BIM practices and tools supporting circular economy: feedback from survey

Abstract. The purpose of this article is to study practices that maximize the future reuse of new materials and components. In particular, it attempts to demonstrate how BIM and its complementarity with material passports maintained throughout the life cycle of a building can encourage and facilitate the reuse of materials and equipment. The integration of BIM tools and material passports would make it possible to study the technical feasibility and economic profitability of different scenarios for selective deconstruction and reuse on or off site in order to facilitate the pre-demolition audit.

Keywords. BIM, Circular Economy, Design for Deconstruction, Material Passport, Life Cycle.

Résumé. Cet article a pour objectif d'étudier les pratiques qui maximisent le réemploi futur des matériaux et composants neufs. Il vise en particulier à démontrer comment le BIM et sa complémentarité avec les passeports matériaux maintenus à jour tout le long du cycle de vie d'un bâtiment peut encourager et faciliter le réemploi des matériaux et des équipements. L'intégration des outils BIM et les passeports matériaux permettrait d'étudier la faisabilité technique et la rentabilité économique de différents scénarios de déconstruction sélective et de réutilisation sur site ou hors site afin d'établir plus facilement l'audit de pré-démolition.

Mots-clés. BIM, Reuse Economie Circulaire, Design for Deconstruction, Passeport Matériau, Cycle de vie, Réemploi.

1. BIM as a support for circular economy

1.1 The evolution of sustainable development vs. the evolution of BIM

The oil crisis of 1979 and the general awareness that followed, gave rise to a common desire for a sustainable development of our society. This awareness has contributed to the evolution of various tools over time, capable of measuring the environmental impact of buildings based on more or less precise criteria. Belgium, aware of the importance of a broader vision of the sustainability of the construction sector, has recently developed the TOTEM tool. This tool is in line with other LCA-oriented labels such as LEED in the United States, BREEAM in England and HQE in France (Authors, 2018, Authors, 2019a).

In parallel with this evolution of sustainable development, the architectural design process has undergone a metamorphosis. The advent of personal computers has disrupted the traditional work process by replacing hand drawing with digital drawing (Howard et al. 2019). This change affects not only design tools but also communication with other stakeholders in the construction industry. This metamorphosis has continued to evolve and intensify, culminating in the creation of BIM. Paradoxically, a reluctance to digitise the sector has increased the compartmentalisation effect between disciplines.

Thus, throughout Europe, researchers (Charef et al., 2019) and professionals are making the same observation: the segmentation and disruption of the collaborative workflow in the Architecture - Engineering - Construction (AEC) sector has serious economic (efficiency, profitability, additional costs), ecological (resource use, waste production, energy inefficiency) and societal (well-being and health of users) consequences.

However, the materials used in an architectural project can be supplied from two sources: new materials and reused materials. According to scientists, 100 % new materials will gradually disappear as natural resources are depleted (Servigne & Stevens, 2015). The construction sector will then depend on the remaining sectors, namely secondary raw materials (Worldwatch Institute, 2012).

1.2 Convergence of the evolution of sustainable development and BIM

In order to ensure that the construction sector can continue to supply itself, materials must circulate in loops and thus avoid the extraction of virgin raw materials (circular economy - CE). Xu and Gu (2015) identify four ways to avoid the extraction of natural resources: reduce, recycle, reuse and regenerate. In this article, we focus on the reuse of building materials.

To reach a circular approach, it must be possible to recover components at the end of the building's life in order to prevent them from ending up in the landfill.

One of the main obstacles to the reuse of materials is the lack of information. Indeed, reused materials are often not documented and therefore do not have any certification; structural, thermal, environmental, health and safety performance. This lack of certification of salvaged materials is one of the main concerns regarding the quality and reliability of materials, especially when it comes to structural elements. In Europe, it is currently unknown how European Conformity (EC) markings should be used when reused components are involved (Gorgolewski, 2017; Durmisevic et al., 2017; Ghyoot et al., 2018).

Another important criteria to allow the component to be reused is its disassembly potential. In order to make it technically feasible to recover the building components, it is essential that the building has been designed in such a way that the components can be recovered (Design for Deconstruction - DfD). The literature reveals that DfD is still far from reaching its waste minimisation potential, as less than one percent of existing buildings can be completely dismantled (Dorsthorst & Kowalczyk, 2002).

The BIM process could be a great help in making decisions regarding the implementation of DfD and the documentation of the materials present in the building. Indeed, the advantages of BIM such as centralisation of information, collaboration, visualisations, cost estimation, deconstruction scenario analyses, etc. are very useful to improve the proposed solution (Bilal et al., 2016).

Based on our review of the literature on BIM practices and tools supporting CE, no tools to predict demolition/deconstruction are currently on the market. However, designers need tools at the design stage to predict deconstruction. Some tools to reduce the environmental impact of materials through digitisation are nevertheless under development. These include: digitisation of deconstruction (manual, passive or active); Totem; Madaster; Materials Passport Platform of the BAMB project; or the combination of ACL with BIM. Let us note that each of these tools acts at a different level of information.

The study by Bilal and his colleagues (2016), evaluating major BIM design software, shows that none of these tools currently address (de)construction waste. However, their research shows the need for a plugin dedicated to waste prediction and management. The main goal of this plugin would be to extend the functionality of existing BIM software to predict and minimise construction waste. This plugin should therefore integrate the following functions: analysis of the existing digital model and estimation, visualisation and minimisation of waste generation. The data collected during the analysis of the digital model would then serve as a basis for estimating the quantities of waste generated by the building. The idea is that users would be able to interact with the plugin from their native design tools. Through this process, designers will be able to design buildings with better design strategies, material selection and sourcing. In addition, changes can be made during the building design phase (Bilal et al., 2016).

We can thus consider the combination of CE and BIM as a promising lead to reduce the amount of deconstruction waste. The combination of the two practices could indeed encourage deconstruction tracks instead of demolition. The hypothesis of the implementation of a material passport and its integration with an "as-built" BIM model delivered to the project owner could therefore lead to a more efficient future reuse of materials and components. The objective is to obtain a digital model (updated during the building's life cycle) that allows comparison of different scenarios of selective deconstruction and on-site or off-site reuse. In addition, this digital model will facilitate the pre-demolition audit. The resulting "as-built" BIM will be a real support for circular models. However, since the literature refers to the difficulty of maintaining an as-built digital model containing useful information for a later evaluation of the profitability of selective deconstruction, we have opted for an analysis of existing practices combining BIM and DfD.

2. Research methodology

Most of the literature we have consulted concerns the theoretical way of combining BIM and DfD. However, little research has been done on the practices of architects trying to combine them (Guldlager & Sommer, 2016). In order to fill this research gap, we have chosen to look at the current ways in which architects operate. To this end, we conducted an online survey addressed to architects interested in BIM and/or the CE. The goal of this survey was to identify the challenges they face, the solutions provided and their expectations towards existing BIM tools.

The survey consists of four parts. The first section aims to collect demographic data from participants in order to contextualise the information. The second section focuses on the architects' approach towards CE. The third concerns the use or non-use of BIM modelling tools. Finally, we asked some questions on the combination of BIM and CE in order to reach offices involved in both practices.

3. The online survey

3.1 Description of the sample

The questionnaire was mainly addressed to architects who apply CE principles and/or use BIM (digital modelling and/or BIM processes). 26 architectural practices answered the survey. The offices surveyed can be divided into five categories: neither BIM nor re-use (1); re-use only (7); BIM only (8); both practices but not combined on the same project (6); both practices and combined on the same project (4).

The sample represents 35 % of offices operating in Wallonia, 15 % in Brussels, 12 % in Flanders and 38 % abroad (France, Netherlands, Finland, Switzerland and Denmark). Of the offices surveyed, 50% are offices with 1 to 5 collaborators (small), 19% offices with 6 to 20 collaborators (medium), 8% offices with 21 to 50 collaborators (large) and 23% offices with more than 51 collaborators (very large). The small Walloon offices are the most represented in this study.

The majority of the questionnaire consisted of multiple-choice questions in order to facilitate the processing of responses. However, in this article, we provide a qualitative analysis of the responses to the open-ended questions.

3.2 Circular Economy

We note that the offices surveyed attach the most importance to the flexibility of technical installations: 73 % find it quite or very important to design a technical installation that can be adapted or disassembled instead of demolished (Figure 1). The flexibility of the facade/cladding is important for 69 % of the participants, while the interior layout (partition walls) is only 65 % in favour of "Design for Deconstruction". Architects are significantly less interested in the reversibility of the structure than in other building layers. A demountable structure is of little or no importance for 35% of the offices surveyed.

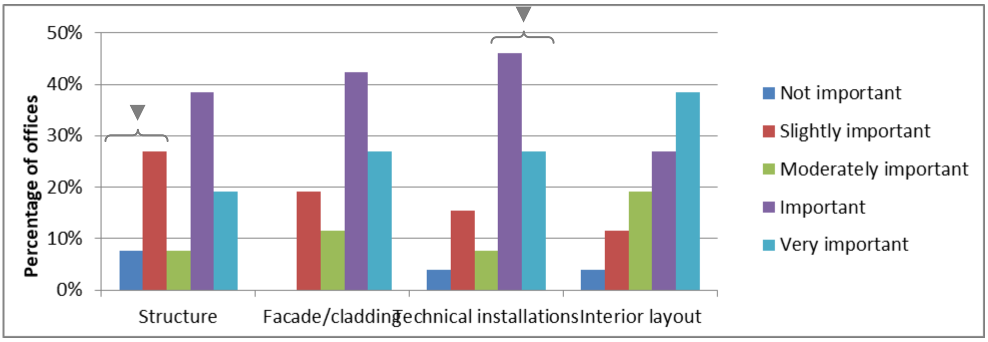

Figure 1. Importance of flexibility in building layers

Among the offices who are familiarised with reused materials, the main reasons given by architects for using this type of materials are (in order of importance): (1) to avoid waste, (2) to save costs, (3) to save money, (4) to meet a particular customer's request, (5) to obtain green/LEED/ BREEAM/HQE certification, etc.

With a multiple choice question, we asked the architects who are not acquainted with reuse why they have not (yet) used such materials. Among the answers given, the most frequently mentioned were: lack of procedural knowledge (33 %), never came to mind (31 %), desired materials are not available (25 %), unsuccessful attempt (8 %).

Architects are not against the use of reused materials in their projects, 80 % would even support the use of salvaged materials if there were more incentives and/or tools available.

3.3 BIM

All of the architects surveyed claim to be at least familiar with the term BIM. However, not all offices have adopted these new practices. In Wallonia, 67 % of the offices say they are aware of the term BIM but are not interested in it, 2/3 of the Flemish offices surveyed are in favour of its use, and the Brussels offices have mixed opinions (Figure 2). For the foreign offices that responded, 80 % of the offices say they use BIM in the majority of their projects.

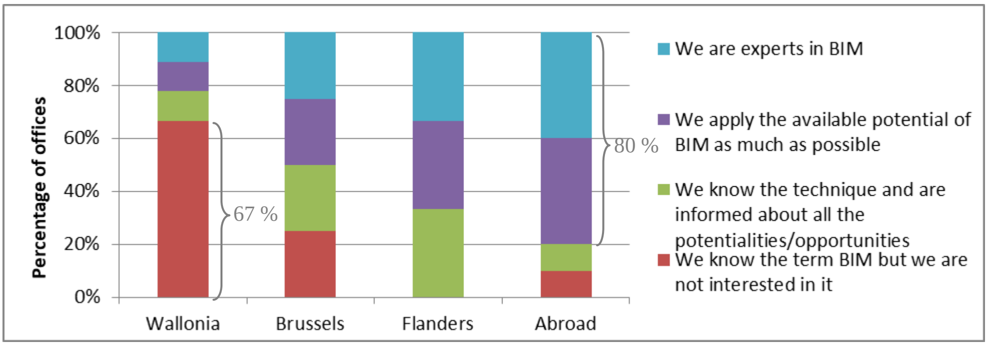

Figure 2. Knowledge of BIM depending on office location

However, we have to mention that the legal framework towards the use of BIM differs from one country to another. The results of foreign offices in favour of BIM are not necessarily due to a personal interest in this practice but are in some cases influenced by legal obligations (Charef et al., 2019).

According to our study, all but 15 % of the architects surveyed are convinced of the need to use BIM (Figure 3). A large proportion (46 %) of small offices and the majority of mid-sized offices (60 %) agree that they will have to use BIM, but have not yet taken the plunge. In very large offices, 67 % of architects are convinced of the need to use BIM. For the remaining 33 %, it is mostly the management that is convinced of the advantages of the BIM process.

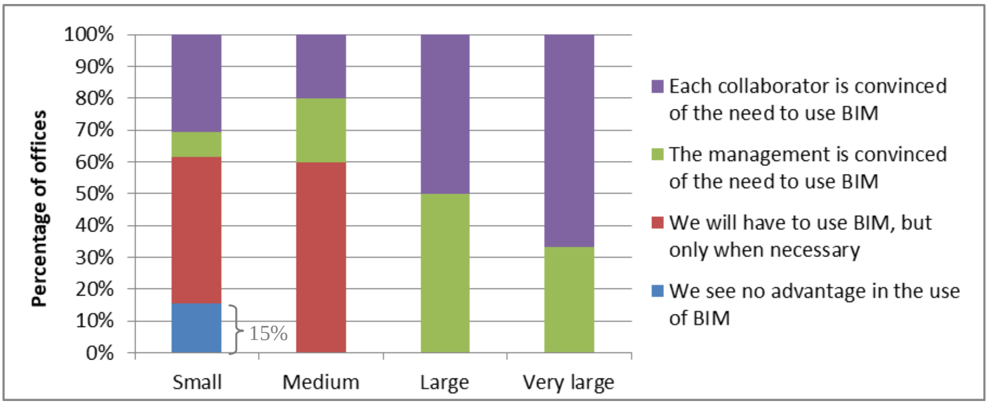

Figure 3. The need to use BIM in relation to the size of the architectural office

3.4 Combination of BIM and circular economy

3.4.1 Entering data about salvaged materials into a BIM model

According to our survey, 85 % of architectural offices say they have never incorporated information about salvaged materials into a BIM model. Following a multiple-choice question, the main reasons that offices give are presented in figure 4.

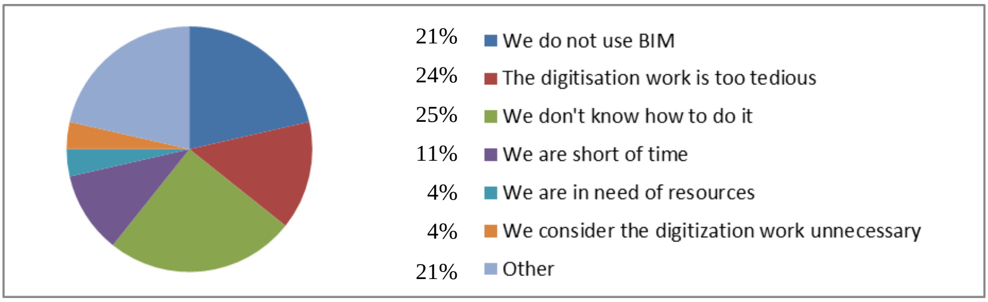

Figure 4. Reasons why offices do not incorporate information about recovered materials into a BIM model

An architect, working in a small Walloon office and having mostly medium-scale projects (101 to 1000 m²), explains why he has never tried to integrate information about recycled materials into a BIM model: *"Reusable elements can appear very late in the project (in our experience, 9 times out of 10 directly on the building site): there is therefore no interest in any prior digitisation for us so far."*[1]

3.4.2 Current practices

The current solutions found by the offices are modelling and manual input of data into the BIM model and/or related synchronised files. The mentioned problems concern the loss of time in order to introduce all the information and the time spent setting up the nomenclatures to extract and sort the information. A Brussels architect working in a small office mentioned three types of knowledge that architects need to acquire in order to combine the two practices: (1) knowledge of materials and construction methods in accordance with CE; (2) proficiency of a BIM modelling tool; (3) knowledge of the networks and reuse channels in the architect's area of practice.

3.4.3 Desires

Of the four practitioners of the combination of the two practices of our survey, all of them would like to have a material passport of the reclaimed material with information on quantity, composition, properties, environmental impact, etc. Three of the four architects would like to have a BIM model of the building from which they want to recover materials during selective deconstruction. Finally, two of them would like to have a 3D scan (point cloud) of the recovered objects in order to facilitate the digitisation of geometric information. They also ask for tools that automatically integrate the information into the

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[1] Original verbatim : *« Les éléments de réemploi peuvent faire leur apparition très tard dans le projet (dans notre expérience, 9 fois sur 10 directement sur le chantier) : il n'y a donc aucun intérêt à une quelconque numérisation préalable pour nous, jusqu'ici. »*

BIM model so that they don't have to waste time doing it manually. These architects would also like to have tools to provide a clearer overview of the networks and reuse channels.

Following the analysis of the answers to the online survey, we identified a group of ten architectural offices applying both the principles of CE and the use of BIM. In order to identify the specific problems and the solutions found by this group of forerunners, we conducted a series of retrospective interviews, with the aim of drawing useful conclusions for the development of these practices, which are currently not widespread. The results of these interviews have been published (Author, 2019b). The analysis of these interviews have highlighted that the objectives of architects in their BIM/DfD application vary according to the projects under consideration. We have divided these objectives into 7 categories: (1) minimizing construction waste, (2) documenting deconstruction, (3) optimising transportation, (4) valorising a BIM “as-built” model on the market, (5) maximising the percentage of reuse, (6) promote collaboration, and (7) planning for the end of the building's life.

4. Discussion

4.1.1 The combination of BIM and CE, only for idealists?

According to our online survey, the combination of BIM and DfD is still very uncommon within architectural offices, even though the questionnaire was targeted at users of one and/or the other practice. Our survey shows that, in general, the negative image of "waste" and the lack of knowledge about reuse are a major brake on the use of salvaged materials. Architects are nevertheless in favour of using such materials, but they currently lack tools and paid time to do so. An architect who is a practitioner of reuse testifies to this difficulty: *"As an architect, using reuse in a project requires more work than a traditional project, except that we are not necessarily paid for it"*[2] However, this does not prevent this architect, working in a small office, from putting the CE into practice in his projects.

4.1.2 Big vs. small offices?

According to our survey, very large offices are less familiar with CE than small offices. Large offices with large scale projects (1001 to 5000 m²) often have difficulties finding materials in sufficient quantities on the reuse market and are often subject to higher standards than projects for individuals. We note that interest in CE emanates from architects' personal interest in these practices. Indeed, at present, there is no legal obligation regarding reuse in the countries whose architects we surveyed.

In terms of BIM, the trend is reversed: overall, BIM is more widespread among large offices. At the same time, we note that the financial investment devoted to BIM is proportional to the size of the architectural office. We also observe a large difference in the use of BIM between Belgium (and more particularly Wallonia) and foreign countries. This difference can be explained by the fact that BIM is already imposed for certain projects abroad, unlike in Belgium. It is therefore not always out of conviction that foreign offices have chosen to use BIM.

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[2] Original verbatim : *« En tant qu'architecte, utiliser du remploi dans un projet nous demande plus de travail qu'un projet traditionnel, hors nous n'avons pas spécialement d'honoraires complémentaires. »*

4.1.3 Circular economy and BIM, two upheavals?

According to our survey, the combination of the two practices is still very uncommon, regardless of the size or location of the office. Offices interested in CE are not necessarily interested in BIM and vice versa (but for other reasons). Among the architects who combine the two practices, all would like to have material passports on a component level that include information on quantity, composition, properties, environmental impact, etc. An architect working in a small office in Brussels explains that he currently spends a lot of time implementing all the information and setting up the nomenclatures in the BIM model to be able to extract and sort the information.

We observe that BIM and the CE are two upheavals inflicted on architects. All the architects who combine the two practices we spoke to (following the survey responses), had strong BIM knowledge prior to their interest in reuse. As a result, they have integrated BIM practices into their regular work processes. They say that they are at an experimental stage where they are proceeding by trial and error, as there are no good practice rules or regulations yet. Indeed, according to Hochscheid and Halin (2019), there are five key moments in the adoption of a new practice; awareness, assessment of potential, decision to adopt, implementation, confirmation of adoption. Architects currently trying to combine CE and BIM are in the fourth phase of this model, i.e. implementation. According to these researchers, it is primarily the characteristics of innovation and change that will influence the success of implementation and the anchoring of new practices.

Offices interested in CE that do not have knowledge in BIM are not very open to a change in methodology. Indeed, the combination of BIM and CE is mainly hampered by a lack of knowledge and tools available on the market. Moreover, not all offices are interested in this approach or do not know how to start.

In addition, architects are not trained as IT specialists and therefore often lack the knowledge to program the functions they really need. As a result, it is necessary to create a new profession in order to meet this demand. Another new profession could emerge by the need to manage the "as-built" model in order to keep it up to date throughout the life cycle of the building, until the deconstruction. As a result of our interviews, the question of responsibility for information after the delivery of the building often remains unanswered. Some say that it will be the client who will take care of the digital model, others suggest that an outside person should be involved. This task requires special knowledge. The intervention of an outside person could therefore be envisaged in order to relieve the uninitiated client of this task. This could be the role of the BIM assistant to the project owner, as described in the Belgian BIM protocol, published by the BBRI (2019). Indeed, the role of the assistant to the project owner consists in assisting the client by taking charge of some or all of the tasks related to the BIM model (in the name and on behalf of the project owner). The division of tasks between the client and his assistant should be detailed in the BIM execution plan.

The combination of BIM and deconstruction will therefore have an influence on the creation of new professions, as will the emergence of the CE and BIM.

5. Conclusion

We have observed that it is not enough to have the digital BIM model to make the materials circulate. Indeed, the documentation work through BIM is futile if it is not physically and economically possible to dismantle the component or material without damaging it. For this reason, it is essential to act at the source, i.e. to design buildings that can be deconstructed at the end of their life in order to avoid the production of waste. These practices are nothing new. In their book, published in 2018, Rotor presents three examples of ancient reuse practices: Stonehenge, Roman spolia and Japanese culture. Therefore, it is for us more important to design a building so that it can be dismantled at the end of the building's life (Design for Deconstruction) than having an “as-built” BIM model.

From our point of view, BIM combined with CE serves to have a global vision on the entire life cycle of a building. For us, an “as-built- BIM model is a means of documenting the building, assessing its deconstruction potential and planning deconstruction to encourage the reuse of materials at the end of the building's life. However, it remains a tool and will not replace human intelligence and creativity.

We can conclude that there is still a long way to go before the “as-built” BIM model can become a real aid to the decision between demolition or deconstruction. Some research has been done on the subject, but now it is time to put this theory into practice. We are convinced of the relevance of the approach because it allows us to take into consideration the world we will be handing over to future generations.

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