Toward an IDP-BIM Framework: the Case of the House of Sustainable Development

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Abstract

Integrated design process (IDP) and Building Information modeling (BIM) have been recognized as two approaches to address the problem of fragmentation in the construction industry. Adopting these processes and tools nonetheless requires drastic changes in design practices. The article presents one part of a research project whose ultimate aim is to develop a new body of knowledge, i.e. an IDP-BIM Framework. This paper focuses on a case study performed in this context, including ethnographical observation of the design process of a high-performance building: the House of Sustainable Development (HSD) in Montreal, and investigates the pertinence of the proposed sustainability strategies. For this second aspect of the case study, after the design was completed by the team of professionals, the design process was "reverse-engineered" using BIM technologies. The paper presents the results of this part of the case study, and aims at defining an optimal digital environment as well as a fluent workflow for integrated modeling.

Looking for a holistic presentation of the project, we first created a BIM (Revit) model of the building. Tests for performance and interoperability were then performed for programming, cost-estimation simulation of the construction process, and passive solar energy thermal and lighting simulations. The results of this case study underscored the following aspects: the usability of this software at the very beginning of the design process; interoperability and data exchange with the main BIM model; and consistency of the simulation results. Some recommendations were made to the designers of the HSD. The IDP-BIM framework was informed by the findings on the workflow.

Keywords

Integrated design, BIM, sustainable construction.

1. INTRODUCTION

The construction industry is at a crossroads. It is under strong pressure to deliver a built environment that is sustainable. Clients are dissatisfied by the industry's poor productivity, low predictability and the inconsistent quality of its end product. Authors suggest that the construction supply chain should leave behind the linear and fragmented design and delivery to adopt integration of practices, processes and data. They suggest various ways to achieve this transformation, namely to adopt Integrated Design Practices (IDP), Integrated Project Delivery (IPD) and/or Building Information Modeling (BIM) technologies.

Such transformation requires generating new knowledge and discarding obsolete paradigms. It also demands breaking down the boundaries between specialized knowledge fields and creating a new relationship between research, education and industry to provide a fertile

ground for collaboration and innovation. Furthermore, this new knowledge has to be mediated and normalized within a new, integrated body of knowledge.

The paper focuses on two elements of an on-going research, i.e. the front-end of project development, namely the project definition; and the interoperability between software packages that are proposed in this framework. The question raised was how the proposed process and technologies could improve the performance of the team in designing a high-performance sustainable building. First, ethnographic methods were used to observe the project definition process of a demonstration project for a sustainable building. Experiments were then conducted using BIM technologies to leverage redefined design processes. The objective of this research is to develop a beta version of an IDP-BIM framework that will be a platform for exchanges between the construction and the IT industry for the development of a new, integrated and adaptive body of knowledge

2. THE NEED FOR AN IDP-BIM FRAMEWORK

The construction industry has been distinguished by its lack of value generation and productivity. These problems are associated with fragmentation and linear design and construction. The early IT solutions proposed were first focused on the integration of design practices through interoperability (Grilo et al., 1996). More recently, the concept of BIM was introduced with the aim to automate the design process and increase productivity (Eastman et al., 2008).

With regard to productivity, BIM has proved to be successful for improving design development and construction processes. Value generation, however, has not yet been properly addressed. Value is about meeting stakeholders' needs and expectations, i.e. delivering all that is required and only what is required. The value generation process occurs at the front-end, during which most of the decisions that will determine the end result of the design process are taken. The integration of design processes and data could be a solution for improving value generation. This would require rethinking and redesigning existing design practices, creating a new body of knowledge describing a new integrated design and BIM process. However, there has been little research aimed at improving the project definition process. Moreover, design practices are based on procedural approaches defined by existing codes of practices. Professional associations do not have the ability or the will to redefine these codes. We posit that, in order to cope with the speed and scope of changes in existing practices of the construction industry, it is essential to redefine and integrate their specialized bodies of knowledge. Moreover, mechanisms have to be designed to ensure that this integrated body of knowledge evolves in a coherent manner. The paper presents an experiment to develop such mechanisms, using an approach inspired from reverse engineering to understand, analyze and transform design practices. This experiment is part of a larger project, undertaken in collaboration with local professional associations to develop a first version of an IDP-BIM framework.

3. RESEARCH APPROACH & STUDIED CASE

Developing a knowledge framework that redefines design practices is not common in the realm of applied research, as it is not aimed at developing this type of knowledge. With the necessity to cope with accelerating changes and the need for new related knowledge, innovative theory and research methods have emerged in other disciplines, such as Constructive re-

search and Development Work Research. In the former, it is proposed to generate new knowledge about practices by challenging the existing ones using relevant theories to drive changes. The validation of this new knowledge is made via the industry's recognition of its value. In the latter method, new knowledge is viewed as a social process that takes place within a specific activity, for example the design of a building. It is generated through the resolution of contradictions within a new work context, one that is unfamiliar to the different specialists involved in the activity.

Our research mixes both methodologies. The studied case is the reverse engineering of a design process, using BIM technologies. A core aspect for the successful use of BIM is interoperability. Presently, technology is barely used in the front-end of the planning and design process. It is perceived as a barrier to creativity and as having little value (Leiserin 2010). New BIM technologies aimed at improving or leveraging planning and design at the front-end are emerging. It is our assumption that to be effective, they need to be well integrated into the whole of the design process. The studied case is the House of Sustainable Development (HSD) in Montreal, which was conceived as a highly ecological building. Situated in the downtown city sector, this building aspires for a LEED-Platinum certification and aims to serve as an educative example of sustainability in construction for the public. The building is presently under construction (begun 5 months ago). The HSD is a 5-floor office building, including a restaurant on the street level and a daycare.

An ethnographic study conducted through interviews with one of the architects and with the mechanical engineer of the project, showed that the main principles for sustainable construction were taken into consideration during the design process. According to the design team, the orientation and form of the building were virtually imposed by urban regulations. Thus, creating a high-performance envelope was of primary importance for the building's low energy objective. Triple windows with argon provide a very high level of thermal isolation. A green roof was also designed. As for the energy source , biomass, solar and wind energy were studied at the beginning of the design, but finally a geothermal system was chosen to supply 100% of the energy for the HSD. Other 'green' elements were introduced into the design: a vegetal wall, ventilation by moving air, cement-replacement additives in the concrete, etc.

An integrated design process was used during the conceptual phase. Design workshops were conducted in a collaborative laboratory. A Gating approach was successfully introduced to resolve alignment problems between client expectations and design professional's proposed solutions (Forgues 2009). This approach also solved issues regarding the application of the integrated design process and its integration with the SBTools sustainability rating system. The framework proposed in this paper is an evolution of this Gating process.

4. INTEROPERABILIYT AND PROPOSED FRAMEWORK

As asserted by Winch (2002), the management of value generation in construction projects is about information processing. The aim is to meet clients' needs and requirements. It is therefore essential to provide a means to ensure that interim deliverables in the design process are aligned with these needs and requirements. According to a large research study (Standish Group 1994) about 60% of the causes of project failures are related to the requirements.

Approaches such as configuration management and agile product or software development methods have been devised in system and software engineering to design and build complex, software-intensive products such as warplanes. Our proposed framework is derived from a combination of these methods. The framework is divided into a series of three iterations for which BIM tools are planned to be used for design, optimization or verification. Commercial

off-the-shelf BIM technologies have been identified to integrate leverage planning and design processes during iteration. They accomplish three functions: design, simulation and configuration management (Table 1).

ITERATION	TOOL	OBJECT	USE	PURPOSE
0	Affinity; D-Profiler; Ecotect	Definition of needs, requirements and space configuration; target setting	Defining verification criteria for the Gating process	Alignment of building requirements with business needs
1-2-3	Revit	Generic building information model	Design	Building data for simulation & verification tools
	HelioDon; Ecotect; Athena-EIE	Strategies for passive, active & embodied energy	Design optimization	Minimizing consumption of energy & resources
	Affinity; Exactal		Design verification & validation	Configuration management & cost tracking
3	Navisworks	Coordination between models, 4D	Verification of design feasibility & integrity	Constructability

Table 1: Use of BIM tools during the 3 iterations of the design process

BIM software tools facilitate interactions between designers and clients in the design process. Different aspects of the project are studied, modeled, communicated and discussed. Some software tools (available and somewhat adopted by avant-garde practices) are proposed to be used in the ID workflow to tackle various aspects of building design:

- Configuration management is an approach devised in system engineering and then applied in software engineering to manage requirements in complex projects. While there is no such practice and related software, Affinity (by Trelligence) offered characteristics that, combined with a gating process, can allow for a relatively effective management of the configuration.

- A cost target is a common practice in leading-edge industries. A project cost target is established at the outset. The team has to achieve the best design for this target. DProfiler facilitates the identification of the cost target and provides the ability to assess the real time cost and cash-flow impacts of various building volumes and geometries. However, a more appropriate tool is required to assess the evolution of costs when the design is refined. Exactal provides parametric functions to assess design changes in a 3D model, identifying the changes and their related cost impact(s).

- Revit (Architecture and Structure) integrated modeling was selected as the main BIM design tool because of its market share in the North American market.

- Regarding design optimization, three software products were selected to support the team in devising strategies and optimizing for passive, active and embodied energy: eQuest, Ecotect Analysis and Heliodon.

- One of the key problems with any construction is the lack of predictability in terms of cost and schedule. Problems are related to poor requirement management, poor coordination among design professionals and the lack of involvement of the builder during the design

process. NavisWorks offers characteristics for testing the integrity and constructability of the model.

The proposed IDP-framework was first introduced in an experiment involving students from different disciplines (Forgues and Iordanova, 2010). The process dimension of the framework (time-boxing the design process within three two-day iterations) proved to be quite successful. Digital and BIM environments, however, seemed to hinder productivity and creativity. There were multiple issues related to ergonomics and the interoperability of software. This case study focuses on some problems of interoperability encountered during the first implementation of the IDP-BIM Framework.

5. ASSESSING ERGONOMICS AND INTEROPERABILITY THROUGH REVERSE ENGINEERING

Paper is still the most important mediating artifact for communication and exchanges within a design team workshop in the construction industry. It is expected that replacing paper by collaborative and BIM tools could improve the productivity of the project team by reducing the time required for descriptive or explanatory tasks (Liston et al. 2001) and streamlining the management of project information. In order to adopt BIM technologies for collaborative work, members of the project team have to recognize the added value of these new mediating artifacts. Their utilization has to be intuitive and should not interfere with the conversation that is established within the design process. The exchange of information between BIM tools is expected to be robust and manageable. Therefore, a mapping of interoperability was devised for the HSD (Fig. 1).

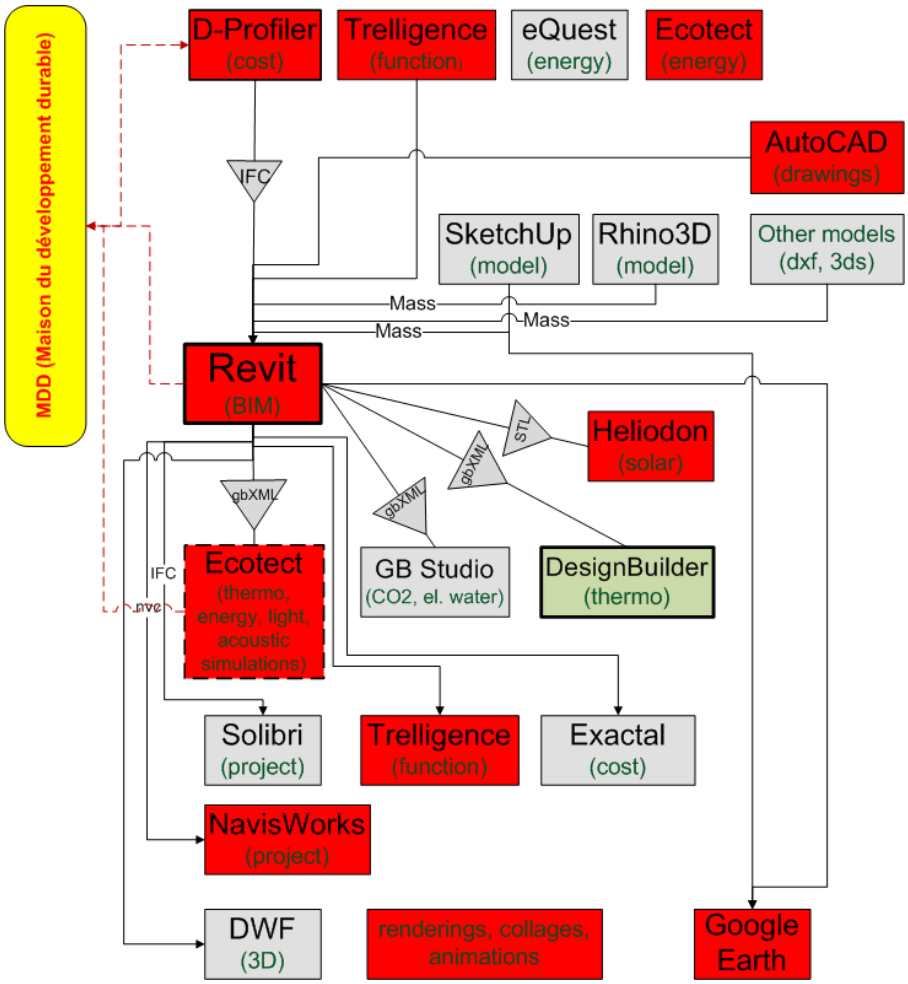

Figure 1: Interoperability scheme (non-exhaustive) for a BIM modeling workflow (the software tools tested during the reverse-engineering case study are in red)

5.1 Reverse-engineering study of the workflow

A reverse-engineering case study was carried out with the objective to test the possible workflow for a BIM model and to compare design outcomes, if relevant.

As a preliminary stage (corresponding to the 0- iteration of the ID-framework), several schematic models were created to serve as references for the design.

1. The building was modeled in 3D using D-Profiler to test its ability for parametric costing. (Cost tracking using Exactal was abandoned because of the requirement to build a cost database.)
2. The building's orientation and form were studied for optimization on a schematic level within Ecotect's Weather Tool. A link to eQuest from the DProfiler model was attempted but proved unsuccessful.
3. The program prepared by the architect on an Excel spreadsheet was loaded into Trelligence Affinity software to assess its characteristics for facilitating space configuration and for checking the conformity of design with the program.

Ideally, within a flawless workflow, the already-mentioned schematic models should have been imported into Revit and further developed through the design iterations proposed by the IDP-framework. As this was only partially possible (see further in the paper), a main BIM

model of the building was created in Revit Architecture, based on the 2D drawings provided by the design team. A Revit-Structure model was already available from the design team.

Interoperability with simulation software was tested, taking the Revit model as a basis. A non-detailed Revit model was exported to gbXML and then to STL in order to be imported, respectively, to Ecotect Analysis and Heliodon. However, due to the heavy imported geometry,, it was easier to perform simulations on a simplified model recreated in the respective simulation software.

A relatively fluid 2-way interoperability was established with Affinity space programming software. This can only be done on a rather schematic stage, however.

Construction simulation and clash detection software NavisWorks is well integrated with Revit (Architecture and Structure) and allows for the detailed export of complex buildings. However, Some issues remain to be resolved with this process

Rendering, 3D publishing or export for animations and other representations, as well as Google-Earth referencing can be relatively well managed from a Revit-Architecture model.

5.2 Issues with interoperability:

A considerable number of interoperability issues were found during the reverse-engineering experience with the HSD. Some are due to the immaturity of the software tools that were tested; others show limitations (today) in working with real complex building models. In the order of the tests, here are some of the inconsistencies or interoperability issues that we found:

5.2.1 Database limitations:

DProfiler does not have a link to the metric RSMeans database (even if the building can be modeled in metric units). Exactal requires a project cost data base to be built.

An energy analysis was attempted directly from DProfiler through its link with eQuest. This proved to be impossible, due to the impossibility of using a Canadian postal code. Even with a zip code from a neighboring USA town, the energy analysis could not be performed (due to an undefined error).

5.2.2 File-transfer limitations and conflicts

Even if defined as a norm, the IFC (Industrial Foundation Classes) file format is not implemented in the same way by the different software tools. This leads to the issue of incomplete/inaccurate « translations » of a model, even between software using the same exchange format (IFC).

During transfer from DProfiler (via IFC) to Revit-Architecture, inconsistencies were found in the imported model – the parts seem to have different transformation matrices. In addition, at this time D-Profiler can import only 2D files, which is a limitation on 2-way interoperability.

The 2-way interoperability of Trelligence ->Revit Architecture ->Trelligence proved to be good for schematic models. However, some basic elements such as ‘Lavel’ (in Revit) are not automatically well-mapped when translated from ‘Story’ (in Affinity).

The link from Revit to Naviswork is robust even for very big models. There are two issues worth noting: (1) the different layers (materials) of a wall cannot be separated to show the actual construction process (a wall is usually not built at once, but has different construction work on it: i.e. brick, insulation, finishing, etc.); and (2) The object structure imported into Navisworks is only structured by “levels” corresponding to the Revit model, but the lower hierarchy is too detailed and difficult to manage. In reality, new objects have to be created in Navisworks by filtering and grouping the imported very-subdivided objects.

5.2.3 Export to simulation software

The export of real models (even schematic) to Ecotect Analysis (via gbXML) is difficult and often inconsistent. The building had to be re-modeled in order to perform simulations on it.

The Revit file (even schematic), once exported through STL to Heliodon is too heavy for any simulations to be performed. Once again, remodeling was needed.

5.3 Findings during the reverse-engineering process

The BIM modeling in Revit and the combination of the Architecture and Structure files into Naviswork allowed for inconsistencies in the 2D drawings to be detected. Animation of the construction process was also performed.

The energy simulations (solar exposure and solar heat gains) in Heliodon and Ecotect showed proportional results, but were not similar in values. This means that their calculation models are different and that the results could be used for comparison but not for the dimensioning of installations, for example.

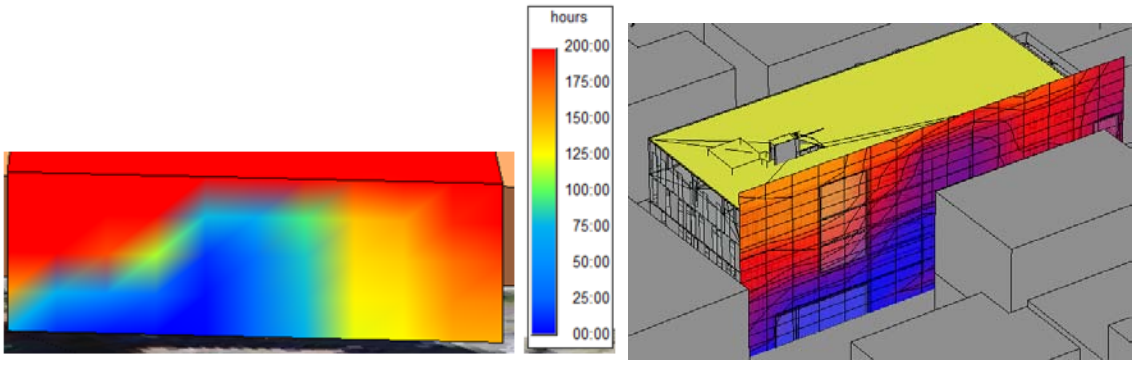

Figure 2: simulation of the hours of sunshine on the southern façade of the HSD: (left) with Heliodon, (right) with Ecotect.

Recommendations were made to the design team concerning placement and type of solar panels and shading devices based on the models in Figure 2.

6. DISCUSSION & CONCLUSION

The BIM technologies that were selected offer many promising features for leveraging value generation at the front-end of the design process. Many issues remain to be resolved, however, in order to reap the benefits that these technologies have to improve value generation, the most important being interoperability.

One of the expected values of BIM at the front end is to decrease the time wasted for tasks related to descriptions, explanations, research of information and optimization, by accelerating and streamlining information processing. This can be achieved only through seamless interoperability between applications. BIM technologies proved to suffer major problems of interoperability that hinder the design process, whereas the proposed IDP framework was quite successful in accelerating the quality and speed of this process.

It is worth mentioning that the technologies selected were not designed to be used in such a framework. The challenge for developers is to develop software for planning and design processes that do not yet exist. Software development companies are aware of this and put considerable effort into assuring interoperability between their own products. But the issue remains much more problematic when an ‘outsider’ enters into the workflow.

The BIM field is rather new and quickly evolving, and so knowledge bases have not yet been established in the industry. Creating a 'repository' of good practices and a guide for the BIM-design workflow would very likely be welcomed by AEC professionals.

This paper highlights the problems regarding the interoperability of BIM technologies at the front-end. It also proposes research approaches and suggests a common framework to facilitate interactions among researchers, practitioners and software developers. The research is nonetheless at its early stage. Larger-scale interactions with developers of these technologies and practitioners will be required in future research. Variables will also have to be identified and measured in order to evolve and improve the framework.

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