BUILDING INFORMATION MODELING SUPPORTING SEISMIC DESIGN OPTIMIZATION

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ABSTRACT
The actual context is characterized by technologic progress in support of seismic design, such as the Building Information Modeling, that allows for visualizing an accurate virtual and parametric model of a building and managing a huge amount of data and complex activities through a system of collaborative processes, related to the life cycle of a structure.
In this paper, the applications based on integration between BIM methodology and virtual or augmented reality for the seismic engineering sector, and the related remarkable benefits, are discussed. The main topics deal with structural design criticality, focusing on anti-seismic parameters about structural and no structural elements. First of all, this study shows a framework to visualize, in virtual environment, the steel reinforcement mounting sequences, to verify the feasibility on field and to monitor a greater number of data, because of increasingly complex structural design in seismic zones.
Then, the research carries on the response of flexible pipes on seismically base-isolated structure, with elastomeric isolation systems, subjected to a seismic displacement. In order to define the behaviour of these elements, following the occurrence of a seismic event, BIM modelling connected to virtual reality allows to visualize deformed configuration, to identify the degree of strains and to observe the potential interferences.

1 INTRODUCTION

The construction industry is widely being criticised as a fragmented sector, but however it is one of the main driving force of the world economy. Nowadays, the importance of construction industry cannot be disregarded, because it is an elaborate system aimed to the structural safety optimization. This reference context has led to a growing demand performance of civil engineering, which is becoming increasingly complex. Accordingly, the entire building process generated a huge amount of information, data and conventions difficult to manage without appropriate technological support.

In this context, the "Building Information Modeling" (BIM) methodology is seen as a tool that can assist in integrating the inadequate industry by eliminating collaboration and communication, and enhancing overall productivity. Consequently, BIM development has to be interpreted within the remarkable change of manufacturing industries (Industry 4.0) in general, and buildings ones in particular, following the growing digitization and the increasing use of IT (Information Technology), in a historical and philosophical moment of aggregation, sharing and economic and environmental sensitivity. The world of building information modeling includes many virtual object and each object contains different attributes. In this way, the management of all building data increases, allowing the knowledge of the structure information through its life cycle, "from cradle to grave", i.e. from project inception phase to feasibility, design, construction, handover, maintenance and eventual demolition one [2]. So, BIM implementation impacts on all stages of the construction process, feasibility [1; Cheung et al., 2012; Ham et al., 2008), design (Azhar et al., 2012), construction (Azhar et al., 2008; Grillo et al., 2010; Ibrahim et al., 2004, Yan and Damian, 2013) and operation and management (Ibrahim et al., 2004).

In particular, the structural engineering sector needs BIM-based approaches, providing deep changes in terms of work practices, human resources, skills, relationships with clients and contractual arrangements. The adoption of BIM tools in structural engineering improves design quality, reducing errors in drawings and increasing improvement in labour productivity. (Kaner et al., 2008)

This paper suggests that Augmented Reality (AR) and Virtual Reality (VR) can be integrated with BIM to enable real world environment to be visualized through added interactive data. The proposed framework fuses these different area to solve the problem of monitoring of construction activities and tasks and visualizing in real time of the non-structural element behaviour, subjected to seismic displacement. BIM-AR/VR integration related research can provide an useful tool to enhance communication and collaboration between stakeholders and to improve the design quality through simulation and virtual construction. The page size should be A4 with all the margins set to 15 mm.

1.1 Building information Modeling

Building Information Modeling can be defined as a computable representation of the physical and functional characteristics of a facility and its related project/lifecycle information using open industry standards to uniform decision making for realizing better value (NBIMS 2007), that is data model based on a three-dimensional model, but also the whole process that embraces the realization and management of all the digital information to define the physical and functional characteristics of the buildings.

It’s not easily establish a clear definition of the term Building Information Modeling, taking on a variety of definitions, because the same meaning has long been evolving, even before it was adopted by the industry.

Today the term seems to have somehow turned into a "triad", that is the acronym contains three concentric and complementary concepts. So when it comes to BIM must first pay attention to what you want with this acronym indicate. There is a common basic meaning, that the protagonists are always the information, in particular those concerning the building, that is a built environment (civil works or infrastructure). Established the meaning of the B and I, M contains three levels. M can be defined as a model, something concrete and deliverable digitally, i.e. an intelligent 3D virtual building model that can be constructed digitally by containing all aspects of building information – into an intelligent format that can be used to develop optimized building solutions with reduced risk and increase value before committing to a design proposal. (Woo et al., 2010). M can be referred to modeling, so the set of technologies and processes to create a template containing the information; in fact, the BIM can be define as the process of creating and using digital models for design, construction and/or operations of projects (McGraw Hill, 2009) or M can be referred to management, ie the management of information throughout the life cycle of building/built environment of our interest.

Figure 1. BIM definition

These meanings of BIM, seem to have stabilized in some way, and in the international arena, some countries and organizations have developed legal frameworks and process maps to define the models, the modeling processes and the management of information. A few years later, the BIM is understood in its broadest sense is giving proof of his tremendous potential, stimulating innovation, reducing the fragmentation of the supply chain and ultimately improving the efficiency and effectiveness of the projects in which it was implemented.

Some studies revealed what a building information model represents. It can be used to define the building life cycle (Bazjanac 2006), characterized by the geometry, spatial relations, geographic data, quantities and material properties of building elements.

BIM can be viewed as a new paradigm within AEC that encourages integration and collaboration of all stakeholders on a project. (Azhar at al., 2008) As the model is being created, team members are constantly refining and adjusting their portions according to owner preferences, systems compatibility, and design intent to ensure the model is as accurate as possible before the project ever physically breaks ground. (Carmona and Irwin, 2007) It is important to note how a building information model can be used for several goals, such as easy visualization and fabrication drawing, quick review of building project, automatic cost estimating, simple forensic analysis, reducing waste, in terms of the materials, resources and costs. (Azhar, 2011)

The benefits of using BIM can be summarized in decreased capital costs throughout a project's supply, reduced errors in contract documentation, improved estimation during budding and procurement, improved coordination in construction sequencing, assisted conflicts identification that may arise during construction and enhanced clients and end-users' understanding of the end product. (Wang et al., 2012)

Then, the success of BIM depends on many factors such as the size of the project, team members' BIM proficiencies, the communication of the project team, as well as other organizational external factors. (Barlish thesis, 2011)

2 AUGMENTED AND VIRTUAL REALITY INTEGRATION WITH BUILDING INFORMATION MODELING

Virtual Reality environment engages the user in a real-time simulation and interaction through different perspectives, different sizes and different time scales, allowing not only a visual contact of user viewpoint with the physical world, but mainly a full immersion inside the virtual 3D world. Therefore, an impossible knowledge-building experience in the real time becomes available using the virtual reality delimiting the criticalities and limitations in the civil engineering field. Instead, the Augmented reality allows to overlap virtual world on a real world, defining the reality in a better way, from a geometric and information point, through computer graphics interface. Augmented Reality can be implemented using different portable devices, such as smartphones and tablets, but also wearable tools, such as Google Glass.

These fields of research allow a user to work in a real world environment while visually receiving additional computer-generated or modelled information to support the task at hand. (Wang et al., 2013)

Virtual research prototypes to develop in construction are increased thanks to recent progress in computer interface design and hardware capability. (Hou and Wang, 2011; Dong and Kamat, 2010; Chen et al., 2011) The development of these reality for the engineering and construction industries allows to describe the technologies and principles for applying such computer interfaces to support all phases of the constructed facility project life cycle. (Dunston and Wang, 2005)

These methods result more adaptable than any other technology in a dynamic sector, such as construction industry. The integration of real world technology, through AR or VR procedures, within a project lifecycle BIM-based improves safety management, reduces the building realization costs and increases iterative and structural processes performance.

The BIM method, connected with AR or VR practices, allows to check the efficiency of plants in case of catastrophic events as an earthquake. Applying this technique, the potential displacements seismic-induced of these components are evaluated. In this way, the continuous functionality of plants is guaranteed; it is a very important aspect for strategic buildings (i.e. hospitals, public offices) in which the plants have to work in continuous way in every conditions. Thanks to BIM integrated approach is possible to achieve this result in much more rapid way automating the check processes and the control of anti-seismic details thanks to the possibility to insert input data that constrain geometry and distances between various components.

Consequently, an important potentiality refers to seismic isolation system of buildings, a technique used to protect structural and non-structural components from the crushing effects of ground shaking; indeed, the behaviour of a seismically base-isolated structure, subjected to an earthquake, approaches to the rigid-body motion. The relative and different displacements developed between isolated portion and non-isolated base cause to be useful appropriate devices to contain the different effects, based on the seismic input, such as the pants cutting or the hammering between structures.

Figure 2. Example of joint for MEP systems

Through a complete and integrated three-dimensional virtual model, the check on the design displacements is feasible, but also the deformed configuration visualization, the identification of strains degree and the definition of potential interferences.

A further benefit, that the presented system can insure, refers to the possibility of managing complex and non-traditional structural elements shape, an advantage that cannot be exploited using traditional approaches. So, the use of BIM related methodology allows to avoid an increase of criticality in the entire construction process, given by this complexity in the innovative building components. Starting from the design phase until to the realization one, the shape representation presents several difficulties and the modelling used for the analysis are characterized by important approximations that reduce the global accuracy, providing incorrect data as output. Since the BIM is a parametric methodology, different kinds of properties can be attributed to the single shape, such as mechanical, physical or thermal properties, ensuring a greater and more effective control of processing techniques. If Virtual Reality supporting the Building Information Modelling, the benefits grow up in the project flow; one of these is represented by mounting sequences simulation of considered building element.

In the structural engineering sector, in fact, there are several capacities of BIM methodology, connected to possibility to take place an integrated structural design, to manage interactions between structural and no structural elements and to perform easily check tests on seismic assessment.

In fact, in the case of seismic event occurrence, the building collapse could depend not only on a brittle or ductile failure of a structural element, but on the damage of a non-structural component as an obstacle to the escape routes or as a danger to people's safety. Using this methodology, characterized by rapid, integrated and standardised procedures, is possible to forecast the use of anti-seismic criteria in relation to the no structural elements design, in order to increase safety level for all building heritage.

3 CASE STUDY: DIGITAL SIMULATION OF STEEL REINFORCEMENT MOUNTING SEQUENCES

Following the past events, such as earthquake, that affected some countries, the modern seismic Code involves strict requirements. Consequently, the carpenters become complex and difficult to understand, increasing the possibility of errors in the entire process. In this context, BIM approach is very useful, because allows to avoid mistakes both in design and realization phase. In order to illustrate some possible and tangible benefits that in seismic design can be gained by integrating the Building Information Modeling with a virtual environment, an application has been developed. In this case study, the dynamic visualization of steel reinforcement mounting sequences, related to reinforced concrete foundation beam, is presented.

The first phase of the proposed work requires the investigated structural element to be modelled. To carry out the architectural modeling, can be used Autodesk™ Revit®, an appropriate software BIM-based. Each loaded object is characterized by different properties, such as material, dimensional, mechanical and other attributes.

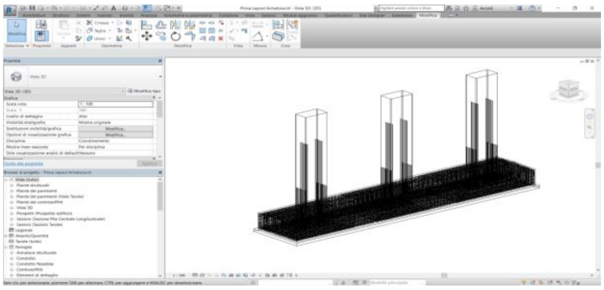

Figure 3.Foundation beam modelling, implemented in Revit®

Successively, the created model is imported into a different three-dimensional graphic modeling software, called 3DVIA Composer. It allows to create a dynamic time sequence, in order to achieve technical illustrations, interactive 3D animations and experiences.

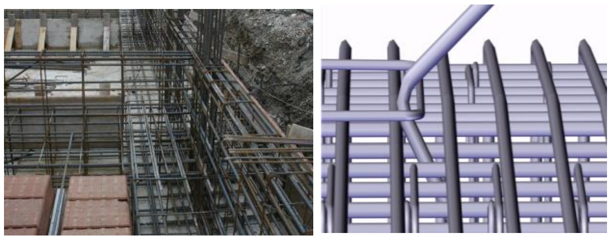

Figure 4. Example of virtual reality for steel reinforcement mounting sequences

From a structural point of view, this proposed tool is useful to visualize all the intersections, common in a traditional 2D model, considering an adequate margin in the mounting and binding of the reinforcing steel, a sufficient space in order to avoid inert segregation, during the concrete laying operation.

The aim of this application is to provide professional experts and workers with a valid and simple support for the creation of a general structural element, a sort of digital manual. In fact, the firsts can use the showed work as a tool to follow all the realization steps, ignored often in the design phase; instead the seconds as a reference that can be used in every situations and event, increasing design process understanding.

During the project realization, several details are often inserted into two-dimensional design tables, in order to provide workers and carpenters with the greatest number possible of information, reducing time and cost and avoiding potential errors.

The resulting advantages are different; the three-dimensional model can be easily interrogated, to evaluate potential interferences. In addition, for the designer and workers, the project understanding results more immediate and intuitive. The chance to visualize all the realization steps in a virtual manual facilitates certainly the work. In this way, the goal is to reach a standard procedure that minimize all possible mistakes.

4 CASE STUDY: PLANTS DISPLACEMENT ASSESSMENT ON A BASE-ISOLATED STRUCTURE

In this section, the role of BIM connected with Augmented Reality, in support of structural engineering optimization, and its current benefits are discussed.

This study shows a simplified example of a seismically base-isolated structure, using elastomeric isolation systems.

4.1 The model

The first step of this work is the structure modeling, carried out thanks to the use of an appropriate software, “Revit® Architecture”, a platform specifically built for Building Information Modeling (BIM), empowering design and construction professionals to bring ideas from concept to construction with a coordinated and consistent model-based approach. The model, implemented in Revit, consists of a rigid body joined with a mobile body, that rests on elastomeric seismic system. Therefore, the Revit model presents also the flexible pipes and ducts modelling.

About the modeling of structure and pipes behaviour, following a given displacement, the Dynamo add-on is used. Dynamo is a platform that allows designer to explore visual programming and to solve design problems. In fact, through this application, all elements, called nodes, are linked within a visual programming process, in order to define the relationship and sequence of specific custom algorithms activities.

The correct modelling of this pipes allows Dynamo application to read data in the best possible way and so to develop algorithms accurately. This type of pipes is modelled through a NURBS (Non uniform Rational Basis-Splines) curve, a generalization of the B-Spline and Bézier curves.

NURBS curves are geometric curves used in computer graphics, characterized by different check points.

Dynamo algorithm involves the definition of rules to modify NURBS curves configuration, allowing the flexible pipes to reach a straight shape without going through extreme length variations; in other words, a relationship to define the NURBS linearization, maintaining the constant length. The fundamental parameter to fix is the NURBS curve length.

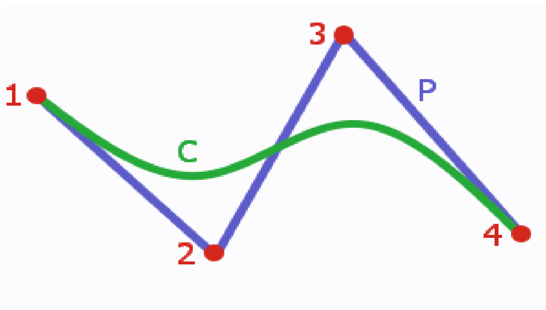

Figure 5. In verde la curva NURBS, in rosso i 4 punti di controllo mentre in blu il poligono che congiunge i punti controllo

In order to handle easily the length parameter of the NURBS curve, the trend of the curve can be approximated to a fourth degree polynomial equation:

$$y = a + bx + cx^2 + dx^3 + ex^4$$

The resolution of the equation depends on the satisfaction of the 5 boundary conditions.

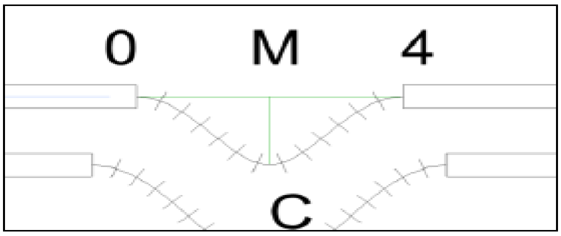

Figure 6. Flexible pipe drawing

The first and the second conditions are respectively the transition of the curve for point 0 (x_0, y_0) connected to the fixed part of the structure and for the point 4 (x_4, y_4), connected to the moving part. The third condition is the transition of the curve for the point C (x_c, y_c), that is the curve arrow. The coordinates of these three points are known. These conditions occur in the three equations:

$$y_0 = a + bx_0 + cx_0^{\ 2} + dx_0^{\ 3} + ex_0^{\ 4}$$
$$y_4 = a + bx_4 + cx_4^{\ 2} + dx_4^{\ 3} + ex_4^{\ 4}$$
$$y_c = a + bx_c + cx_c^{\ 2} + dx_c^{\ 3} + ex_c^{\ 4}$$

The last two conditions are tangency conditions of the curve in the point 0 and 4.
So, the curve derivative:

When listing use either the style Bullet List or the style Num List numbers. E.g.:

- Element 1 (STYLE: Bullet List).
- Element 2.
- Element 3.

or:

1. Element 1 (STYLE: Num List).
2. Element 2.
3. Element 3.

4.2 Equations

Use the equation editor of the selected word processor. Equations are not indented (STYLE: Formula). Number equations consecutively and place the number with the tab key at the end of the line, between parentheses. Refer to equations by these numbers. See for example Equation 1 below.

The failure probability can be expressed as

$$P_f\left(\overline{S_a}(T_1)\right) = P\left[\theta_{max}\left(\overline{S_a}(T_1)\right) > C\right] \qquad (1)$$

where C is the structural capacity etc.

4.3 Tables

Locate tables close to the first reference to them in the text and number them consecutively. Avoid abbreviations in column headings. Indicate units in the line immediately below the heading. Explanations should be given at the foot of the table, not within the table itself. Use only horizontal rules: one above and one below the column headings and one at the foot of the table. Type all text in tables in small type: 10 on 11 points (STYLE: Table). Align all headings to the left of their column and start these headings with an initial capital. Type the caption above the table to the same width as the table (Style: Table Caption). See for example Table 1.

4.3.1 Table captions (Style: Heading 3)

Always use the Table Caption style (10 points size on 11 points). Place the caption above the table. Type as follows: ‘Table 1. Caption.’. The style will leave 6pt between the text and the table caption.

Table 1. Table caption.

C1	C2	C3	C4
A	B	C	D
E	F	G	H
I	L	M	N

4.4 Figures

Number figures consecutively in the order in which reference is made to them in the text, making no distinction between diagrams and photographs. Figures should fit within the column width of 85 mm or within the type area width of 175 mm. Figures, etc. should not be centered, but placed against the left margin (use the style Figure). Leave about two lines of space between the actual text and figure (including caption). Never place any text next to a figure. Leave this space blank. The most convenient place for placing figures is at the top or bottom of the page. Avoid placing text between figures as readers might not notice the text. For the text into figures use Times New Roman. Nine points should be the minimum size of the lettering. Photographic reproductions cut from books or journals, photocopies of photographs and screened photographs should be avoided.

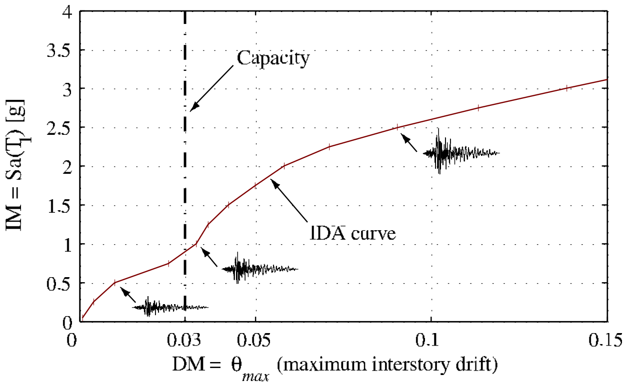

Figure 7. Figure Caption. (Style: Figure Caption)

4.4.1 Figure captions

Always use the Figure caption style tag (10 points size on 11 points). Place the caption underneath the figure. Type as follows: 'Figure 1. Caption.'. The style will leave 6pt between the text and the figure caption.

4.5 References

In the text, place the authors' last names (without initials) and the date of publication in parentheses, e.g (Rossi et al. 1996), (Rossi and Bianchi 1996). At the end of the paper, list all references in alphabetical order underneath the heading REFERENCES (STYLE: Reference title). The references should be typed in small text (10 pt on 11 pt) and second and further lines should be indented 5.0 mm (Reference text tag). If several works by the same author are cited, entries should be chronological:

Rossi, M., 1996a. Development ...

Rossi, M., 1996b. Facilities ...

4.5.1 Typography for references

Last name, First name or Initials (ed.), year. *Book title*, Publisher.

Last name, First name or Initials, year. Title of article, *Title oft Journal (series number if necessary)*, **volume number**(issue number if necessary), page numbers.

See below for an example.

REFERENCES (STYLE REFERENCE TITLE)

Rossi, M., Bianchi, A., 1996. Prediction of Horizontal Response Spectra in Europe, *Earthquake Engineering & Structural Dynamics*, **20**(4), 371-400.

Bianchi, A., Rossi, M., 2001. A response surface approach for seismic fragility assessment of r.c. structures. *10th International Conference on Civil Engineering*. July 31-August 3, Tokyo, JP.

Rossi, M., 1990. *Earthquake Hazard Analysis*, Columbia University Press.

Bianchi, A., Rossi, M., 2001. Estimation of response spectra and simulation of nonstationary earthquake ground motions. *Bulletin of the Seismological Society of America*, **86**(2), 337-52.