CHAPTER #5.11

PROBLEMS IN THE ADOPTION OF BIM FOR STRUCTURAL REHABILITATION

Víctor Fernández-Mora[a]; Víctor Yepes[b]
[a]Universitat Politècnica de València, Spain.
[b] ICITECH (Instituto de Ciencia y Tecnología del Hormigón), Universitat Politècnica de València, Spain.

1. Introduction

The Architecture, Engineering and Construction (AEC) Industry has been changing during the last years for several reasons. The appearance of new technologies like Building Information Modelling and techniques like Lean Construction or life cycle analysis are creating new trends and opportunities that alter the methodologies of this industry. Moreover, in the recent years the business model is also suffering changes. Rehabilitation is gaining more and more importance in the AEC Industry. In 2001 the annual turnover in Spain was 77,7% from new buildings and 22,3% from renovation and rehabilitation, while in 2014 the percentages were 44,3% and 55,7% respectively ("Observatorio de Vivienda y Suelo. Boletín Anual 2017," 2017) with a total of 25.825 buildings under renovation on the year 2015. These changes are not stationary and in the near future the trend will continue leading the industry to new horizons. As Eastman stated "This is an exciting time to be an architect, an engineer, or any other AEC industry professional." (Eastman et al., 2011).

Many authors have stated (Volk et al., 2014) that BIM is leading this change, but there isn't still a broadly adopted definition for BIM which difficults its understanding by the Industry. Following the explanations given by National BIM Standard - United States (2016) and Eastman et al. (2011), BIM could be defined as a trichotomy of a product, a methodology and a software. This differentiation proves that there isn't any ontological approach to the BIM definition (Matějka and Tomek, 2017), that some professionals have a partial view of the concept and that the three aspects are used indistinctly. This means that BIM is a mix between the three, formed by an n-dimensional matrix of the project's data where the user can define and relate new dimensions and variables inside them. There are predefined dimensions like geometry or areas, but the user can add new ones like weight, cost or sustainability. This data forms a digital model, and it is what is understood as a "product", in some cases named Building Model. To create this Building Model the user utilizes a specific "software" and follows a "methodology" to define the model, its variables and the connections and constraints among them.

The widespread adoption of BIM is logical considering its capabilities and the great amount of advantages that it can provide. The key advantage to BIM is the accuracy in the geometrical representation and the other parameters defined in the project. This speeds the processes related to the AEC Industry making them more efficient and improves the design while detecting and solving possible problems or incompatibilities (Azhar, 2011). Several professional can work at the same time on a BIM Model and the modifications are coordinated. Also, the BIM environments can implement Building Performance Simulation (BPS) tools with ease and integrate the automatization of processes to handle new criteria like sustainability (Diao et al., 2011), energy consumption or risk management (Zou et al., 2017). It also provides ways to handle the Black Box Effect derived from the excessive automatization in processes (Fernández-Mora, 2018). This great level of automatization and control is directly shown in the cost, producing savings of up to 10% of the contract value and a 7% reduction in project time (Azhar, 2011).

BIM can also handle time-related parameters and stablish objects that exist at some points and disappear at others. This can be used to implement the renovation project into BIM, following the actual trend of the AEC Industry. In the bibliography we can find a few examples of researches to this (Volk et al., 2014) and techniques to apply point-cloud technologies[1] to create accurate Building Models (Jung et al., 2016) are becoming vital to gather accurate data. Despite this, the connection between BIM and the rehabilitation project, has not been developed by the Industry. Considering the expansion that the research in BIM has had in these last years, we can assume that there exist some problems which prevent this use for BIM. In this paper we are going to define these barriers and try to find a way to work around them. Our aim is to find a way to implement the structural rehabilitation and design the structural reinforcement into BIM.

Regardless the methodology applied on a restoration there is a difference between the terms rehabilitation and reinforcement that needs to be clarified to avoid future misunderstandings. Rehabilitation is the reacquisition by the elements of their initial capabilities, allowing them to perform the same as before they had received the damage. Instead, reinforcement is defined as an increase in the structural performance of the element (Calavera, 2005). Most of the techniques are valid in both cases, but there are some that are not. As our focus is the structural reinforcement we will be increasing the actual structural performance of the element even if that means just to recover its original state.

2. Methodology

The big difference between BIM applied on new buildings and rehabilitation is the existence of a building as a base point and the need to know how this building has been built and how to reproduce it in BIM (Almeida et al., 2018). So far, we have proved the advantages of BIM to the industry and the necessity to adopt its procedures, so it is normal to assume that, in fact, there exist some barriers regarding this adoption and that they probably lay in the rehabilitation problem's nature.

To find the problems we need to further study the actual methods and methodologies used in the structural rehabilitation project and then compare it to the BIM procedures. This analysis is going to be divided in two main parts. First, the methodology used by the professionals to acquire enough information about an existing structure. Second, the different theoretical approaches to obtain the efforts that define the structural behaviour and design a structural reinforcement. While there can be specific solutions we will cover only generally adopted ones, as they fit better into the BIM environments.

2.1. Structural surveys

To use BIM in a satisfactory way we need to develop not only the tools, but the methodology to use it. For this, we need to stablish the actual methodology used by the professional to determine the demands of the building and analyse how it fits into BIM. To study the procedure in developing a structural survey our research data was collected from personal and non-personal (Almeida et al., 2018) professional experience and from a restoration manual (Vegas López-Manzanares, 2017). From there we have stablished common points in the different processes and developed a pattern that can be seen in Fig. 1 that synthetizes the process.

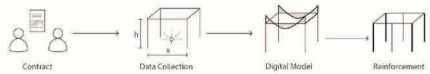

Figure 1. Process of the structural rehabilitation

Most of the times the professional is contacted by the building's responsible who exposes the new needs of the building and its actual problems. With that in mind the data collection phase starts, the professional must collect data from the building, its state, possible affection and if possible, historical data. Once the data is collected, it is time to create a structural model of the building, study the new

[1]This technologies are based on the use of 3D-scanners to create a point-cloud to accurately define the geometry of an object and define a 3D Model (Rebolj et al., 2017).

demands for the structure and determine the contribution that the existing element can make to the new structure. In case that that existent structure proves insufficient for the new loads, a reinforcement must be designed and built guaranteeing the right connections between the old and the new parts.

2.2 Structural reinforcement design methods

To design the structural reinforcement and solve the problem it is necessary to understand the building and its necessities. This makes this part the most delicate one as the professional needs to combine the knowledge of the building with its necessities and determine the proper design. A lot of data has to be taken into consideration besides the buildings geometry. The position of the element and its importance to the global equilibrium, the warning capacity of the element, the live loads over the element and the damage that it has suffered among others (Calavera, 2005).

Another important part is the numerical method used to design this reinforcement. On the one side, it has to reproduce the structural behaviour of the element and its real structural capacity. On the other hand, it has to incorporate the state of the element and the contribution needed by the reinforcement. While sometimes is assumed that the existing element does not contribute to the structure and the structural reinforcement is the responsible to held the loads, this is an oversimplification that leads to oversized reinforcements, there are methods proposed by several authors to determine the part that the existing element can handle. (Calavera, 2005) (Hangaru et al., 1997) (Teng et al., 2002) (Newman, 2001).

Nowadays, there are several materials which are widely being used to reinforce a structure and different applications of them depending on the effort to resolve. To determine these techniques and the materials used we have conducted a bibliographical research and extracted the most common used materials and solutions to reinforce a structure. There are three materials that are broadly used to design reinforcement, concrete, steel and fibre reinforced plastic (FRP), and each one has some preferred uses.

3. Discussion

Every problem regarding the use of BIM for the structural rehabilitation can be summarized in one word: uncertainty. This concept can be extended to a lot of points that affect the process and we are going to categorize and analyse each one of them to be able to define the problematic and study it step by step. But this does not change the fact, the uncertainty is what is creating a gap between the rehabilitation and the different automatization processes, because as we have seen a complete preliminary study is vital. There are several points were this uncertainty has to be solved to solve the structural reinforcement.

-Uncertainty in the materials: The specifications of the materials used previously in the structure can be unknown for the professional designing the reinforcement. This is solved with a proper structural study of the building developing a series of tests to determine the characteristics. BIM environments are ready to be used with present materials and the user can define new ones to reproduce the existing characteristics without too much difficulty. Probably, different materials for certain groups of elements should be defined to obtain accurate predictions. There can appear some difficulties when modelling the reinforcement design and new materials are encountered with existing ones. It is also important to note the importance to introduce in the mathematical model the interphase between different materials to accurately define the reinforcement behaviour.

-Uncertainty in the structural behaviour: This has to be understood from two different points. On the one side, the structural behaviour defined when the original design was made. Generally speaking there are three methods to do the structural design (lineal, lineal with redistribution and non-linear) the application of any of these generates deviations of the results from the others (Calavera, 2005) and can imply some mistakes when studying the structural behaviour. On the other side, there is the "real" structural behaviour which can or can't be the same as the original one, due to structural modifications or to different elements receiving structural loads. Phenomenon like repositioning or elimination of elements, beams with excessive deflection or presence of compartmentation with high stiffness among others can alter the structural behaviour and produce important pathologies and cracks on the building.

-Uncertainty in the design: Directly related with the previous point is the structural design. To determine the exact design and dimensions of every element isn't an easy task, but it is important to find a certain pathology or to design the structural reinforcement. Modelling this structural design can result in a challenge, as BIM software usually is not ready to handle small deviations in an element. It is also vital to define, not only the original design, but its actual state and possible alterations. The use of point-cloud technologies can be crucial to get an accurate definition. If the structural element presents some damage it is also necessary to estimate the affection of this damage to its structural performance. Typically, this has been left to the professional's criteria and most of the time it implied to estimate that the contribution to the structural performance of the element is zero and to design oversized reinforcements. There exist numerical methods like Hangaru et al. (1997) to estimate this damage index, but they result impractical due to high computational demands and the need of data from the original state of the element. Calavera (2005) presents a table with parameters to estimate this damage index.

Aside from that, there is another reason against the adoption of BIM in every rehabilitation project: the difference in scope. A rehabilitation does not have to affect the whole building neither have a great budget. But when using BIM, we need to create a digital model of the building, which implies an investment in time and economy by a professional. This extra time, increases the budget and the delivery time in small projects and it can suppose a great impact which leads to the decision of not to use the BIM methodology.

This is not a problem in the buildings that already have a BIM model, because it can be updated with the current data and pathologies and used for the new analysis regarding of its magnitude. It is not unreal to think, given the actual trend, that in a few years we could have access to BIM models from the design phase of existing buildings, especially in public buildings. At the end of this year 2018 the Spanish Ministerio de Fomento is going to require a BIM model for any public building (ITeC, 2015), this follows an European requirement that sets this objective for 2020 (European Parliament, 2014) and has been required in UK since 2016 (Chi et al., 2014). There are also techniques like point-cloud modelling that nowadays are able to input data into BIM and create accurate models. If the need of modelling the building in BIM disappears in the next years, it will be a great advantage to use this methodology for rehabilitation.

Most of this uncertainty is also a problem if using CAD software, but using BIM we get additional advantages. If using CAD the professional is in need to maintain updated several copies of the drawings. Instead using BIM in the renovation project creates the opportunity to develop the project through the time and define how the elements change along it. This allows the user to follow the evolution of an element and locate the different tests developed on the structure and the changes for the reinforcement, avoiding at the same time some errors due to data misplacement. Additionally the introduction of BPS into BIM introduces analysis tools with the whole picture of the project taken into account automatizing processes and reducing costs.

4. Conclusion

During these last years the AEC Industry has adopted BIM and made use of its advantages. Simultaneously to this technological change there has been a shift in the business model as the number of rehabilitation projects have drastically increased. The use of BIM has been focused on new buildings and has been ignoring this business change, but it can also provide its advantages to these projects. The problems that prevent the adoption of BIM for the structural rehabilitation are:

- Lack of data of the existing building in need of structural reinforcement, which makes mandatory an intense data collection through technologies like point-cloud.
- Inability of BIM software to handle small

deviations among different elements (beam deflection or vertical deviations).

- Difficulty in determining the structural design and behavior.
- Inexistence of BPS tools destined to rehabilitation.
- Rehabilitation projects affecting only a section of a building and not justifying the creation of a BIM Model of the building.

Despite these problems the rehabilitation project can make use of the advantages provided by BIM. Due to the great adoption of this methodology by the industry, in the next years the professionals will be gaining access to existing BIM Models when rehabilitating a building making unnecessary the creation of the model for it and erasing some of the problems. But further research is required to integrate the structural rehabilitation as there is a need to define a damage index method and to create a BPS tool able to design the structural reinforcement into BIM.

References

AlAlmeida, J., Tenorio, R., Sánchez, E., Carballo, R., n.d. BIMrras Podcast #15: BIM en rehabilitación y restauración, BIMrras Podcast.

Azhar, S., 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. Leadersh. Manag. Eng. 11, 241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Calavera, J., 2005. Patología de Estructuras de Hormigón Armado y Pretensado, 2nd Edition. ed. INTEMAC, Madrid.

Chi, H.-L., Wang, X., Jiao, Y., 2014. BIM-Enabled Structural Design: Impacts and Future Developments in Structural Modelling, Analysis and Optimisation Processes. Arch. Comput. Methods Eng. 22, 135–151. https://doi.org/10.1007/s11831-014-9127-7

Diao, Y., Kato, S., Hiyama, K., 2011. Development of an optimal design aid system based on building information modeling. Build. Simul. 4, 315–320. https://doi.org/10.1007/s12273-011-0054-3

Eastman, C.M., Teicholz, P., Sacks, R., Liston, K., 2011. BIM handbook : a guide to building information modeling for owners, managers, designers, engineers, and contractors, 2nd ed. ed. John Wiley & Sons, cop2011, Hoboken, NJ.

European Parliament, 2014. Directiva 2014/24/UE.

Fernández-Mora, V., 2018. Black Box Effect in the structural project. Archi-DOCT 10, 39–52.

Frequently Asked Questions About the National BIM Standard-United StatesTM | National BIM Standard - United States [WWW Document], 2016. URL https://www.nationalbimstandard.org/faqs (accessed 3.14.16).

Hangaru, A.D., Barbat, A.H., Oñate, E., 1997. Metodología de evaluación del deterioro en estructuras de hormigón armado, 1st Edition. ed, Monografía CIMNE. CIMNE, Barcelona.

ITeC, 2015. La implantación del BIM en España. ITeC - Inst. Tecnol. Constr.

Jung, J., Hong, S., Yoon, S., Kim, J., Heo, J., 2016. Automated 3D wireframe modeling of indoor structures from point clouds using constrained least-squares adjustment for as-built BIM. J. Comput. Civ. Eng. 30. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000556

Matějka, P., Tomek, A., 2017. Ontology of BIM in a Construction Project Life Cycle. Procedia Eng., Creative Construction Conference 2017, CCC 2017, 19-22 June 2017, Primosten, Croatia 196, 1080–1087. https://doi.org/10.1016/j.proeng.2017.08.065

Newman, A., 2001. Structural renovation of buildings: methods, details, and design examples. McGraw-Hill, New York [etc.].

Observatorio de Vivienda y Suelo. Boletín Anual 2017, 2017. 96.

Rebolj, D., Pučko, Z., Babič, N.Č., Bizjak, M., Mongus, D., 2017. Point cloud quality requirements for Scan-vs-BIM based automated construction progress monitoring. Autom. Constr. 84, 323–334. https://doi.org/10.1016/j.autcon.2017.09.021

Teng, J.G., Chen, J.F., Smith, S.T., Lam, L., 2002. FRP-strengthened RC structures. John Wiley & Sons, Chichester [etc.].

Vegas López-Manzanares, F., 2017. Aprendiendo a restaurar: un manual de restauración de la arquitectura tradicional de la Comunidad Valenciana. Colegio Oficial de Arquitectos de la Comunidad Valenciana, Valencia.

Volk, R., Stengel, J., Schultmann, F., 2014. Building Information Modeling (BIM) for existing buildings — Literature review and future needs. Autom. Constr. 38, 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Zou, Y., Kiviniemi, A., Jones, S.W., 2017. A review of risk management through BIM and BIM-related technologies. Saf. Sci., Risk analysis and land use planning: managing safety on the short and long range 97, 88–98. https://doi.org/10.1016/j.ssci.2015.12.027