Abstract:

Globally, there is a concern about the environmental damages caused by human’s activities, especially from the construction industry. Sustainable construction is becoming more demanding in order to diminish these impacts. However, the tendency is more focused on large-scale projects, mostly commercial, rather than residential buildings, which have been acknowledged to cause more environmental impacts than any other type of building, mainly during its life cycle. The UK government has expressed its interest in building more sustainable residential buildings through the creation of standards and policies. Along with sustainable construction, the implementation of BIM in the construction field is increasing worldwide. Due to the advantages offered by BIM, its implementation is considered important in the development of sustainable projects. The UK is known as a BIM leader country, having set a deadline to implement level 2 of BIM in public projects by 2016. This context suggests the possibility of implementing BIM in sustainable residential projects. This paper aims to investigate the current implementation of BIM in sustainable residential projects in the UK; analyse its challenges, which were several and significant; and give a perspective of how its implementation is likely to be in the future. The methodology proposed includes a literature review and the analysis of four sustainable residential projects developed with BIM in the UK, Finland, and the USA, which were selected from different countries due to the difficulties of finding good examples of these type of projects in the UK. The results suggested that there is still an immature knowledge of BIM implementation for sustainable residential buildings not only in the UK, but worldwide. This research may be beneficial to any professional of the construction who has worked or is interested in BIM implementation and sustainable construction.

KEYWORDS: BIM, RESIDENTIAL BUILDINGS, SUSTAINABILITY, UK GOVERNMENT, ZERO CARBON HOMES

1. INTRODUCTION

Commercial and residential buildings in the UK are responsible of almost 50% of the carbon dioxide emissions which mostly come from heating and their operation. Additionally, it is estimated that three million of houses will be built by 2020. Due to the government’s purpose of reducing to an 80% the emissions of carbon, it has become really important to guarantee that, both, new and already built homes meet the sustainable requirements necessary to diminish the climate changes and adapt to the changing climate (Seyfang, 2010). In another context, the UK government, through the document “Construction 2025”, has set out its vision to position the UK at the vanguard of the global construction in the coming years. Among the commitments of this strategy are included the topics of sustainable design and BIM implementation. The government states that there will be a big demand to enhance the energy performance of the existing

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1 University of Wolverhampton, s.subashini@wlv.ac.uk
building stock. In order to give to the industry enough confidence to get involved in these innovative markets, it is considered a must to build a low-carbon construction industry and promote with more clarity and certainty the emerging sustainable and low-carbon construction practices. As to BIM implementation, it is exposed that the BIM strategy has had a good start and that the industry must meet the target to implement BIM in all centrally procured Government contracts from 2016. It is considered that only with the implementation of BIM will be possible to develop more sustainable buildings, in less time and with more efficiency. Moreover, BIM is seen as crucial in the development of offsite manufacturing (HM Government, 2013).

The government has the urge to develop a more sustainable housing stock and has proposed BIM as a method to build more sustainably. However, is it the UK residential sector focusing on sustainable construction? And, moreover, are they currently implementing BIM for these purposes?

2. LITERATURE REVIEW

BIM implementation

BIM is a combination of technologies, communications, methods and procedures which connect together in order to create a plan that can be used to supervise digitally the most important aspects about the design of a project as well as the information related to it during the building's life-cycle (Succar, 2009).

The benefits of BIM in the construction industry have been exposed by many authors and proved in numerous real-life projects. Eastman et al. (2008) give an explanation that covers very well the benefits of implementing BIM in every phase of the construction process: Preconstruction benefits to the owner: Conceptualisation, feasibility and design of the project; the increment of the building quality and performance; the enhancement of the collaboration between designer and client thanks to the implementation of Integrated Project Delivery for project procurement. Design benefits: Precise and early visualisations of the design; automatic corrections in the design process; production of precise and logical 2D drawings at any phase of the design process; collaborative work with other disciplines at the early stages of the process; easy confirmation of the uniformity of the design; cost estimations in the design stage; energy efficiency and sustainability. Construction and manufacturing advantages: Usage of the design model for fabrication of elements; fast solutions in case of design changes; detections of any design mistakes and omissions before the construction phase; coordination between the design and construction strategy; more successful incorporation of lean construction practices; coordination of the design and construction with the procurement of the project. Post construction benefits: Enhancement in the commissioning and delivery of the project’s facilities; improved administration and performance of the facilities; unification of the project (model) with facility operation and management procedures. On the other hand, the literature also indicates that there are multiple challenges in the implementation of BIM. Arayici et. al (2011) identified some aspects that hinder BIM
adoption which include change the position some people have about BIM adoption and make them realise how important BIM and the advantages it offers compared to 2D drafting; adjust the current workflows to lean architecture and construction systems; instruct people to use BIM and get a project team with the skills to manage and comprehend how BIM works; the comprehension of all the conditions needed in order to manage proficiently BIM applications and tools, such as high-end hardware resources and networking facilities; unification, cooperation and interoperability among the MEP (Mechanical, electrical and plumbing) and structural designers/engineers; and the comprehension from the construction lawyers and insurers about all the responsibilities that the stakeholders have in this new way of work. Moreover, Khosrowshahi and Arayici (2012) mention other important challenges such as the high costs that implies the investment in hardware, software and training and the lack of demand of projects developed with BIM.

Regarding sustainability, Kriegel and Nies (2008) identify that BIM can help in different sustainable aspects of a project, which comprehend the orientation of the project thanks to its modelling properties; building massing, to examine the building shape and its surroundings in order to optimise the building envelope; daylighting evaluation; water harvesting, to decrease the need of water in a building; energy modelling, to decrease the costs and minimise the use of energy by the exploring possible ways to use renewable energy; sustainable materials, which helps to reduce the need of materials by the use of recycled materials; and site and planning management for the reduction of waste and carbon footprints. Despite all these benefits, BSI (2010) reported that the sustainable aspects of BIM are underused. It is cited the 2009 McGraw-Hill survey taken place in the US in 2009, where only 15% of the BIM users were getting the best performance of energy analysis in BIM.

3. BIM OUTLOOK IN THE UK

The UK government has been an important driver of the implementation of BIM. The Cabinet Office of the United Kingdom issued a document in 2011 called The Government Industry Strategy whose aim is to decrease the cost of the activities involved in the construction process up to a 20% by 2016. A condition specified in this document is the usage of Building Information Modelling for projects whose budget exceeds the 5 million pounds (Ngo, 2012). In this document is also stated the government’s plan of implementing collaborative 3D BIM (BIM Level 2) on projects from the central government department by 2016 (NBS, 2012).
Regarding BIM awareness and adoption, the last National BIM report presents a significant increase since 2010 (See figure 1). However there was registered a small decrease of its implementation in 2014. Despite these results, the report considers that BIM adoption in the UK is still increasing and it will grow faster in the last years (NBS, 2015). In contrast, it has been identified that BIM is not widely implemented in the residential sector in the UK. According to the report of the NHBC Foundation (2013), only an 11% of house builders were using BIM by 2013 and a 24 % did not have any knowledge about BIM. A 64% were aware of BIM but were not implementing it.

4. SUSTAINABILITY OUTLOOK IN THE UK'S RESIDENTIAL SECTOR

Residential buildings are considered as the major contributors of CO2 emissions in the UK. In 2005 was reported that 27 % of these emissions (about 150 million tonnes yearly) were related to the operation, heating and lighting of domestic buildings (Seyfang, 2010). Furthermore, Palmer et al. (2013) presented, in a study about the energy performance of different sectors in the UK, that the residential sector was the highest energy consumer of the UK by 2012 with an energy consumption value of 502 TWh, surpassing road transport (459 TWh), industry (293 TWh), commercial and public administration (197 TWh) and air transport (144 TWh).

Facing that situation, the UK Government created the Zero Carbon Home Policy in which was demanded new homes to be Zero Carbon from 2016, following the specifications of a standard named Code for Sustainable Homes (Lester, 2013). However, in the document "Fixing the foundations: creating a more prosperous nation", published the 10th of July, the government announced the cancelation of this scheme (Oldfield, 2015). Several environmentalists and house builders have reacted against this decision, mainly alleging the confidence it gave to the industry as to energy efficiency and low-carbon solutions...
Nevertheless, this end was expected to happen due to aspects related to its general acceptance in the construction industry and effectiveness. According to Graham (2014) Zero Carbon Homes plan received many critics from house builders who considered this goal would imply higher costs in the residential building sector affecting, specially, small builders. Regarding is effectiveness, the target of the scheme did not include the existing housing stock, which is very important in the government's goal of reducing carbon emissions: “There’s slow progress in the construction sector in tackling the carbon agenda. We are starting to address matters in the new build housing market, but the commercial sector is faced with a confusing non-mandatory code. The focus is also on the new build market, rather than the existing stock – which is where the real issue is” (Hammerson, in GVA, 2011, p.3). The CIOB (2013) states that 50% of the UK dwellings are 50 years old and a 5% are more than 100 years old. The process of renovating or modernising, which is undertaken approximately every 20 and 30 years of a building lifecycle, helps significantly in the objective of reducing the emissions of carbon produced by the building. According to Boardman (2007) new homes within the domestic construction sector are not a significant element due to the turnover’s slowness. Despite the advancements achieved in the construction sector, they will represent from a quarter to a third part of the building stock by 2050. Even though they can be considered as a solution when the old ones are demolished due to inefficiencies, a new building implies more carbon emissions, while refurbishment is a saving.

5. METHODOLOGY

The research technique applied in this research was the analysis of case studies. As several case studies were required, it was implemented a type of collective/multiple case studies named case study of "structured, focused comparison", which is defined by George and Bennett (2005, p.67) as follows: "The method is “structured” in that the researcher writes general questions that reflect the research objective and that these questions are asked of each case under study to guide and standardize data collection, thereby making systematic comparison and cumulation of the findings of the cases possible. The method is “focused” in that it deals only with certain aspects of the historical cases examined". It was first intended to search and analyse case studies exclusively from the UK, however, there were some obstacles in finding case studies of this type of projects. Due to these difficulties, the research had to change, expanding its scope and including case studies from overseas. This decision did not interfere with the purposes of this study, otherwise it made possible to give another perspective to the investigation. The inclusion of international case studies helped to attain the following aspects: a perception of the status of the UK compared to other BIM leader countries in regard the implementation of BIM in sustainable residential projects; analyse every case and make comparisons among them in order to see which of these projects implemented BIM more successfully; and, depending on the results of every case, give recommendations to the UK construction sector on how to address the issues encountered in the research.

Table 9 Variables and weighting of the performance matrix
The analysis of the cases studies was divided into two phases. The first phase consisted in answering the general questions as part of the case study of “structured, focused comparison”. A total of 6 general questions were formulated: 1. How BIM was implemented in this project? 2. Which environmental sustainable benefits were obtained with the implementation of BIM? 3. Were there any other environmental sustainable benefits not intrinsically related to BIM? If yes, which ones? 4. Which other benefits could be obtained with the implementation of BIM? 5. Did the project follow any sustainable standard? If yes, which one? Was the implementation of BIM useful to comply with the standard(s)? 6. Has the project been assessed for any sustainable assessment tool? If yes, which ones? Did BIM help in the assessment process? The second phase of the data analysis consisted in a performance matrix where two aspects, the implementation of BIM and the sustainable benefits related to its implementation, were measured in every project. For this analysis, the variables to be weighted in these two aspects were identified (See table 1). Regarding BIM, the variables comprehended different levels of BIM implementation, which are described in table 1 along with their weight. On the other hand, the sustainable variables were the sustainable features contained in the Code for Sustainable Homes (CSH), which are divided into two sections: mandatories and flexibles (BREEAM, 2014). The maximum weight of “2” was assigned to the mandatories and the minimum “1” to the flexible, indicating that the first are more significant than the latter. After checking the variables in every project, the variables of BIM were multiplied with the total sum of the variables of the sustainable features, giving a value to the project. It should be noted that in every project were only checked the variables that could be identified according to the information gathered. None assumptions were taken.

<table>
<thead>
<tr>
<th>SUSTAINABLE CATEGORIES</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibles: Pollution, management and ecology</td>
<td>1</td>
</tr>
<tr>
<td>BIM IMPLEMENTATION</td>
<td></td>
</tr>
<tr>
<td>Fully implemented (including facilities and life cycle management)</td>
<td>4</td>
</tr>
<tr>
<td>Implementation in the design and construction phase with all the parties involved</td>
<td>3</td>
</tr>
<tr>
<td>Implementation in the design and pre-construction phase. Eg. Mechanical, electrical and plumbing services (MPE)</td>
<td>2</td>
</tr>
<tr>
<td>Implementation in the design process</td>
<td>1</td>
</tr>
</tbody>
</table>
6. CASE STUDIES

For the case studies search, an investigation of BIM implementation around the world was undertaken. In this manner, the most influent countries in BIM were identified (USA, Finland, Norway, Sweden, Denmark, Germany, Singapore, South Korea, United Arab Emirates, Australia) and the case studies were specifically searched in these countries. In total, eight cases studies were found: two from the UK, five from the United States, one from Finland and another one from Sweden.

These cases were reviewed with the questions formulated in the first data analysis and the ones that could give most significant information were selected. The selection comprised four projects: 1. UK: A pair of 3-Storey Victorian terraces, Liverpool (refurbishment) 2. USA: Loblolly House, Taylor’s island, Maryland (new-built) 3. USA: Ross Street house, Madison, Wisconsin (new-built) 4. Finland: Härmälänranta neighborhood, Tampere (combination of new-built and regeneration of an urban area, compound by residential buildings).

7. FINDINGS

First of all, through the analysis it was noticed that most of the projects were not implementing BIM as a working process. This confirms that there is still a misunderstanding of what BIM is. In the case studies, some of the developers considered and presented their projects as a “BIM product”. However, BIM was actually implemented in specific tasks. For instance, in the neighborhood Härmälänranta is only specified that BIM was used for the carbon footprinting estimation of the residential buildings. There is not a description of BIM being implemented as a process. Secondly, it could be noted that the implementation of BIM with sustainable purposes is translated to the use of a software rather than a process: e.g., “thanks to ArchiCAD”, “With the use of Revit”, “With the model” etc. Furthermore, the underuse of sustainable aspects of BIM was evident in one of the projects analysed: Härmälänrant, where many sustainable aspects were accomplished, but the implementation of BIM was limited. The project was developed in two phases and a BIM model was only used to measure the carbon footprinting of the first phase and to conduct a LCC (Life Cycle Costing) analysis for the energy efficiency of the second phase. In contrast, the sustainable benefits obtained without BIM were more in quantity (See figure 2).

Due to the general concern about energy efficiency, projects' developers tend to centre their attention in energy performance when developing a sustainable project, although this is not the only feature to take into account in a sustainable building. In most sustainable projects, not only residential, the implementation of BIM is translated to the use of energy analysis tools/software implemented in the early stages of the design process. This could be exemplified in the case study of the pair of 3-storey houses were the only sustainable benefits that could be attained were related to energy efficiency. There was not attempted any other sustainable approach in this project.
On the other hand, the project of Ross Street House showed how beneficial can be the implementation of BIM in the sustainable assessment with rating systems. This house had several sustainable benefits thanks to the use of BIM: daylighting and ventilation; energy efficiency; and ecology, which helped them significantly to achieve 102 LEED points and get a Home Platinum Certification.

Figure 18 Summary of the general questions of each case study

<table>
<thead>
<tr>
<th>Project</th>
<th>Question 1</th>
<th>Question 2</th>
<th>Question 3</th>
<th>Question 4</th>
<th>Question 5</th>
<th>Question 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1. Early stages of the design process: design element of the house accurately and the coordination among them; 2. The procurement of materials; 3. Prefabrication process of the house’s elements; 4. Collaborative work among the different parties of the team by sharing information about the project.</td>
<td>1. Energy savings and reduction of carbon dioxide emissions; 2. Sustainable materials; 3. Site’s ecology preservation; 4. Waste management; 5. Reduction of the construction process to a period of 6 weeks</td>
<td>All the sustainable aspects developed in the project were intrinsically related with the implementation of BIM.</td>
<td>1. Communication; 2. Collaborative work; 3. Cost savings in the construction process; 4. Clash detection</td>
<td>Not specified</td>
<td>Not specified</td>
</tr>
<tr>
<td>3</td>
<td>1. Design process; 2. Collaborative work among the different parties of the team by sharing information about the project.</td>
<td>1. Day lighting and ventilation; 2. Energy efficiency; 3. Ecology preservation</td>
<td>1. Energy efficiency; 2. Sustainable materials; 3. Water efficiency; 4. Water harvesting; 5. Water management</td>
<td>1. Communication; 2. Collaborative work</td>
<td>Not specified</td>
<td>Yes, it has been assessed by two different assessment systems. The house received a rating of 42 in the Home Energy Rating System (HERS), being G, a zero energy home. LED for Home Platinum certification with a total of 192 points: the highest within this assessment rating system.</td>
</tr>
</tbody>
</table>
| 4       | 1. First phase of the project: carbon footprinting calculation; 2. Second phase of the project: to conduct a LCC (Life Cycle Costing) analysis in order to determine the lowest lifecycle energy design alternatives for the project. | 1. Carbon footprinting; 2. Energy efficiency | 1. Energy efficiency; 2. Environmental materials; 3. Water management; 4. Water efficiency: Urban sustainable benefits: 1. Stormwater management; 2. Green spaces; 3. Reuse of existing buildings; 4. Sustainable lifestyle | 1. Cost savings; 2. Visualisation | In this project were implemented three sustainable standards, two of them created by the company Skanska: 1. LAB Methodology (Skanska’s Living Area Design); 2. Finish M1 standards; 3. The Skanska Finland’s standard waste management | The project has not been assessed with any sustainable assessment tools, however the company made an evaluation of the project using a system called “the Skanska color palette”.

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Based on the questions, the best example is undoubtedly the Loblolly house. This is an example of a project that received multiple benefits thanks to a coordinated and integrated design. This house was the only project that did not centre its attention in energy efficiency. When this project was designed, the project team did not have tools available to undertake an energy analysis, however some of the benefits obtained could help in the energy efficiency of the construction process.

These projects showed a variety of benefits a sustainable building can offer. It could be noted that some of the sustainable benefits obtained with the implementation of BIM were not explicitly defined by the developers and some were obtained as a result of others. Furthermore, some benefits were not sustainable in the first place, but could help in attaining environmental targets. To conclude, a common factor observed was that none of the projects utilised BIM for lifecycle management, which is another aspect ascribed to BIM that can help significantly in maintaining the sustainable attributes of a building, considering that most of the environmental damages are caused when a building is used.

Figure 19 Performance matrix of the case studies

<table>
<thead>
<tr>
<th>Sustainable category</th>
<th>Sustainable category weight</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and carbon dioxide emissions</td>
<td>2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>2</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface water-run off</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste</td>
<td>2</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health and Well-being</td>
<td>1</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Management</td>
<td>1</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecology</td>
<td>1</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Total of sustainable categories weight</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>BIM implementation weight</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Product of both weights</td>
<td>6</td>
<td>24</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Legend:
Project 1: A pair of 3-Storey Victorian terraces, Liverpool
Project 2: Loblolly House, Taylor’s island, Maryland.
Project 3: Ross Street house, Madison, Wisconsin
Project 4: Härmälänranta neighborhood, Tampere.

The second data analysis also revealed that Loblolly house was the project that had more sustainable features thanks to the use of BIM: five in total (See figure 3). In addition, this project, along with two others, were the ones that more implemented BIM as a process of work, getting a weight of 3 in the BIM implementation category. An aspect that helped this project in attaining all these sustainable characteristics was the decision to use prefabrication as a method of construction. This method is environmentally friendly and BIM made its execution easier, faster and more accurate. The project with the lowest sustainable performance related to BIM was Härmälänrant, basically due to the underuse of BIM for sustainable purposes.

8. CONCLUSIONS

The shortage of information in the literature review and the difficulties arose in the methodology indicated how immature the topic of implementing BIM in sustainable residential projects still is even in the UK, a country that has been widely recognised in the field of BIM implementation. The research showed that the total spread of this practice in this type of projects is not likely to happen in a near future. Undoubtedly, more time is needed for the UK industry to clearly see the benefits obtained after meeting the BIM mandatory target for public projects in 2016, thus its implementation can be spread in, both, private and public sectors and in different types of projects. Furthermore, more time is needed for the residential sector to increase the use of BIM. The implementation of BIM is still seen as a challenge in the construction sector in general, more in the residential sector where BIM adoption is relatively limited. The barriers of BIM implementation tend to be bigger in this sector for several reasons: Most of the residential buildings developed in the UK are dwellings, which means they are small projects. The high cost that implies the adoption of BIM does not look very attractive to companies that develop small projects. Furthermore, it is difficult for the small builders involved in this sector to make such investments taking into account the quantity and size of projects they normally develop. Another aspect is the client’s demand in this sector. For the economic implications of implementation of BIM, it is not likely that clients ask for sustainable residential projects to be developed with BIM.

From this research could be drawn several recommendations for the UK industry:

The government must act quickly and propose a substitute of Zero Carbon Homes Scheme and create new and less severe standards in order to drive the construction of sustainable residential buildings.

The government must also implement standards that cover the refurbishment of residential projects, which is very important due to the low rate of new-built residential projects compared to the high need of refurbishment in this sector.
Spread the implementation of more environmentally friendly methods of construction that could be implemented in residential buildings and also be developed by the use of BIM. As shown in one of the case studies, it can be suggested the use of off-site technologies, for example the prefabrication, which is not widely adopted in the UK.

This study suggests further investigation of the topic and also of the development of projects of this type in the UK. It is also suggested to follow the future government's actions regarding this area.

9. REFERENCES


