Limitations of Using Digital BIM Models to Carry out Thermal Analysis

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Abstract— **To meet ever more demanding thermal regulations, Building Information Modeling (BIM) and its geometrically semantically enriched building models are presented as a powerful means. In this article, we focus more specifically on the thermal performance of the envelope of existing buildings. Based on the modelling of an existing case, we discuss the potential of extraction and use of the information contained in the digital models to carry out two types of studies: a regulatory certification in the Energy Performance of Buildings (EPB) software and a simulation of energy needs in the Green Building Studio (GBS) software. Through them, we present a panel of the possibilities and the limits of using digital models for this type of study by considering, on the one hand, the quality of the models and on the other hand, the hypotheses governing the methods of the analysis tools.**

Keywords-digital Building Information Modeling (BIM); energy analysis; building data modeling and understanding; reverse engineering.

I. INTRODUCTION

This article is part of a context where digital technology takes a prominent place in the architect's profession. Project design is evolving towards a computerized design thanks to technological advances including BIM tools.

The sector is today subject to ever more numerous requirements in terms of costs, performance and construction techniques. The sophistication of equipment (security, air treatment, home automation, etc.) and the addition of legislative and regulatory constraints increasingly complicate projects and involve dealing with an increasing amount of data [1][2].

Furthermore, another major transformation is underway: the energy transition that results from an international awareness of environmental problems [3]. The building sector has a major role to play in the latter since it is responsible at a European level for 50 % of primary energy consumption and 30 % of greenhouse gas emissions [4]. However, the focus on the energy performance of new buildings is not sufficient and the objectives will not be achieved without an energy improvement of the existing building stock. Thus, energy renovation is one of the main levers for energy saving [5]. In this context, it is essential to have tools that enable to evaluate the environmental impact of a building and to analyze the improvement measures of its energy efficiency in an accelerated manner. It is on the basis of these considerations that states are increasingly encouraging the use of BIM to support the energy transition of buildings.

Regarding the scientific literature, this acronym can refer to several distinct notions. In this article, we focus on BIM as « Building Information Model », i.e., *« ... a digital representation of physical and functional characteristics of a facility, which serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle. »* [6].

The purpose of this article is to identify the possibilities and limits of using digital models to evaluate the thermal performance of an existing building shell. In that respect, we will first study the exploitation potential of the data contained in the BIM models for a regulatory encoding in the EPB software, and we will then analyze these models to perform dynamic thermal simulations in GBS software. These tools are chosen among those available on the market and we have a certain maturity in their use.

This article is structured in four parts. Section II presents a state of the art of the current use of digital models in the building sector. Section III details the methodology established to answer the exploitation issue of these models. Section IV is dedicated to the presentation of results of the implementations that will serve as a support for the discussions developed in Section V.

II. STATE OF THE ART

A. BIM applications

A global survey conducted by the American company McGraw Hill Construction in 2014 revealed that among the 25 applications of BIM, the 3D coordination between construction disciplines and the visualization of design models are the most common cases of uses in the pre-construction phase [7].

The use of BIM is relatively limited for analysis and simulations.

In the energy sector, which is the case of this article, the frequency of use of BIM and digital model barely reaches 25% [8]. However, this study highlights a paradox between the frequency of implementation and the perceived benefit of certain BIM uses, like shown in Figure 1. Indeed, the majority of these are perceived as positive by the respondents, whereas they are not frequently implemented. The main reasons given for their low application rate are the interoperability problems that result from using different file formats, as well as the resistance of the construction industry towards innovation [9].

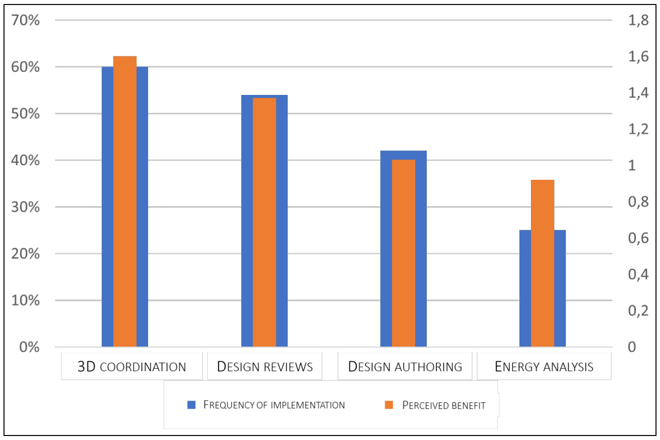

Figure 1. Relation between the frequency and the perceived benefit for implementing each BIM use, adapted from [8].

B. Interviews

In parallel with reviewing scientific literature concerning BIM practice in the construction industry, we realized semi-structured interviews at ASSAR Workshop Architects, a BIM precursor architecture office in Belgium. The purposes of these interviews are, on the one hand, to understand how this office implements BIM for renovation projects and, on the other hand, to have an overview of the workflows characterizing projects requiring thermal or energy studies.

These interviews revealed that the digital model is very little exploited for thermal and energy studies while ASSAR is between the most advanced Belgian offices in the implementation of BIM. The interview's answers also indicate that workflows are still very fragmented between architects and energy consultants. In order to evaluate the building's performance, a considerable time is spent on recapturing the project data or adapting the digital model transmitted by the architects.

III. METHODOLOGY

The issues, arising from the review of scientific literature and interviews, guide the work towards studying and modelling a concrete case, in order to evaluate potentialities and limits of using a numerical model to realize thermal analyzes. Figure 2 illustrates the research methodology adopted in this work. First, starting from a modelling protocol and using Revit and Sketchup software tools to produce different models of the case study: "Monolayer Model", "EPB Model" and "Multilayer Model".

Then, quantitative tables were exported from each of these models. The EPB software needed manual encoding to generate its report. Sorting the data collected from the quantitative tables was also necessary to be able to compare the data in Excel software. Exports in Green Building XML (gbXML) were also accomplished and compared to verify the integrity of the data transfer.

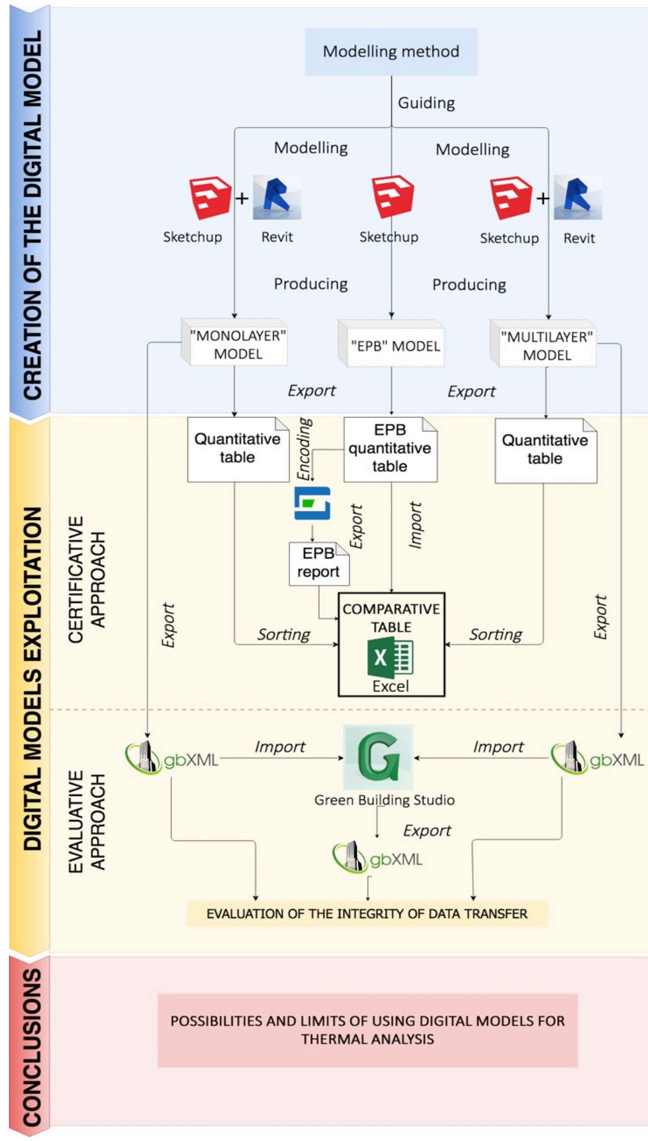

Figure 2. Overall methodological scheme.

A. Case study

Our case study is an existing residential building with two parts built respectively in 1900 and 2007 and characterized by:

- a poor thermal performance ;
- a degree of complexity related to the form and constructive hypotheses that involve establishing certain assumptions and simplifications to carry out the modelling;
- a subdivision into five apartments corresponding to six separate thermal zones, identified in Figure 3.

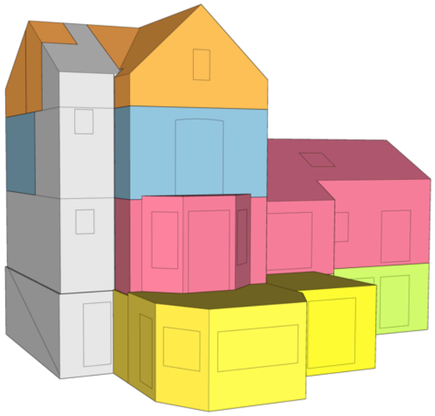

Figure 3. 3D representation of the energetical sectors composing the building.

B. Method

Modeling : The first step of our process is dedicated to building modelling. Autodesk Revit is the chosen modelling tool because it is an object-oriented software, widely used in BIM processes. In addition, it integrates energy analysis and simulation tools useful for our study. Two building models are created based on the available documentation of the existing building by using two different modelling techniques. Figure 4a shows the first technique is the "monolayer" model, which consists of isolating the load-bearing, inner and outer layers of the walls, as distinct elements. Figure 4b illustrates the second technique is the "multilayer" modelling technique, using composite walls, containing several layers of materials.

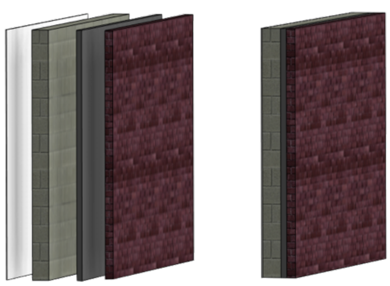

Figure 4. (a) Monolayer modelling. (b) Multilayer modelling.

1) Exploitation of digital models : The created models are then analyzed and exploited according to two distinct approaches.

a) First approach : certificative approach.

The first approach seeks to evaluate the potential of a digital model in a regulatory thermal study in the EPB software. To evaluate this potential, we extract useful data from Revit models. Figure 5 shows that raw data is then sorted and compared with the values calculated and entered previously and manually in the EPB software.

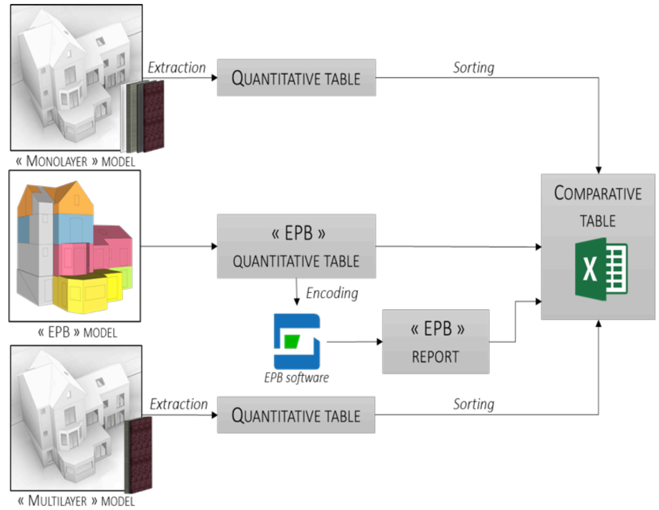

Figure 5. Generation of a comparative table based on the extraction of Revit quantitative tables from "Monolayer" and "Multilayer" models and EPB report.

The studied parameters are :

- heat loss wall surfaces separating the different energy sectors ;
- heat transfer coefficients U and thermal resistances R of the walls, roofs, floors and openings ;
- the heated or conditioned floor surfaces of each energy sector ;
- the volumes of each energy sector.

Most of parameters are extracted from physical models, but analytical energy models are also used to obtain the heat loss surfaces and the volumes of energy sectors (see Table I).

TABLE I. DATA EXTRACTED FROM PHYSICAL AND ANALYTICAL MODELS.

	Heat loss surfaces	U and R coefficients	Heated floor surfaces	Volumes of energy sectors
Physical models	V	V	V	-
Analytical models	V	-	-	V

Figure 6 illustrates the analytical model obtained directly from the physical model and composed of simple surfaces with no thickness. It is interpreted by the and relying on the detailed composition of the construction elements.

The processed data from Revit models are then compared with the data previously encoded in the EPB software, by calculating a variation percentage for each element.

To evaluate how much this variation is detrimental to the EPB study, it is indeed necessary to set thresholds of variation.

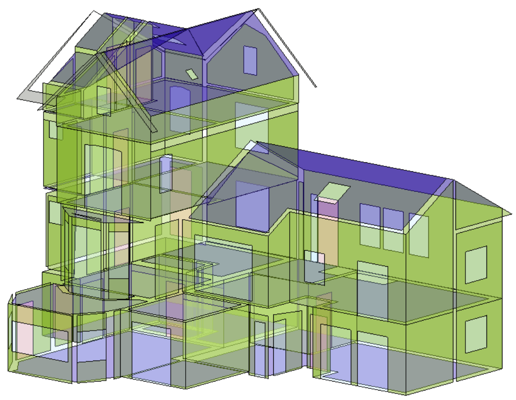

Figure 6. Analytical model.

These are defined in relation to the values of two EPB indicators: Figure 7 shows the specific primary energy consumption and Figure 8 illustrates the net heating energy requirements, which are represented using two scales of values. These values will be used for the analysis of the results.

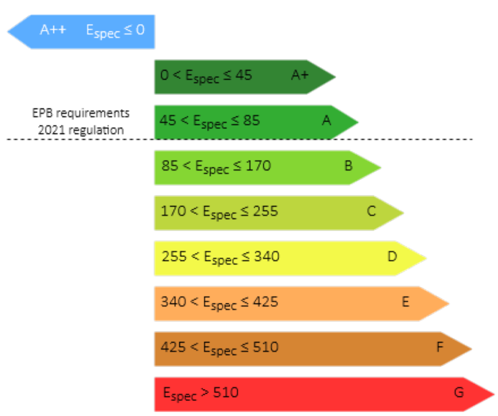

Figure 7. Specific consumption of primary energy.

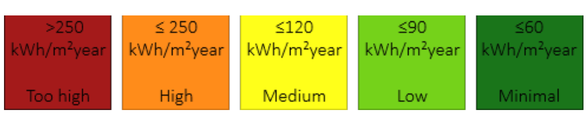

Figure 8. Net heating energy requirements.

To determine the thresholds of variation, we make it possible to fluctuate iteratively and independently the values of the parameters encoded in the initial EPB file. The threshold is then set to the percentage change for which the results indicate that the limit of energy class or performance category of the EPB unit is reached.

b) Second approach : evaluative approach.

The second approach aims to estimate the exploitation potential of the models for an energy simulation. It is performed by GBS software, an Autodesk product, which minimizes the risk of interoperability problems. Figure 9 illustrates the approach that consists of evaluating the integrity of the data transfer upstream and downstream of the simulation, by comparing the exported gbXML Revit files and issued from GBS simulation to the original Revit models.

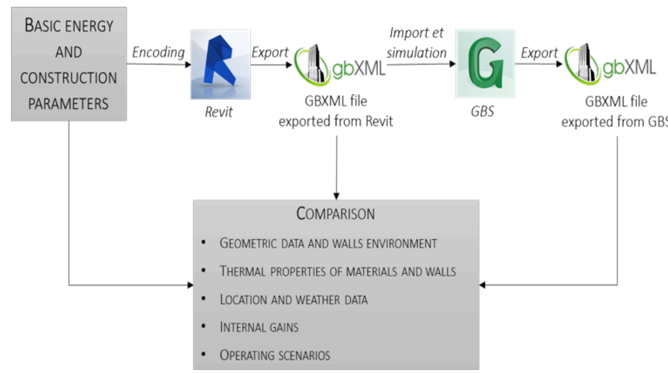

Figure 9. Comparison of the gbXML files and Revit models.

The analyzed data are :

- the surfaces of the walls and their environment (exterior, floor, interior) ;
- the thermal properties of the materials;
- geolocation and meteorological data from the project used to determine heating and cooling design temperatures ;
- internal inputs, which are determined by the energy provided by occupants, equipment and lighting ;
- occupancy and operating scenarios, which include building occupancy times and defining the set point for heating or cooling ; they also include lighting and equipment usage schedules during which heat gains occur.

IV. RESULTS

A. Regulatory study in the EPB software

The results obtained for the first implementation are synthetized in Table II.

TABLE II. SUMMARY OF THE RESULTS FOR THE FIRST APPROACH.

Parameter		**Physical models**	**Analytical models**
Heat loss surfaces	Walls	X and -	X
	Floors	V	X
	Roofs	V and -	X
	Openings	V	V
Protected volumes		/	X
Heat floor surfaces		V	/
U and R coefficients		X	/

- = Some values are not defined
/ = Values that cannot be extracted from physical or analytical models
V = Most values are in the variation boundaries
X = Most values are beyond the variation boundaries

The results obtained for the geometric parameters (surfaces and volumes) indicate that the wall loss surfaces extracted from Revit physical models are far from the values calculated for the EPB encoding. Some of them could not even be determined. This difference is explained by the fact that the physical models correspond to the constructive reality of the project. This means that Revit calculates the wall surfaces as they are or will be constructed based on a physical model of the building. However, the regulatory EPB defines the wall surfaces in relation to a conceptual model which simplifies this reality. On the contrary, the floor surfaces coincide because there have not been determined from the floor instances but from surfaces cropped manually in specific plans.

Table II also indicates that most of the geometric data extracted from the analytical models are beyond the thresholds of variation. This difference is explained by the fact that these surfaces are based on an approximative interpretation of the building elements by the calculation algorithm and are not defined the way the EPB method advocates.

In addition, Revit calculates the thermal properties of the walls in a simplified way: it does not take into account the surface exchange heat resistances to determine the U coefficient and it does not distinguish the walls according to their environment whereas these parameters are essential in a regulatory energy calculation.

B. *Thermal simulation in Green Building Studio*

The results obtained for the second implementation are synthetized in Table III. The results indicate that inconsistencies occurred during data transfer. These have not all been preserved or interpreted during the simulation.

Additional surfaces were superimposed on the openings (doors and windows) and were assigned the same constructive type as the host wall. This results in erroneous geometric data for both gbXML files.

TABLE III. SUMMARY OF THE RESULTS FOR THE SECOND APPROACH.

Parameter	gbXML file exported from Revit	gbXML file exported from GBS
Geometric data	X	X
Walls environment	X	X
Materials and walls thermal properties	V	X
Location	V	V
Weather data	-	X
Internal gains	V	X
Operating scenarios	V	X

- = Non-exported data
V = Successfully exported data
X = Non successfully exported data

Furthermore, the belowground surfaces are defined in Revit based on a horizontal reference plan. The elements under this plane are thus considered buried. However, the land on which the building is located is inclined.

On the contrary, all the thermal properties were exported correctly from Revit to gbXML format. Moreover, the gbXML file analysis of the monolayer model shows that the different layers have been assembled logically. The U values calculated for each layer of material are consistent between the files. However, the thermal transmittance coefficients U of the gbXML file exported from Revit do not take into account the surface exchange heat resistances since this property is not available initially in Revit. After the simulation, the gbXML code analysis of the single layer and multilayer models indicates that all types of doors have been substituted. Green Building Studio has also assigned default thermal properties to additional surfaces that have been created at openings and stairwells when exporting in gbXML.

Location data were successfully retrieved during the gbXML export.

The gbXML file exported from Revit does not contain meteorological data. These ones are normally set automatically by GBS after defining the project location. After the simulation, the analysis of the meteorological data indicates that the heating and cooling design temperatures of the file resulting from the simulation are slightly different from those calculated by Revit. One of the explanations that can justify this difference is the choice of the weather station used to calculate the temperatures for each of the two softwares.

The analysis of the gbXML code exported from Revit indicates that the data on the internal loads are consistent with those encoded in Revit. However, a surface contribution generated by the interior equipment was automatically added during the simulation in Green Building Studio.

The analysis of the gbXML code exported from Revit indicates that operating and occupancy schedules defined in Revit have been exported correctly.

Green Building Studio has, for its part, taken into account four additional scenarios for the simulation: a cooling scenario, a heating scenario, a scenario of domestic hot water use and a ventilation scenario. The equipment operating schedule was replaced by two scenarios: one for the equipment that had previously been defined in Revit, the other one for additional equipment considered by Green Building Studio.

V. LIMITS AND OUTLOOKS OF DIGITAL MODELS FOR THERMAL STUDIES

Our first implementation shows that most quantities extracted from the Revit models cannot be used as they are, but must be sorted in order to compare their values with those of the EPB encoding. The determination of the heat loss surfaces especially requires the use of time-consuming processing methods and involves juggling constantly between the digital models and the extracted tables of quantities to select only the useful elements for EPB calculation.

In the walls quantitative tables for example, it is necessary to keep only those that separate distinct energy sectors. This implies having to remove a large part of the elements contained in the extracted quantities (see Table IV).

TABLE IV. COMPARISON OF THE NUMBERS OF EXCEL LINES FOR THE HEAT LOSS WALLS SURFACES IN THE MONOLAYER AND MULTILAYER MODELS.

Models	Gross statement	Intermediate statement	Final statement
Monolayer	306 lines	84 lines (27%)	42 lines (14%)
Multilayer	284 lines	84 lines (29%)	42 lines (15%)

The data sorting of the single-layer model especially requires the most investment because of the large number of object instances generated. Furthermore, some areas could not be determined on the basis of the constructive model, such as roof areas. Therefore, the wall surfaces of the Revit models obtained on the basis of a material survey are difficult to use for an EPB encoding since they cannot be calculated on the basis of a detailed physical model.

Although analytical energy models have some potential and provide much simpler geometry, their walls areas cannot be encoded in the EPB software. Indeed, the latter are based on an approximative interpretation of the construction elements by the calculation algorithm and are not defined the way the EPB method advocates.

In addition, the first approach highlights the constraints faced by energy consulting firms when working with architects that use digital models. Their work relies on the use of regulatory calculation engines based on historical methods that require manual data inputs. On the one hand, they do not make it possible to directly import the information of a digital model, which prevents the consulting firms from working on the basis of integrated flows. On the other hand, these calculation engines are based on simplifying assumptions whose objective is to facilitate manual encoding. This results in models that are generally far removed from the physical reality of the building.

The second approach highlights a series of inconsistencies upstream and downstream of the simulation in Green Building Studio. Therefore, while it appears to be an interesting tool to perform and analyze various alternatives at the beginning of design, this software is however not very suitable for obtaining an accurate diagnosis of the energy performance of an existing building. There is no doubt that the use of such tools requires analysis, technical know-how and the ability to interpret the results. However, architects and engineering offices need consistent information to guide the design and facilitate the optimization process. Any simulation tool should therefore inform the architect more precisely of the assumptions underlying the results.

VI. CONCLUSION

A. *Contributions to research*

Our study explores two distinct building modelling methods in order to perform two types of energy studies: a regulatory study and an energy simulation. It allows to define a non exhaustive list of possibilities and limits of using such models, related on the one hand, to the modelling tools (Revit) and to the characteristics of the models themselves (mono and multilayer) and of the other hand to energy analysis tools (EPB and GBS). Finally, exploitation of Green Building Studio allows us to point out the limits of a simulation software and the erroneous conclusions that a user could draw from it.

B. *Limits of the research*

This work is based on a deep analysis of the digital model and its possibilities and limits for conducting energy studies. The case study was modeled to meet specific energy needs and does not integrate all needed information for all other disciplines in a project. The collaborative aspect of BIM has not been investigated. Nevertheless, this aspect remains one of the intrinsic characteristics of BIM. Exploring BIM as a method of collaboration is not relevant in this work.

A similar finding can be made for the first implementation. Indeed, the exploitation potential of the digital model is not evaluated on the basis of its direct import but on the possibility of using the data that it contains and to be able to encode them manually in the EPB regulatory software, which does not allow currently importing a digital model. However, the objective of BIM is to avoid re-entrying information between the different pieces of software used.

Finally, the method for setting the variation thresholds developed in the first validation process could still be improved. In addition, the setting of these thresholds remains subjective because it is specific to the studied project type and to the initial values of the indicators.

C. *Future work*

One of the avenues for reflection concerns the computer development of regulatory tools. Indeed, these tools are currently designed to be used at the end of the design as a guarantee of final certification and rely on manual data entry. However, any new or renovation project must comply with the regulations and must therefore be analyzed at its earliest stage, in order to evaluate various possible solutions. It would therefore be interesting to develop interoperability between the BIM digital model and certification softwares such as EPB from exchange formats such as Industry Foundation Classes (IFC) or the gbXML. In addition, the work focused on using Revit software as a modelling tool and Green Building Studio as an energy analysis software. Future work could focus on using other modelling softwares.

Acknowledgment

We would like to give our special thanks to ASSAR l'Atelier Architects, for the time they gave us during the interviews and for enlightening us on the practice of BIM in business.

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