Using BIM to streamline the energy renovation processes of residential buildings during the early design stages

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ABSTRACT: The existing European building stock is responsible for 40% of total energy consumption and 36% of greenhouse gas emissions in Europe. In order to reduce these values, the European Union (EU) has been strengthening and updating the regulations which define the minimum energy requirements for buildings. Therefore, Member States started to increase their energy requirements for buildings, with the purpose to raise their efficiency, reduce their emissions and energy needs, making them more sustainable at the energy level. The renovation of the existing buildings, especially those designed before the first thermal codes is an essential step to achieving the EU proposed targets, due to their low energy performance. Thus, the energy renovation of existing buildings, combined with other sustainable design practices, is a priority to reduce EU's energy dependency and carbon emissions. On this context, this study aims at presenting the energy renovation of a Portuguese dwelling, built in the late 60's, using a Building Information Modelling (BIM) approach during the design phase. BIM methodology was used to perform an energy analysis of a case study, in order to discuss the advantages of this approach at identifying the best energy renovation scenario. From this study, it was possible to verify that the main added value of the BIM is that it can streamline the designers' decision making by improving better integrating between different design areas, saving time and money during the design stages and therefore promoting the better efficiency of the building stock.

1 INTRODUCTION

1.1 *Background*

The European Union (EU) building stock is responsible for 40% of the total energy consumption and 36% of greenhouse gas emissions. On the past years, sustainable buildings had an increase importance in the construction industry, with owners and regulations demanding for better and efficient buildings. Therefore, the EU has been strengthening and updating the regulations which define the minimum energy requirements for buildings in order to reduce the energy dependence and carbon emissions from the Member States (Konstantinou and Knaack, 2011, Almeida, Ferreira, et al., 2013, Bragança, Mateus et al., 2013).

More than 80% of the existing buildings in Europe were built before 1990 (Gökgür, 2015) (most of them before the firsts thermal regulations – low energy performance) and for that reason, it is essential to think in energy renovation as a possible way to reduce those values and achieve EU goals and, at the same time, increase their value in the real estate market (Sousa, Silva et al., 2012).

In addition, studies show that the environmental impact of life cycle extension of a building is less than demolishing and building again (Konstantinou and Knaack, 2011). The renovation of residential buildings provides a considerable potential for energy conservation and further sustainable benefits (Konstantinou and Knaack, 2011). A real reduction of emissions in the building sector can be achieved only by acting on the existing stock (Galante and Pasetti, 2012).

"The most effective decisions related to the sustainable design of a building can be made in the early design and preconstruction stages" (Azhar and Brown, 2009), so it is necessary to find a way to intervene in the mentioned stage. The Building Information Modeling (BIM) may become an important tool on the renovation process because it *"allows multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures and performance analyses to be performed throughout the design process"* (Azhar and Brown, 2009). In fact, BIM could lead to several benefits on the energy renovation practice like supporting decision making at an early stage of the project, improve stakeholder's collaboration, reduce time, save money and develop better and efficient buildings.

Despite the increasingly importance and use of BIM in the construction industry and the proved benefits provided, this methodology is more popular for new buildings, but it is feasible to be used in renovation projects and *"it has not reached its full potential yet"* (Gökgür, 2015).

This leads to the conclusion that the real potential for sustainable building and CO_2 reduction lies in the management of the existing residential building stock (Mickaityte, Zavadskas et al., 2008) and due to the complexity of this kind of operation the use of BIM become an essential tool to develop better and sustainable buildings.

Based on this context, this paper aims at discussing the contribution of the BIM methodologies to support the decisions related to the energy renovation processes during the early design stages. It is discussed the state-of-art of BIM integration in the sustainable renovation process and also the added value provided. As an example, a case study is introduced to demonstrate how BIM can be integrated and its benefits in the early design phase.

1.2 *Energy efficiency and rehabilitation*

As the society is growing and developing, it is natural that an increase exist in the occupant's comfort demand and energy consumption. The main reasons which lead to an energy consumption increase are directly related with the building weak performance and with the irrational use of energy (ADENE, 2016a, Horta, 2012, Cardoso, 2013).

Is essential to think about energy efficiency for a sustainable development and this means to optimize the energy use without compromising the indoor environmental quality, through the use of efficient technologies and passive and active construction solutions (Horta, 2012, Machado, 2014).

Among the most significant advantages for the society and environment, it should be highlighted the reduced building operation costs, the increase of energy production from renewable sources and the use of less amount of natural resources (Lamberts, Dutra et al., 1997).

The energy renovation allows buildings to have a better thermal quality and also increase the comfort conditions of users, in order to reduce energy needs for heating, cooling, ventilation and lighting, supporting the country to achieve the EU goals (ENERGIA, 2004).

The main aspects affecting the thermal performance of a building are (ENERGIA, 2004):

- Insufficient thermal insulation in the building envelope;
- Thermal bridges in the building envelope;
- The presence of moisture;
- Lower thermal performance of glazed areas and doors;
- Lack of appropriate shading devices;
- Uncontrolled ventilation;
- Inadequate behavior of the occupants.

To overtake these aspects, first, it is necessary to improve the thermal insulation of the building envelope, control the air infiltrations and integrate renewable energy systems. In a second phase, building users must get aware of the correct behavior to adopt to operate the building at an efficient level.

Despite the fact, that 71.1% of the Portuguese residential building stock do not need any kind of structural or aesthetics renovation, they are still responsible for 17.7% of the global energy consumption in the county, mainly because most of the Portuguese building stock were built before the implementation of the first national thermal regulation, in 1991 (INE, 2013, Costa, Bragança, et al., 2014). Therefore, there is a need to renovate these buildings with the aim to improve their habitability, indoor environmental quality and performance, becoming essential to think in energy rehabilitation as a possible and feasible solution (INE/DGEG, 2011).

1.3 *Building Information Modeling (BIM)*

Construction projects are becoming more difficult and complex. In order to improve the lifecycle of the built environment, there is a need to automate and modernize the construction processes. This was the main reason for the development of the Building Information Modeling (BIM). In the last years there is an increasingly demand by project owners for this kind of processes and, in some countries, like the UK, a standard that requires the use of BIM in all the public projects is in force since the beginning of 2016 (Bryde, Broquetas, et al., 2013).

On the construction industry, BIM presents itself as the most recent method for developing projects, taking the place of the typical CAD 2D and 3D.

Actually, there are different definitions of the BIM concept and methodology. The BIM Handbook (Eastman, Eastman, et al., 2011) presents BIM as a

> *"paradigm change that will have far-reaching impacts and benefits, not only for those in the construction industry but for society at-large, as better buildings are built that consume fewer materials and require less labor and capital resources and that operate more efficiently".*

BIM is a set of policies, processes and technologies which create a work methodology to manage the design and project data in a digital format during all the construction lifecycle on a virtual model, which contains all the building physical and functional characteristics (Lino, Azenha, et al., 2012, Azenha, 2014).

The essence of BIM lies in sharing information. When compared with the traditional approach (Fig. 1), which is a sequential and disorganized method with lack of information sharing, the BIM model allows to all stakeholders to work individually but, always connected to a central model, which contains all the information from all design disciplines. This allow the designers to quickly identify incompatibilities and errors, facilitating decision-making and reducing time and costs (Bryde, Broquetas, et al., 2013).

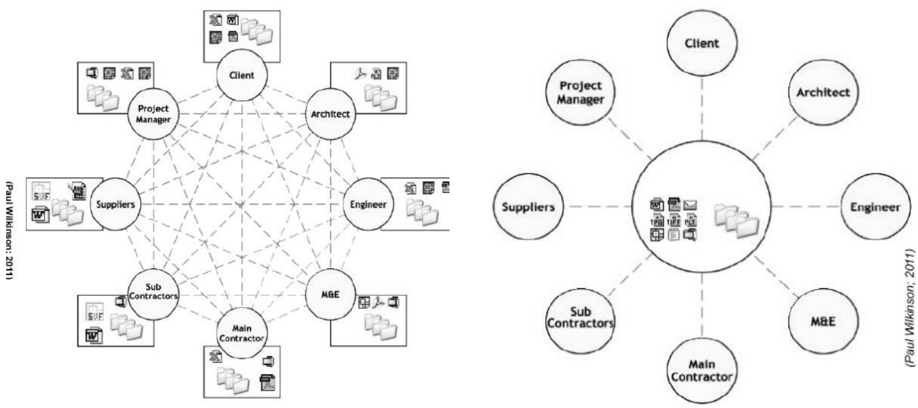

Figure 1. Traditional methodology vs BIM methodology (Azenha, 2014).

Applied to a construction project, this methodology results on a virtual model named Building Information Model that contains all the properties and characteristics of the project. This model can be made through an object-oriented parametric modelling. In a simple way, it can be characterized by the objects (columns, beams, ducts, etc.) modelling, which contains their specific properties and they parametrically relate with each other, in other words, parameters are defined to characterize the relationship between objects. This model must be made with a certain Level of Development (LOD), as stated before starting the shaping, so the model can be enough detailed (amount and type of information) to perform the desired operations (Azenha, 2014). To perform a sustainable design analysis the required LOD needed is significantly low (Ceranic, Dean et al., 2016).

The compatibility and information sharing between different disciplines models can be performed directly via extensions, which usually happens when the software's used belong to the same company. When such a connection is not possible, it is possible to use the Industry Foundation Class (IFC) protocol, developed by *BuildingSMART*, which is characterized by being a kind of standardized universal sharing format, making it possible to exchange information between different computer programs (e.g. the IFC can be used to export a structural model made in *Tekla Structures* to the architectural model held in *Revit*).

The BIM model can be use through all the building lifecycle stages and in several areas, like visualization and documentation, construction management, planning costs, maintenance, building operation, programming, analysis, detailed design, logistics, demolition, among others. (Dispenza, 2016).

Currently, despite the advantages of using BIM, only 36% of the Western Europe construction companies use this methodology (Azhar and Brown, 2009). This fact can be justified by the difficulty to adapt new business processes in a company, in particular, to fight against the resistance to change from the traditional processes, largely due to the lack of knowledge by the project teams. Other possible reasons are related to the high investment costs in purchasing new software and training the company staff, which indirectly leads to a productivity loss during the adaptation process. Restrictions on interoperability between programs and the lack of standardization can also have a negative contribute in BIM implementation (Azenha, 2014).

1.4 *BIM applied to sustainability and rehabilitation*

Given the need of the construction industry to respond to the increased demand for more sustainable buildings, several processes and technologies have been developed with the aim to save energy and reduce CO_2 emissions (Motawa and Carter, 2013). Among them, is BIM methodology that, through a virtual model, at an early stage of the project, allows to check the energy use, perform thermal analysis, identify solar patterns, between other sustainable measures, in order to assess the best solutions to implement (Motawa and Carter, 2013).

Rehabilitation of the existing building stock could be an optimal solution to reduce the energy demand of buildings and their CO_2 emissions. BIM stands as a possible mean to *"works management and decision making assessment, due to their capacity to coordinate all the information needed for the diagnosis of the building and the planning of rehabilitation works."* (Lagüela, Díaz-Vilariño, et al., 2013).

In 2009, Hardin (Hardin, 2009) has defined three main areas of sustainable design directly related with BIM – Material selection and use, site selection and management and systems analysis. In 2008, other aspects where BIM can support sustainable design were established by Krygiel and Nies (2008) and they are listed below:

- Building Orientation – analyze building orientation in order to reduce energy costs;
- Building massing – study the building form and optimize building envelope;
- Daylight analysis;
- Water harvesting – reduce freshwater needs;
- Energy modeling – reduce energy needs, by performing energy analysis, and analyze renewable energy options;
- Sustainable materials – reduce material needs and use recycled materials.

The main advantage of BIM applied to sustainability is the interoperability between modeling and thermal analysis software's that allows to perform a wide range of studies which consider several important parameters (Azhar, Carlton et al., 2011).

The use of BIM with the purpose of designing and managing sustainable buildings, can represent 20% savings of the construction value during the lifecycle (Azhar and Brown, 2009).

When assessing the BIM advantages on the renovation processes, it is possible to identify most of the advantages that result from the use of this process in new constructions. Nevertheless, the use of BIM is more common on new construction than in the renovation processes most due to the fact that owners are not aware of BIM benefits in the renovation process and the lack of studies in the field, contributing to the lack of knowledge in this type of operations (Gökgür, 2015). The main advantages of using BIM in the design of new or renovated buildings are (Clemente and Cachadinha, 2012, Gökgür, 2015):

- Generate precise drawings at any stage of the project, saving the time spent drawing them by hand;
- Automated and accurate cost and quantities estimating;
- Prototyping and energy simulation;
- Reduce resources use;
- Managing waste on the renovation site as support for organizing logistics, separating waste types and structuring material handling.
- Conflicts and collisions detection at an early design phase;
- Project modifications automatically updated in all drawings;
- Facilitate LEAN techniques implementation, since it is required a strict coordination between stakeholders;
- Support collaboration, coordination and planning of construction activities.

Despite these general advantages of using BIM, there are other benefits of using it in the renovation process. Fontan (2016), applied BIM to a renovation and rehabilitation project, exploring the use of renovation status filters, simplifying the identification of the several stages of the operation. There were used 5 type of renovation status filters: Existing plan, demolition plan, after demolition, new construction and planned status. Figure 2, shows the application of some of the listed filters and how they can help on visualization and documentation.

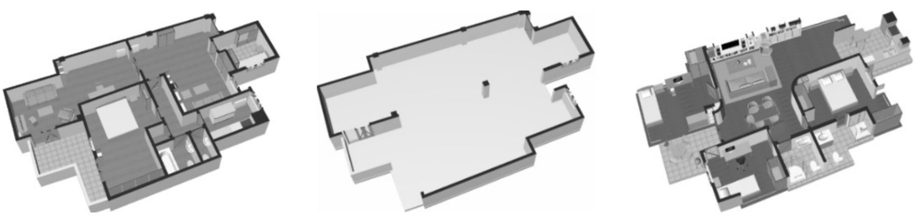

Figure 2. Renovation filters. Existing plan, after demolition, new construction (Fontan, 2016).

Considering all of the benefits on both areas and the complexity of renovation projects it is consistent to say that BIM can be an essential tool to achieve better and sustainable buildings, helping to get environmental performance certificates, supporting decision making, optimizing time and costs.

2 METHODOLOGY

In order to evaluate some of the BIM benefits through the rehabilitation process, a Portuguese dwelling with a poor energy performance was chosen. The dwelling was built in the late 60's, before the entrance into force of the first Portuguese thermal regulation, so it has a high-energy demand, most due to the fact that there is no thermal insulation in the building envelope.

To integrate the renovation process into a BIM approach, all the processes must be connected. In other words, this means that the dwelling virtual model must be the same through all the software's used (both modeling and analysis software's). Therefore, a virtual model was created on Revit and after exported to Green Building Studio and DesignBuilder by *IFC* and/or *gbXML* format. These softwares were chosen by their potential capabilities and interoperability between each other.

In order to improve the dwelling performance, a set of measures were suggested from the introduction of thermal insulation and the replacement of the old glazing and frames, to the purpose of efficient mechanical and renewable systems. For simplification, it was only analyzed the interventions on the building envelope. Two solutions to improve the passive performance of the building at this level were defined: i) the use of an External Thermal Insulation Composite System (ETICS); and ii) the use of a ventilated façade, as alternative. For each solution, 3 sub-solutions with different insulation thickness were analyzed. Therefore, seven different virtual models (1 base model + 6 renovation scenarios models) were developed and analyzed in Green Building Studio and DesignBuilder.

After the modulation, the base model and all the alternative renovation models were analyzed and the results regarding energy savings were compared.

3 CASE STUDY

The chosen dwelling was built in the late 60's, with 1 floor, with a total area of $90m^2$ has 3 bedrooms, as presented in Figure 3. The total glazed area is $6.3m^2$ (7% of the floor area) and all the windows have single glass and aluminum frames.

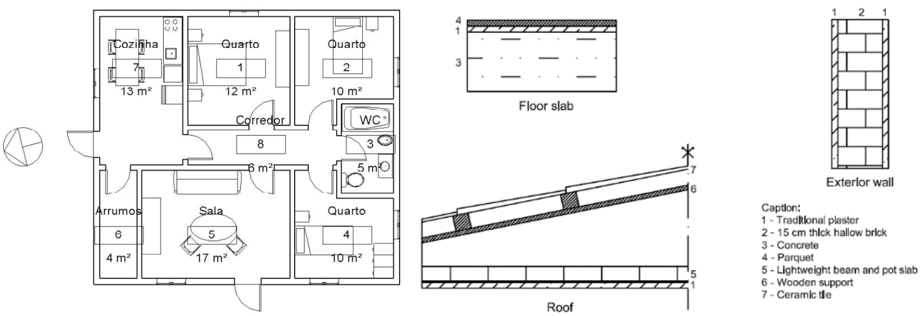

Figure 3. Dwelling floor plan and construction details.

Regarding the construction details, they are also represented on Figure 3. The external walls are single pane walls made up of 15cm thick hollow bricks, plastered on both sides. The pitched roof has a wooden structure, and ceramic tiles, the horizontal slab is a lightweight beam and pot slab, plastered on the ceiling. The ground floor is made on concrete and finished in parquet.

The six renovation solutions defined are presented in Table 1. The materials characteristics are reference values for Portugal (Pina dos Santos and Matias 2009) and the thickness was based on the energy efficient guides from ADENE (ADENE, 2016b, ADENE, 2016c).

Table 1. Characterization of the intervention solutions.

Exterior walls		Floor slab		Roof slab		Glazed areas
ETICS System with EPS insulation, primary and plaster for finishing	4cm	XPS thermal insulation	4cm	XPS thermal insulation over the horizontal slab, keeping the ceramic tile	4cm	Double glass with a low emissivity film and PVC frame
	6cm					
	8cm					
Ventilated façade with XPS thermal insulation and laminated plasterboard	4cm		6cm		6cm	
	6cm					
	8cm					

In order to perform an accurate simulation, it is necessary to detail the BIM model with some parameters needed for the simulation software. After the architectural modulation (Fig. 4), the materials characteristics are defined (density and thermal conductivity), the exact project location is set (the climatic data used was from Porto weather station) and *spaces* or *rooms* need to be created. The information regarding the spaces use, like ventilation, lighting or number of occupants is defined. This information must be set for every indoor space. At the end, before exporting the model, the energy settings (building type, building service, project phase, etc.) must be adjusted to the reality.

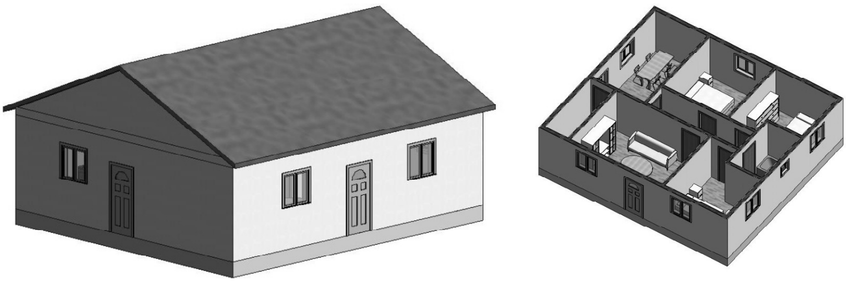

Figure 4. Dwelling BIM model.

After this step, the base model was exported to Green Building Studio (GBS) and DesignBuilder (DB) in order to assess the energy needs of the dwelling.

4 RESULTS AND DISCUSSION

The results for the base model are presented in Table 2. The illumination and domestic equipment's energy needs were kept constant for all simulations. The comfort temperatures were set in 23ºC for the cooling season and 18ºC for the heating season.

Table 2. Base model energy needs.

GBS	DB	GBS	DB
Annual Heating Needs (kWh/m^2)		Annual Cooling Needs (kWh/m^2)	
52.75	43.92	5.11	3.66

Tables 3 and 4 show the total results for the annual heating and cooling needs of the 6 proposed renovation scenarios, the annual savings and differences compared with the base model. The results show that is possible to reduce at least 50%, up to over than 60% of those needs, only by acting on the building envelope. The advantage of BIM in this process was the quickly and easily process of editing and simulate the different models in the project phase. This way, it was possible to assess which one is the best scenario and the savings that result from different options taken at an early stage of the project. Therefore, it was possible to save time and make a supported decision about the solution to select.

The differences between the results in each software may be justified by different calculation methods and/or differences on some consider parameters (Green Building Studio is a web-based software, so many of the parameters cannot be simply modified).

Table 3. Proposed solutions energy needs and savings - Green Building Studio (EW – Exterior Walls; HE – Horizontal Elements).

	Solution 1 - ETICS			Solution 2 – Ventilated Façade		
	Annual Heating and Cooling Needs (kWh/m^2)	Annual Savings (€)	Difference compared with base model (%)	Annual Heating and Cooling Needs (kWh/m^2)	Annual Savings (€)	Difference compared with base model (%)
EW: 4cm HE: 4cm	24.99	506.3	-56.8	22.64	542.5	-60.9
EW: 6cm HE: 4cm	22.69	541.7	-60.8	21.32	562.5	-63.1
EW: 8cm HE: 4cm	21.36	561.9	-63.1	20.53	574.8	-64.5
EW: 4cm HE: 6cm	22.96	537.4	-60.3	20.70	572.3	-64.2
EW: 6cm HE: 6cm	20.75	571.4	-64.1	19.55	590	-66.2
EW: 8cm HE: 6cm	19.49	590.8	-66.3	18.62	604.3	-67.8

The presented energy analysis results are concerning the general results but the software's allow to study each envelope element, in order to assess which are the most critical elements and the ones that should be intervened.

Regarding renewable energies, Green Building Studio has an optimal tool to evaluate and calculate the renewable energy potential. Based on the roof area, energy cost and investment costs, it estimates how much energy the dwelling is able to produce during the year. In order to have an accurate estimation, the location and orientation of the model must be precise. Concerning DesignBuilder, it allows to estimate the solar thermal potential. For the current case of study, the application of 50m^2 (half of the roof) of PV panels would result on an energy production over than 100kWh/m^2/year, which is enough to support the dwelling energy needs.

Also on Green Building Studio, it is possible to calculate the water use in the dwelling and also assess the water savings potential, for example, by implementing a rainwater harvesting system. The information needed for this tool is the number of occupants, the number of water devices, the irrigation area and the annual rainfall. For the present case, a rainwater harvesting was considered, with a catchment area of 100m^2, leading to savings around of 100€/year on the water bill.

Table 4. Proposed solutions energy needs and savings – DesignBuilder.

	Solution 1 - ETICS			Solution 2 – Ventilated Façade		
	Annual Heating and Cooling Needs (kWh/m^2)	Annual Savings (€)	Difference compared with base model (%)	Annual Heating and Cooling Needs (kWh/m^2)	Annual Savings (€)	Difference compared with base model (%)
EW: 4cm HE: 4cm	23.96	363.8	-49.6	21.73	398.2	-54.3
EW: 6cm HE: 4cm	21.73	398.2	-54.3	20.73	413.6	-56.4
EW: 8cm HE: 4cm	20.40	418.6	-57.1	19.84	427.2	-58.3
EW: 4cm HE: 6cm	22.60	384.8	-52.5	20.52	416.8	-56.9
EW: 6cm HE: 6cm	20.49	417.2	-56.9	19.34	435.0	-59.4
EW: 8cm HE: 6cm	19.23	436.6	-59.6	18.48	448.2	-61.2

Daylight analysis can also be performed, both in Revit and DesignBuilder, and the results show that the existing glazed areas are not enough to provide an adequate daylight. Only one of the bedrooms (that has 2 windows) presents acceptable daylight values.

DesignBuilder also allows the definition of the "best practice", which recommends best practice values for some factors like lightning, walls insulation, glazed areas, etc.

5 CONCLUSIONS

This paper has the purpose of discussing the benefits of using the BIM methodology on an energy renovation operation to improve the efficiency of a case study.

In order to achieve these objectives, one modulation and two analysis softwares were used, Revit to create the BIM model and Green Building Studio and DesignBuilder to perform energy analysis. Regarding Revit, the software has several potentialities when used on the BIM context. Despite that, this software it is not so focused on energy analysis because many of the needed parameters are not fully developed, creating an opportunity to improve. Even so, on the recent years, it has been witnessed an increasing concern by the software developers to improve and create tools to assess this issue.

Regarding the thermal analysis software, despite the differences between them, a supported comparison was performed. Because Green Building Studio is a web-based program (internet access is needed), it was very difficult to define some of the important parameters, change the analysis period and find the most adequate characteristics from the data base (not fully developed). Despite that, the software has some interesting tools like the water use simulation, the renewable energy tool and more comprehensive weather stations data base. DesignBuilder is already a well-known analysis software in the industry with the EnergyPlus simulation interface and a large data-base. Nevertheless, there are some constrains regarding the use of DesignBuilder, like the lack of weather data, the necessity of having a product license or the need to know about many other parameters that can influence the simulation.

Completed the simulation and analysis process it was possible to achieve some conclusions regarding the added value of using BIM in the energy renovation processes:

- To understand the impacts of thermal insulation on the different elements of the building envelope in order to define the optimal renovation scenario;
- To analyze the most suitable renovation scenario, supported by energy and long term economic analysis;
- To study the possible integration of renewable energy and water use reduction systems;
- To assess the carbon emissions reduction potential;
- To calculate the quantity of materials and to estimate the life-cycle cost;
- To produce a complete building prototype and detailed drawings of construction elements.

The integration of the BIM methodology appears to be more advantageous during the design phase, allowing to quickly compare the several scenarios under analysis for the building, predicting the energy consumption, the water consumption, estimating cost, analyzing solar thermal and photovoltaic harvesting potential and assessing compliance with regulatory requirements. Therefore, BIM is an excellent tool that can help architects and engineers in choosing the best solutions to achieve the proposed goals at a preliminary stage, without spending too much time and money. Due to all benefits that the BIM methodology provides, this can become in a short term, a key tool to achieve better and sustainable buildings.

REFERENCES

ADENE. 2016a "*Eficiência Energética*". Available at: http://www.adene.pt/eficiencia-energetica [Accessed on 22 March 2016].

ADENE. 2016b. 10 Soluções para Eficiência Energética - Isolamento de Coberturas.

ADENE. 2016c. 10 Soluções para Eficiência Energética - Isolamento de Paredes.

Almeida, M. G. d., Ferreira, M. & Pereira, M. 2013. Cost optimal building renovation with a net zero energy target for the Portuguese single-family building stock built before 1960. *SB13 Portugal–*

International Conference on Sustainable Building contribution to achieve the EU 20-20-20 targets. Multicomp.
Azenha, M., Lino, J. C. & Caires, B. 2014. Introdução ao BIM - Slides de apoio às aulas teóricas do MIEC da UM.
Azhar, S. & Brown, J. 2009. "BIM for sustainability analyses". *International Journal of Construction Education and Research*, 5(4): 276-292.
Azhar, S., Carlton, W. A. & Olsen, D. & Ahmad, I. 2011. "Building information modeling for sustainable design and LEED® rating analysis". *Automation in construction*, 20(2): 217-224.
Bragança, L., Mateus, R. & Pinheiro, M. 2013. Portugal SB13: contribution of sustainable building to meet EU 20-20-20 targets. *International Conference Portugal SB13-contribution of sustainable building to meet EU 20-20-20 targets*. Multicomp.
Bryde, D., Broquetas, M. & Volm, J. M. 2013. "The project benefits of building information modelling (BIM)". *International journal of project management*, 31(7): 971-980.
Cardoso, L. P. S. 2013. "Reabilitação sustentável de edifícios anteriores a 1951".
Ceranic, B., Dean, A., Faulkner, M. & Latham, D. 2016. "Case study based approach to integration of sustainable design analysis, performance and building information modelling".
Clemente, J. & Cachadinha, N. 2012. Building information modeling como ferramenta de visualização de realidade aumentada em obras de reabilitação–um caso de estudo. *Congresso Construção 2012, ITeCons*.
Costa, R. J., Bragança, L., Mateus, R. & Bezerra, J. C. 2014. "Reabilitação sustentável de edifícios antigos: contribuição para os edifícios de balanço energético nulo (nZEB) e otimização do nível de sustentabilidade". *Revista Engenharia Civil*, 49: 65-90.
Dispenza, K. (n.d.). "The Daily Life of Building Information Modeling (BIM)". Available at: http://buildipedia.com/aec-pros/design-news/the-daily-life-of-building-information-modeling-bim [Accessed on 1 May 2016].
Eastman, C., Eastman, C. M., Teicholz, P. & Sacks, R. 2011. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.
ENERGIA (D. G. D. G. E.). 2004. Reabilitação Energética da Envolvente de Edifícios Residenciais, Lisboa.
Fontan, E. 2016. "Renovation And Rehabilitation Projects: Introduction To Renovation Filters". Available at: http://www.weareenzyme.com/renovation-and-rehabilitation-projects-introduction-to-renovation-filters/ [Accessed on 28 July 2016].
Galante, A. & Pasetti, G. 2012. "A methodology for evaluating the potential energy savings of retrofitting residential building stocks". *Sustainable Cities and Society*, 4: 12-21.
Gökgür, A. 2015. Current and future use of BIM in renovation projects. Chalmers University of Technology.
Hardin, B. 2009. "BIM and Construction Management: Proven Tools". Methods, and Workflows.
Horta, R. M. C. 2012. Construção sustentável de edifícios de balanço energético quase zero, Faculdade de Ciências e Tecnologia.
INE/DGEG. 2011. Inquérito ao Consumo de Energia no Sector Doméstico 2010. Lisboa.
Instituto Nacional de Estatística (INE), I. P. 2013. Evolução do Parque Habitacional em Portugal 2001-2011 Lisboa - Portugal: Instituto Nacional de Estatística, I.P., 2013.
Konstantinou, T. & Knaack, U. 2011. "Refurbishment of residential buildings: a design approach to energy-efficiency upgrades". *Procedia Engineering*, 21: 666-675.
Krygiel, E. & Nies, B. 2008. Green BIM: successful sustainable design with building information modeling. John Wiley & Sons.
Lagüela, S., Díaz-Vilariño, L., Martínez, J. & Armesto, J. 2013. "Automatic thermographic and RGB texture of as-built BIM for energy rehabilitation purposes". *Automation in Construction*, 31: 230-240.
Lamberts, R., Dutra, L. & Pereira, F. O. R. 1997. Eficiência Energética. São Paulo: PW Editores.
Lino, J. C., Azenha, M. & Lourenço, P. 2012. "Integração da metodologia BIM na engenharia de estruturas". *BE2012-Encontro Nacional Betão Estrutural.*
Machado, R. A. 2014. "Reabilitação de edifícios visando a eficiência energética".
Mickaityte, A., Zavadskas, E. K., Kaklauskas, A. & Tupenaite, L. 2008. "The concept model of sustainable buildings refurbishment". *International Journal of Strategic Property Management*, 12(1): 53-68.
Motawa, I. & Carter, K. 2013. "Sustainable BIM-based evaluation of buildings". *Procedia-Social and Behavioral Sciences*, 74: 419-428.
Pina dos Santos, C. & Matias, L. 2009. "Coeficientes de transmissão térmica de elementos da envolvente dos edifícios-Versão actualizada 2006".
Sousa, J. R., Silva, S. M. & Almeida, M. G. d. 2012. "Energy rehabilitation of Portuguese residential building stock through its transformation into NZEB".