Usability of BIM in preliminary design: a study of the relevance of the different representations allowed by BIM

Gaelle Baudoux* and Pierre Leclercq

University of Liège – Allée de la découverte, 9 – Liège, Belgium
*gbaudoux@doct.uliege.be (Aspirante FNRS) ; pierre.leclercq@uliege.be

Abstract. In this article, we adopt an interdisciplinary approach incorporating cooperative design, construction and ergonomy perspectives to analyze the use of low-tech analog tools versus high-tech digital tools. We do so through the articulation of traditional design with Building Information Modeling (BIM) methods. This paper aims to study how components of projects in the design concept phase can be prepared to further stages that use BIM tools and methods. To achieve this goal, we used a case study of cooperative design in building architecture. It takes place in a collaborative design process and consists of the collection and analysis of project information required by BIM and how they are represented at the end of the design concept phase.

Keywords: Cooperative design, Building architecture, BIM, Information visualization, Case study.

1. Introduction

The implementation of integrated technologies and processes is announced as a promising way to articulate exchanges between actors and improve the performance of buildings [1]. Called BIM for Building Information Modeling, this digital approach of information sharing allows the modeling of formal and functional descriptions of a building (3D models) but also of its constraints and performances (4D and beyond: cost, structural resistance, lighting, acoustics, etc.). It claims to support the process of data management and coordination in a collaborative approach between the different actors throughout the life of a construction project [2, 3].

While this evolution in practices undoubtedly brings benefits in the implementation phases of the project, the implementation of digital building information technologies has not yet proved its effectiveness in the earlier phases of the process [4, 5].

Indeed, BIM currently impacts the ideation phase, which is the moment of emergence of the creative process, deployment and new ideas exchange. Often expected in architectural projects competition calls, particularly those for public contracts, the BIM digital model, with its descriptive and formatted information on the project, is too restrictive and too rigid to allow the project to evolve further in a creative sense [4]. Moreover, it remains incomplete in the preliminary design (PD) and design concept (DC) phases. As a result, the BIM model remains inadequate for the design activity [4].

In our study, we therefore question the transition between the traditional design of a project in the conceptual design phase and the use of BIM in the later phases. We seek to improve collaborative design practices by studying information sharing in collaborative BIM design processes.

2. Concepts

2.1. BIM tools and processes

Building Information Modeling (BIM) is defined as "3D physical properties with graphical and non-graphical information and documentation data formats for all phases of concept, design and construction, which is considered as a management process using specific platforms for the project life cycle" [6, p.143].

BIM therefore transforms what would be a simple data management and coordination process into a collaborative approach throughout the life of the project [2, 3]. It is an integrated way of working that links a digital model produced with modeling software to a set of collaborative processes exploiting this model [2, 3]. This digital model, known as the BIM model, is the single reference for all actors involved in the design and construction of the building [7]. It compiles all the data and information about the building in a single digital model [3, 8]. BIM is used through the four stages of the building life-cycle (Fig. 1): Design, Construction, In-use and End-of-life.

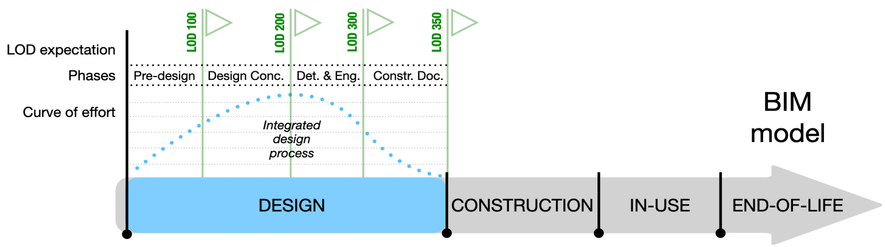

Fig. 1. BIM usage throught building life-cycle, based on the MacLeamy graph [9].

2.2. Practical use of BIM

In the real environment, Rahhal [10] observes that the digital model is not the only medium for sharing information. This information is also transmitted through perspectives, diagrams, texts or tables produced in parallel to the BIM model. Moreover, information is also transmitted through moments of self-sufficient communication, meaning communication that is not assisted by graphic or textual supports.

Calixte [11] also notes that, even though BIM is a collective process, the actors often work individually on separate parts of the project which are then regularly pooled in the model.

These two facts, according to the same author, exist because buildings that are subject to BIM methods are generally complex and involve many elements. The BIM model, to synthesize all the information relating to this type of building, becomes more and more complex and difficult to handle, causing difficulties in its operation. Alternative collaboration spaces are therefore set up, by the actors, in parallel with the model. They can thus return to traditional low-tech methods and tools or put in place complementary uses such as the traceability of the project's history, the juxtaposition of individual works, etc [11].

2.3. Levels of Development (LOD)

A specific term dedicated to BIM methods is Levels of Development (LOD). The LOD concept « is employed to describe the development of a digital building model through the different stages of the building life-cycle. It formalizes the progressive nature of the design process, which enhances the quality of the decisions made. In most approaches, the individual levels of development are described using (informal) textual definitions and graphic illustrations for various building elements. Together these definitions represent the required information quality, i.e. reliability, preciseness, and completeness. » [12, p137].

As the design of the building progresses, the levels of development increase [12, 13, 14, 15]. The design phase is thus divided into 4 sub-phases (Fig. 1).

- Pre-design (LOD 100): at this stage, ideas are generated. Level 100 corresponds to generic and non-geometric elements. The information is presented in the form of symbols, example references or textual elements.
- Design Concepts (LOD 200): ideas are investigated, new ones appear and the project is being geometrically resolved. The documents become more precise. The 200 level presents generic elements with accurate quantity, shape, size, location and orientation. Choice of solutions is made through performance analysis.
- Detailing and Engineering (LOD 300): the project is geometrically solved and its performance is evaluated. The documents are structured and precise. At this level, all the elements are modeled with their quantity, size, shape location and orientation which can be measured directly from the model without referring to non-modeled information.
- Construction documents (LOD 350): the project is exhaustively characterized and the execution documents are produced. In addition to the elements directly measurable from the model, this LOD includes an interface between all the building systems such as allowing coordination between actors and detecting clashes and avoidance.

The LOD system is not yet standardized worldwide, but a global system seems to be emerging through the Level of Development Specification [15], based on the American Institute of Architects, and adopted in particular in our country, i.e. Belgium by each construction national councils. Several other guidelines have been proposed. For example, the UK has introduced seven Levels of Definition characterizing the level of detail and the level of the model [12]. Another example is Denmark, which includes seven Information Levels corresponding to the traditional construction stages [16].

3. Issue

Currently, there are few recent studies on the information exchanged around the BIM model and its utility as an exchange medium [10].

Celnik [2] and Forgues [17] studied the use of BIM and digital models in architecture and construction respectively. Al Hattab et al. [18] modeled information exchange in a collaborative BIM process. Our research laboratory analyzed the cognitive and operative synchronization and information sharing between actors during a BIM process [11]. And also analyzed the formal and informal exchange of information between BIM actors [10].

We, therefore, propose a complementary study, from a BIM perspective, on how information is communicated from the Design Concept phase to the next phase: how are the expectations in terms of BIM requirements fulfilled at the end of the Design Concept phase? How is building information represented?

4. Methods

To answer our questions, we are conducting case study research. Since we are not aiming at statistical generality, but we want to describe qualitatively the phenomenon, a case study allows us to be closer to the studied phenomenon and to have privileged access to the real field data. We have been careful to ensure that the case chosen is representative of an architectural project design phase in a BIM context. We chose to study a design process in an educational setting, detailed below, to ensure a full access to building data and working methods. Indeed, studying in this way a professional context has already been attempted and has highlighted many limitations [11]. Despite the educational field, the participants are expert designers in their 4th year which master the methods and challenges of design.

This case study takes place in the context of the Architectural workshop of the 1st Master Civil Engineer Architect of the University of Liège (Belgium). As illustrated in figure 2, this workshop constitutes the Pre-design and Design Concept phases of a long collaborative design process and is articulated with two other courses forming the Detailing and Engineering and BIM phases respectively for the IMT Mines Alès building project and the University of Liège BIM SDC [19]. Indeed, the architectural workshop consists of the integrated collaborative design of the building to formulate a formal, functional and pre-dimensioned response to the program. The building project then carries out the engineering study by covering the structure, the execution methods and the dimensioning of the systems and ensures compliance with fire safety and accessibility regulations. Finally, the BIM SDC creates the BIM model of the building and uses the model to elaborate the cost estimate, plan the construction site, etc. In the end, designers give a feedback report in which they analyze their workflow.

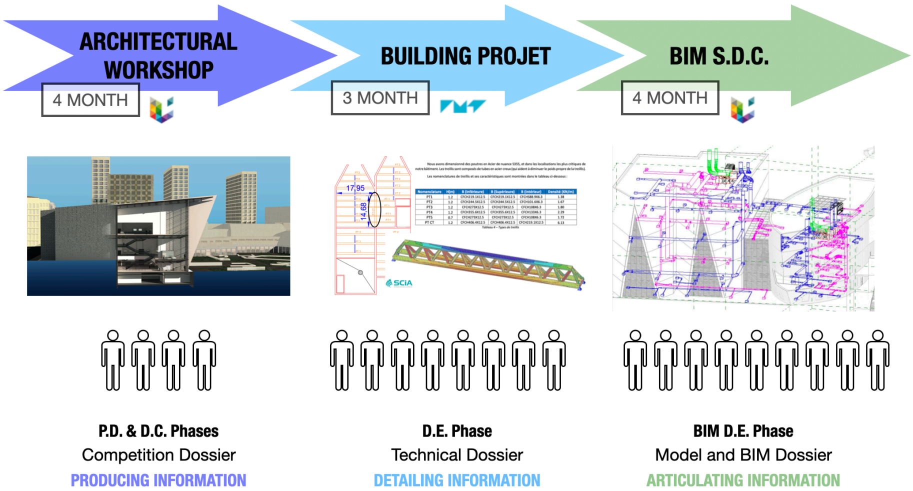

Fig. 2. Articulation of the different workshops, based on [19].

The studied architectural workshop takes place for four months and consists of the collaborative design of a complex 7500m2 multi-purpose museum in an urban site. This workshop is formulated as traditional competition calls in its form, building size, team composition, work calendar, expected deliverables, etc. The particularity of this workshop resides in the realism of the project and the liberty of tool choice for the teams.

We observe five teams of four designers each and we collect the documents transmitted at the end of the Design Concept phase, which is the end of the architectural workshop, for each team. These documents (Fig. 3) are the elements available to the architects and engineers of the Detailing & Engineering and BIM phases to continue the design of the building, notably through the BIM process. These documents, therefore, represent the outputs expected at the end of the Design Concept phase.

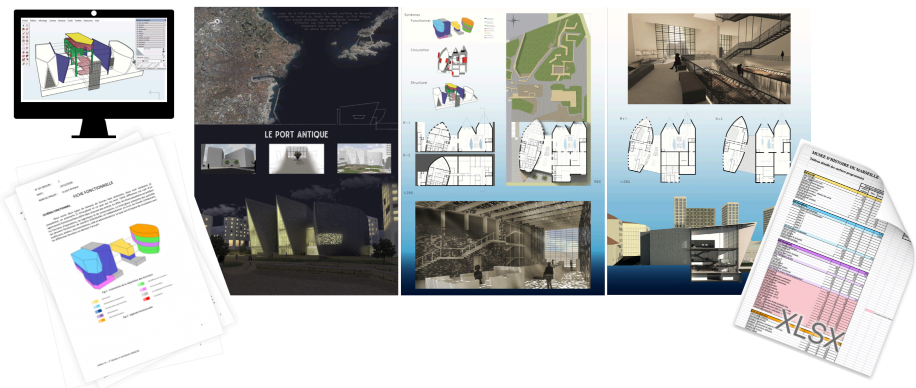

Fig. 3. Example of outputs communicated at the end of the Design Concept phase.

These deliverables are first analyzed according to the BIM requirements for this phase to assess whether the expectations in terms of LOD are met (results in section 5.1). We will then analyze, for each type of expected element, which type of representation in the deliverables shows the pieces of information (results section 5.2). The types of expected information are taken from the specific and precise definition of LODs by the American Institute of Architects and taken up by the Belgian CSTC [15]. At the end of the Design Concept phase, the following elements should be represented with a LOD of 200:

- Spaces
- Vertical levels
- Structure elements (foundation and structural grids, sub-grade enclosure elements, slabs-on-grade, floor and roof construction)
- Ramps and stairs
- Façade (exterior walls, windows, doors/grilles/gates, louvers and vents)
- Roofing
- Overhead exterior enclosures
- Interior elements (interior partition, windows, doors/grilles, railing, louvers, walls/stairs/ceiling finishes, floor finishes)
- Raised floor and suspended ceiling construction
- Vertical and horiz. conveying systems
- Plumbing
- HVAC
- Fire protection
- Electrical equipment & lighting
- Outdoor facilities (vehicle and pedestrian equipment, furnishing, roadways/parking/pedestrian areas)
- Site (site improvements, landscaping, liquid/gas site utilities, electrical site improvement/communication)

The classification of representation used comes from a previously developed classification [20] identifying seven types of information representations:

- Reference image (RI): photo, image or sketch not created by the designers.
- Written text/keywords (T): words that constitute an independent representation.
- Annotation (A): sketches or notes overlaid on a pre-existing representation.
- Blueprint/sketch (S): symbolic simplified production made by hand or computer.
- 2D plan/section (PS): 2D graphic production in form of plan/section
- 2D perspective (P): fixed point of view of a 3D object represented on 2D support.
- 3D immersion (I): immersive physical or numerical three-dimensional model.

In summary, we analyze the architectural worship deliverable of five design teams, each one involving four designers. The observed variables are (1) the actual LOD of the project in each construction batch and (2) the representation's type used to feature every BIM expected element class.

5. Analysis

5.1. BIM requirements

As explained above, we start by analyzing the outputs of the Design Concept phase according to the BIM requirements for this phase to assess whether the expectations in terms of LOD are fulfilled. The BIM requirements are defined as a list of building batches to be designed with a specified LOD for each batch [15, 21]. At the end of the Design Concept phase, information on the following batches is expected [21]:

Table 1. Information on the different batches expected with their level of development.

Batch's information		Expected LOD	Actual LOD of the 5 projects
Model:	Existing build.	LOD 200	N/A
	Existing site	LOD 200	LOD 200
	Projected site	LOD 200	LOD 200
	Architecture	LOD 200	LOD 200
	Stability	Not requested	LOD 100
	Engineering	Not requested	LOD 100
Analysis:	Planning	LOD 100	Not achieved
	Cost estimate	LOD 200	Not achieved
	Thermics	LOD 200	LOD 200
	Lighting	LOD 200	LOD 100
	Acoustics	LOD 200	LOD 200
	Fire safety	LOD 200	LOD 200
	Accessibility	LOD 200	LOD 200
	LCA	LOD 200	LOD 100

In the case of the architectural project studied, the designers almost fulfilled all the expected requirements, except for the level of development, the lighting and life-cycle analyses and the production of a planning and cost estimate (Table 1). They achieved a satisfying level of detail, going far beyond an architectural gesture.

5.2. Information representation

Once the satisfaction of the BIM requirements at the end of the Design Concept phase has been assessed, we investigate how the different building information is represented.

To do so, we analyze the type of representation used to communicate the information to the following actors regarding each type of expected element.

The types of representation of the elements and the documents in which they appeared are shown in Table 2.

Table 2. Representation of the different information of the expected types of elements.

Information elements	**Representation's type**						
	RI	T	A	S	PS	P	I
Spaces		1 2 3 4 5	2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	4
Vertical levels		5	3		1 2 3 4 5		1 4
Structure elements		1 2 3 4 5	3 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 4
Ramps and stairs	1 2 5	1 2 3 5	3 5	1 2 5	1 2 3 4 5	1 2 3 4 5	1 4
Facade	1 2 3 4 5	1 2 3 4 5		1 2 3 4	1 2 3 4 5	1 2 3 4 5	1 4
Roofing		2 3			1 3 4 5		
Overhead exterior enclosure				5	2 5	2	
Interior elements	1 2 5	3 5	1 2 3	3	1 2 3 4 5	1 2 3 4 5	
Raised floor and susp. ceiling					1 2 3 4 5	1 2 3 4 5	
Vert./horiz. conveying systems		1 2 3 4 5	1 2 3 4 5	1 3 4 5	1 2 3 4 5	2	1 4
Plumbing	1	1 2 3 4 5		1 3	3 4 5	1	
HVAC	5	2 3		1	3 4 5		
Fire protections		1 2 3 4 5	1 2 3 4 5		1 2 3 4 5		
Electrical equipment	5	5					
Outdoor facilities		2 3		1	1 3 4 5	1 4	
Site		1 2		1 2 4	1 2 3 4 5	1 2 3 4 5	

Legend RI Reference image; T Written text; A Annotation; S Sketch; PS Plan or section; P 2D perspective; I 3D immersion

Less used → More used (shading); 1 2 3 4 5 Team numbers

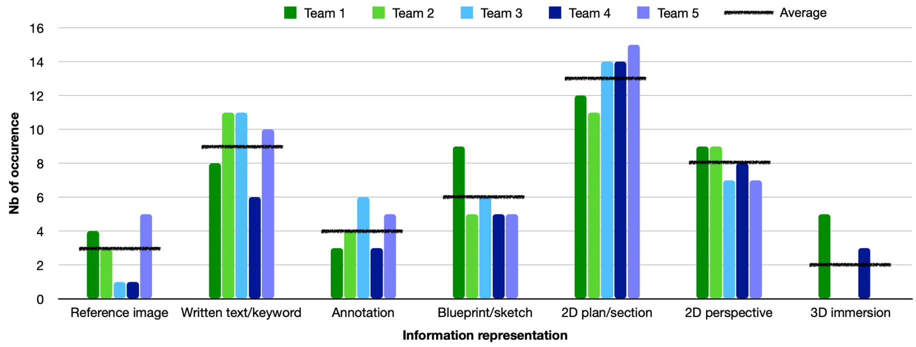

Fig. 4. Proportions of use between each representation types.

We can see that the plans, sections, perspective sections, texts and perspectives (T, PS and P, in the table) contain most of the information required in BIM. They therefore seem to be multipurpose and complete representations. Sketches are then used to describe the spaces, structure and wall compositions, internal partition, conveying systems, systems, fire solutions and site layout. Finally, other types of representation are used for specific elements. Reference images are used for stairs, facades and interior finishes. Annotations are used to highlight interior partitioning, conveying systems and fire safety measures. 3D immersion is used to indicate vertical levels, stability and construction elements and facades.

In addition, a significant amount of information, not expected in the deliverables for the following phases but nevertheless essential to this DC phase and the overall understanding of the project, is transmitted in the documents. Such information is not included in table 2 but is nevertheless transmitted to the actors of the following phases through some specific representations.

The intentions of the architects and engineers are expressed in parallel texts illustrated with extracts from annotated plans, diagrams and images. The same applies to information about user flows and the history of the site. The rationale behind the decision-making process and the history of the project's modifications are conveyed using annotated texts, sketches and perspectives. Finally, the ambiances of the spaces are also characterized via texts illustrated with perspectives. It is important to mention that this additional information, which is not requested, is conveyed in several ways, but not through plans or sections.

6. Discussion

Investigate how the expectations in terms of BIM requirements for the transmitted information are fulfilled at the end of the Design Concept phase, we now know how the building information is represented, and how the BIM model can be useful in the DC phase.

First of all, we can see that the observed DC designers generally fulfilled the BIM requirements. However, some batches are more detailed than requested, and others are less detailed. To determine the influence of the non-fulfillment of the requirements, we refer to the feedback from the architects and engineers of the final phase, the BIM phase, taking place during the BIM SDC project. About two-thirds of the actors, in analyzing their work process, note a dysfunction specifically related to the lack of detail in the information received. Indeed, they state that the documents received are difficult to understand, incomplete (especially due to a lack of cross-sectional information), imprecise and inconsistent. These shortcomings result, for these 12 actors, in delays in starting BIM modeling and made it more time-consuming. They also have to make interpretations and design choices [22].

Looking at the way information is represented and conveyed in the documents, we find that texts, plans and sections remain the most complete and multipurpose representation. They are followed by sketches, which are often used. The other types of representation are only considered for some specific information. BIM modeling, composed of plans, sections and textual information associated with geometric elements, could therefore replace the traditional tools. However, it should be mentioned that this substitution seems to work only for the information expected in the BIM phases. Moreover, the sketches required at this stage of the process and used in our study are no longer provided by this tool. In addition, information other than those explicitly expected by the BIM process is communicated by the designers in the DC phase to the following actors, such as intentions, ambiances, historical background, etc. This information, although not required, are essential to maintain the consistency of the project and is precisely not represented in the plans and sections.

We can therefore conclude that exclusive use of high-tech digital tools is not appropriate but BIM tools are however useful for the Design Concept phase. Indeed, the actors have noted a lack of sections and cross-sectional information, certainly due to the workload involved in drawing multiple sections. However, these sections are automatically generated in a BIM model. The ability to present numerous sections is a first benefit of the BIM model in the Design Concept phase. However, this added value must be moderated, as the modeling of a detailed digital model as a BIM model requires additional initial work. The second observation made by the actors shows that the documents are sometimes inconsistent. From this point of view, as the BIM model is a 3D model from which the various plans and sections are extracted, the risk of inconsistencies between representations is reduced.

Finally, in terms of managing the transition between the traditional initial phases and the following BIM phases, some representations are easily transposable into the BIM model, such as certain textual information, plans, sections, raw perspectives and 3D immersion, while others, such as sketches, graphic annotations, rendering perspectives, reference images and the remaining textual information, will be kept in additional documents to the model.

7. Conclusion

Our contribution improves collaborative design practices knowledge by studying information sharing and external representations function in collaborative BIM design processes

We aimed to understand how projects in the design phase are “Bimable”, and how to use existing building representations to transition to later BIM phases. We, therefore, build an original experimental approach by setting up an experiment in a collaborative design process consisting of the collection and analysis of the project information required by BIM and how these pieces of information are represented.

We can conclude that the information included in the plans and sections is easily transposable in BIM and that the created model will avoid the lack of information in sections, a weak point of traditional tools, and the inconsistencies between representations. Other representations such as raw perspectives, 3D immersion and some textual information are also easily transposable into the model.

However, it is necessary to associate other design tools with the BIM model, allowing the representation of information relating to the ambiances, the intentions and decision-making rationales as well as the history of the project.

The main limitation of our analysis lies in the fact that it is based on a single architectural studio. These projects are representative of BIM context building projects but carrying out the same analysis on other building projects from another design context would strengthen our conclusions.

In terms of perspectives, it would be interesting to analyze how to collect the project's components to transform them into BIM objects. We could therefore feed the following phase based on the information extracted from the concept design phase.

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