement, in tension zone, in comparison zone, irregular distribution over surface...), cracking in concrete also can be associated with rust stains or not.

When the surfaces distresses differ in type (scaling, disintegration and removal of materials, spalling and popouts and dusting...), also differs in terms of location (near to crane or floor transport...).

For concrete elements the following 29 type of distresses can be recognized using this application:

- Insufficient concrete cover.
- Overloading with central compression.
- Overloading with small eccentricities.
- Overloading with large eccentricities.
- Increased eccentricity.
- Decrease in concrete strength.
- Reducing the diameter of tensile and compressed reinforcement due to corrosion.
- Large flexibility from the plane.
- Longitudinal braking action.
- The effect of aggressive environments.
- Corrosion of longitudinal reinforcement.
- Plastic shrinkage.
- Plastic settlement.
- Drying shrinkage.
- Sulphate attack.
- Frost attack.
- Alkali carbonate reaction.
• Alkaline silicate reaction.
• Creep of concrete.
• Compressive Load.
• Previously thermal exposure.
• Wrong storage and transportation.
• Temperature and humidity deformation of concrete.
• Unsuitable construction method.
• Freezing and thawing.
• Chlorine attack.
• Fire exposure in case of fire.
• Mechanical damage during transportation and/or operation.
• Mechanical damage by overhead crane, Damage to floor vehicles

For more clarity one branch of the hierarchically formed knowledge is shown in Figure 2, according to user’s answers.

Figure 2. A branch of the hierarchically formed knowledge.

4. The application
The proposed BIM functionality as computer application for diagnostics and repair activities is of benefit to concrete structure inspectors, engineers and decision-makers. It can assist the user in identifying the distresses, diagnosing the cause of impairment, recommending various repair strategies and providing information for budgeting, planning and life-cycle costs.

The application is designed to assist engineers in diagnosing distresses and in the assessment of current conditions in concrete structures. In order to achieve the desired function, an Add-in for Autodesk Revit 2017 has been developed using the Revit’s API and C# programming language in Visual Basic 2017 framework.
4.1. The user interface:
The user interface is divided into three sections as shown in Figure 3:
- The first section dedicated to User-Revit communication, which allows the choice of the element to be diagnosed and read its properties and then assign the results after conducting the diagnostic process.
- The second section dedicated to User-Add in communication, which is done by asking the user questions and receiving answers from him, and at the end of the questioning the evaluation process is carried out, and the results and recommendations are generated.
- The third section is intended for the user to ensure the correctness of the interrogation process, in which the questions posed by the program and the answers selected by the user are contained. After the diagnosis process, a report with all distress symptoms is generated and allowed to be printed in case of need.

![Figure 3. The user interface of the Add-in.](image)

4.2. The workflow:
After the Revit and Add-in are triggered, the workflow is as following:
- Using the button in the first section the user can select a structural element in the BIM model, then select the of structural element's type from the drop list.
- When the structural element is selected, the Add-in reads the required properties of the element, and based on the selected structural type the appropriate questions and suitable answers are generated in the second section to allow the user to input the observed symptoms.
- After receiving the information from the user, the program analyzes them and generates the next question in this way along to reach the end result.
The reached results are used in two ways, first- the results are assigned to the elements properties for further analysis, second-to generate the report in case of need.

The interaction between the Add-in’s sections shown in Figure 4

5. Conclusion
In this research, an automated approach for structural elements diagnosis has been described on the base of BIM models of building in terms to take the benefits of this leading technology, the following conditions are drawn:

The use of BIM technology for the existing building is actually implemented, where the BIM model can store the required information about the existing structural elements needed to make custom types of analysis in order to draw conclusions about their condition.

The created BIM model can be used to plan further actions, taking into account the importance of choosing the appropriate level of details to meet the required functionality of the model without additional costs.

The acquired knowledge is a subject of continuous development adding a new knowledge, so they are no longer a static database.

The system can be used as an educational tool for inspectors with low level of expertise, using the explanation section supported with pictures of distresses, which helps the inspector make the right design.

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