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BIM Implementation in SMEs: an Experience of Cooperation between an Architect Agency and a Carpentry Firm.

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Abstract:

Most of French architectural agencies are formed by less than 3 people. Architects are generally attached to both traditional knowledge and architectural processes. Thus, BIM is sometimes perceived in France as a disruptive technology that could negatively impact the architect's work. Usually, construction projects featured as BIM projects are often too large and out of touch of small architectural agencies. This situation does not allow them to assess BIM advantages for their daily work. This context and the current strained economic situation of the AEC sector make difficult the integration of new BIM practices in small architectural agencies.

The experience we made is a first step for the definition of a progressive appropriation method of BIM practices leading to a better comprehension of the contribution of these technologies in French architectural agencies.

We experienced a digital mock-up (DMU) exchange between a small architectural agency and a carpentry firm with an engineering consulting department. The architects from the agency have recently begun working with a BIM software program: ArchiCAD. They are very skilled users of Autocad and 2D drawing but have a good understanding of BIM modelling potentialities. According to the model of Succar, they are still in the transition between Pre-BIM and the first stage of BIM level maturity. The particularity here is the alignment between architects choices and engineers decisions who want to solve together errors generated by the traditional process. This context is favourable for implementing and experiencing BIM stage 2.

In this paper we present the context of the experience, the used methodology, the BIM implementation and finally the different encountered exchange problems and the brought solutions.

Keywords: BIM, construction, IFC sharing, carpentry, architecture, experiment, SME, digital mock-up, DMU, ArchiCAD, cadwork.

1. INTRODUCTION

Despite of all the examples of projects which show the advantages of a digital Mock-up (DMU) exploitation not only for clients but also for architects, some architectural agencies are still sceptical about BIM. French Architects are attached to both traditional knowledge and architectural processes. Therefore, BIM is sometimes perceived in by them as a disruptive technology that could negatively impact the architect's work. In France, we see more and more demands coming from public and private clients which want architects to deliver them a digital Mock-up (DMU) of their project. But if some architects (early adopters) are already able to produce it, they don't take all the benefits from this DMU production. Thus, this transition practices toward BIM in order to meet expectations of the clients is considered by architects as an obligation: the change is forced. Let us regard how the change factors can be considered by implicated actors.

1.1 The change factors : the unfreeze-moving-refreeze theory

Kurt Lewin demonstrated that the stability of human behaviour is based on the balance between several forces: status quo, psychological safety and survival anxiety (Burnes, 2004). When these forces are equilibrated, the situation is "frozen" and there is no need to change. According to him, change can't be initiated without destabilizing this balanced state: this is what he calls the «unfreeze» step.

It is exactly what's actually happening to architecture agencies: survival anxiety increases because architects feel that they will have to integrate BIM technologies to stay competitive. But "staying alive" must not be the only benefit of change, and even if some architects perceive the "state of emergency" they are not necessarily ready to take the plunge. The unfreeze step only creates motivation to learn: it's a path toward change.

Lewin also demonstrated that the change has to be followed by a «refreeze» state. During the change, everything is unstable, and if we want changes to last in time, we need to stabilize habits and find a new stable state.

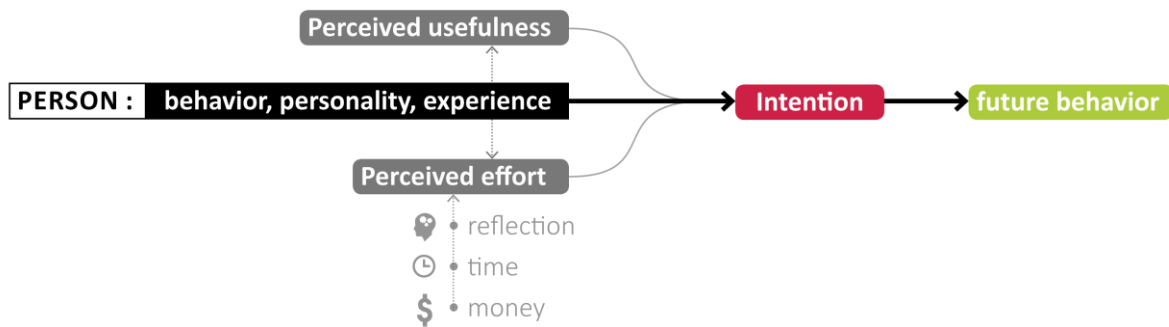


Figure 1. Personal factors that influence the intention to integrate a new technology; inspired from behaviourists models (Venkatesh et al., 2003), and the Lazy person Theory.

The “Lazy person Theory” (Tétard & Collan, 2008) is a theory that integrates the main behaviourists results as the Theory of Planned Behaviour or the Technology Adoption Model. According to these models, the acceptance of a new technology partly depends on the perceived usefulness of this technology and the effort that people think they have to make for the change (c.f. fig. 1). They also demonstrated that people always tend to try to make little effort: that makes change difficult.

The “unfreeze” step make people see the necessity of change, because they perceive the usefulness of it. But that is not enough to intend the change: they also have to find a balance between the perceived usefulness and the perceived effort for change.

1.2 EXPERIMENT change in small architectural agencies

A two architects agency wants to set up a DMU exchange process between their agency and a carpentry firm they often work with.

They solicited us spontaneously, it means that they already perceived the usefulness of using and sharing their DMU: unfreeze already occurred. Nevertheless, they considered that they need someone to work on this project because they have to give all their time to regular projects: the effort to make was considered too heavy.

We set up a first experience organized around two research Master student internships in order to absorb the three types of effort we previously identified (c.f. figure 1). One student worked at the agency, and shared his time between architect tasks and research tasks: his experience as an immersed architect was precious to collect information about the work practices of the architects. This student designed a first BIM model of the chosen project of the experimentation. This internship absorbed a part of architect extra-work and then reduced the reflection and time effort for the agency. The second student worked at the research laboratory to identify tools, methods and theories that could be useful for the operation. He also defined an usual method to guide the exchange practices on the 3D model designed by the agency student.

2. A METHOD FOR ADAPTED BIM INTEGRATION PRACTICES

We first studied the needs, wants and demand of the agency to better understand our mission and to be able to situate their BIM maturity level. We also studied the BIM Project Execution Planning Guide (CIC, 2010), and adapted it in order to set up a method that matches our specific case.

2.1 Architecture agency and carpentry firm demand

Our approach takes into account the statement formulate by the two partner structures highlighting the boundaries of the actual data exchange model (c.f. fig. 2). Thus, as of today, architects were drawing their projects in 2D (Autocad) and were sending DWG files and paper plans to the carpenters. Then, carpenters use these documents as a basis for their own 3D modelling with their business software (cadwork). Two types of files result from this model: internal files, to produce the projects elements with CNC machines and the graphical files allowing architects to check the architectural and technical compliance of the projects. We can remark that this exchange scheme presents two data discontinuities in its global process (materialized by a cross in the figure) which cause interpretation and re-drawing errors. Furthermore, the graphical language used by one partner contains some specific points which are not directly understandable by other partner and then strengthens the previously identified types of errors.

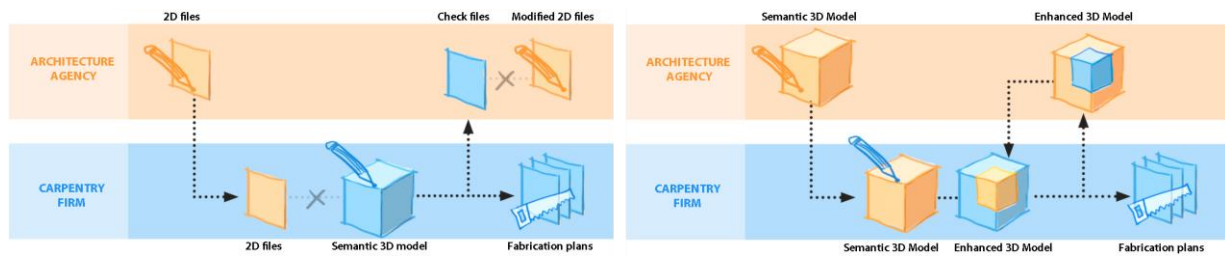


Figure 2. Actual data exchange process (left), and intended data exchange process (right)

The architects recently acquired a BIM software that allows them to draw in 3D and use semantical building objects enriched with construction information (ArchiCAD). Thus, they manipulate an enriched 3D model, from which all the 2D documents (plans, sections, elevations, etc.) are automatically generated. Now architects are able to create a 3D enriched model, so the process step where the carpenters realize this enrichment becomes redundant. This highlights the need to set up a new exchange process (c.f. fig. 2.). One of our main goals is to achieve an interoperable 3D enriched model that carpenters are able to manipulate and complete. After that, the model is sent back to the architects for validation. In this new exchange process, model discontinuities are no longer observed, avoiding the previously mentioned errors. This exchange process also allow a better handling of the changes during construction phase by a virtually overlaying in the 3D enriched model of geometrical objects of both companies.

The potential benefits obtained from this new exchange process are:

- time gain related to the suppression of the modelling step for the carpentry firm.
- reliability gain for the architects, with the automatic generation from one single 3D model of all other documents,
- legibility gain for both companies, with the use of an unique model that avoids wrong interpretations after data exchanging,
- errors risk minimization thanks to virtual checks.

2.2 BIM maturity of the experiment

According to the Bilal Succar BIM maturity levels model (Succar, 2012), the architects concerned in this experiment have achieved the BIM maturity stage 1: an object based modelling. With this experience, they want to reach the stage 2: a model-based collaboration. According to project phase concerned by this experiment, it is important for us to determine the Level of Detail (LOD) of the shared DMU to determine data we'll have to manage. In France, Le Moniteur worked on the description of the information that should be included or needed in a DMU for each project phase according to the French standards and laws (Le Moniteur, 2014). As the experience concerns a carpentry firm and an architecture agency, we will work with a DMU situated between the French level of detail ND3 (*Niveau de Développement*) and ND4, corresponding to LOD 300-Precise geometry, and LOD400-Fabrication.

2.3 BIM project implementation

The BIM Project Execution Planning Guide (PEPG) is a structured procedure for creating and implementing a BIM Execution Project plan. It includes four main steps (CICRP, 2010):

- STEP 1: Identifying BIM Goals and Uses: for example if one of the goals is "managing construction", the BIM use could be "make a 4D simulation".
- STEP 2: Design BIM Project Execution Process: with all the BIM uses identified at the first step, design and depict the process with BPMN to have an overview of the BIM process and information exchanges.
- STEP 3: Develop Information Exchanges: develop the information and DMU content and LOD. Identify responsible party for each exchange.
- STEP 4: Define Supporting Infrastructure for BIM implementation, according to the uses identified at the first step, and the information identified at the third one.

We identified a few problems with this procedure in our case. First of all, it is an extremely complete and complex procedure for BIM implementation. Moreover, the process designed at the second step contains only BIM uses, and doesn't integrate eventual regular practices of architects, engineers or other firms. Not taking into account the work context of people would be a failure factor for the operation. Furthermore, the fourth step of the procedure is to define the best supporting infrastructure for the ideal process designed at the third step. But it is difficult today for SMEs to buy new software programs, new equipment or take time of people.

These three observations make this procedure really difficult to put in practice in our case under this form.

2.4 An adapted method of BIM project implementation in SMEs

We developed an adapted method organised around a general process (cf. fig. 3) defined from the observations we realize on the PEPG. As unfreeze (A) is a lengthy and behaviour depending process, we only intervene after that it occurred. To minimize the impact on the usual process and to make the technology appropriable by the actors, we first study and model the usual practices (B). Then we organize the change by designing a new process that includes new BIM uses in usual practices (C). The exchange experiment (D) allow us to see what was possible to do in a first place with the current infrastructure. According to the observations realized during the previous experiment, we redefine the process (E) and finally we implement it (F).

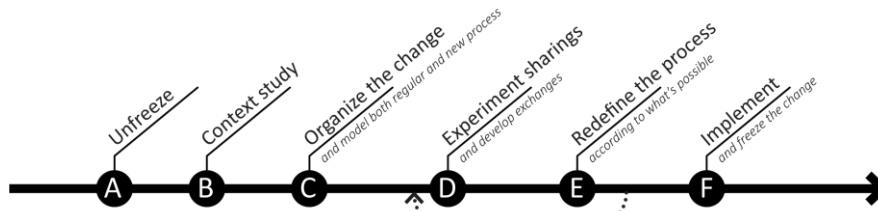


Figure 3. The general process of the proposed method

3. EXPERIMENT OF THE PROPOSED METHOD

3.1 Unfreeze (phase A)

As we said before, the unfreeze step occurred without our intervention in this experiment context. These architects feel particularly concerned about BIM and they want to experiment.

3.2 Context study (phase B)

To introduce our two partners goals, and the methods we set up, we need to describe the different contexts in which this experimentation takes place. The context notion comes from the usage-centred design approach (Constantine & Lockwood, 1999) and use in the model-centred description of collaborative practices and usages (Zignale et al., 2014). These contextual elements are classified and gathered in the Table 1 that summarizes the various identified contexts. Both partner companies will be described within the following table criteria.

Table 1. Contexts definition

Context type	Characteristics
User context	<i>Preferences, habits, competences</i>
Material context	<i>Equipment type, interacting device</i>
Temporal context	<i>Frequency, synchronization</i>
Location context	<i>Place, environment, co-presence</i>

3.2.1 Architecture agency context

User context – Two architects, currently working essentially on individual houses projects, manage the agency. They have a strong eco-conception approach and both equally developed CAO and construction monitoring competences. *Material context* – The agency is equipped with workstations that run 2D and 3D drawing software programs. They used Autocad for nearly a decade and recently decided to acquire a “BIM compatible” tool. They are now in the transition process between the endings of the last projects drawn in 2D and the starts of the first projects yards drawn in 3D. They are between a “defined maturity level” and a “managed maturity level” in BIM stage 1 (Succar, 2013). *Temporal context* – Agency’s work is for a major part synchronized; they define together the architectural directions of every project. Then, work is divided and only one architect carry on a project. The drawing time is then asynchronous. *Location context* – Agency is located in northeast of France and the building is a mirror of the architects work, it is one of their projects.

3.2.2 Carpentry firm context

User context – The firm is specialized in framework, roof work and timber framed houses. It employs about 50 persons and works on a wide range of projects, individual houses as well as public equipment. An engineering office and a manufacture unit are integrated. *Material context* – The wood engineers work with the business software (cadwork) for a long time so they managed it well. However, architects and carpenters software programs cannot directly communicate. As a result, current exchanges are made with 2D DWG files and paper plans. *Temporal context* – There’s no work synchronization. Thus, successive tasks allow switching from the initial 3D model to the final manufactured pieces. Each people within the company have a clearly defined role. *Location context* – Company is also located in northeast of France, about 40 km away from the architects.

3.3 Organize the change (phase C)

To organize the change, we modelled a process with the information we collected on each company, their habits of work and their needs of exploiting DMU. We used the same notation as used in the PEPG: the Business Process Model Notation (BPMN) (c.f. fig. 4.). It allows us to see at each exchange: where the file is coming from, and where it is going after. It's important to know which information it is possible to have in the IFC file as output, and which ones we will need as input. BPMN is not a well-known notation in architectural sector. In order to make the process representation accessible to project's actors we added a timeline representing the project milestones. The timeline shows the expected LOD of the model, which represent an essential information for architects and their partners. The figure below (fig. 3) illustrates this process of the collaboration between the two partners.

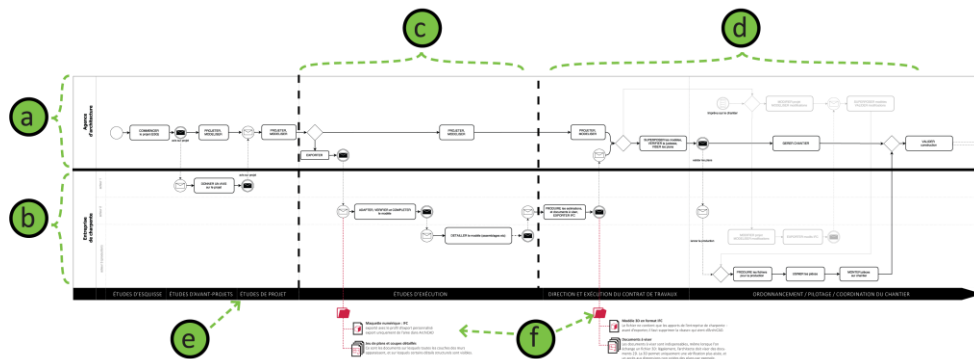


Figure 4. The file exchange process between the architects (a) and the carpentry firm (b). We drew the project milestones timeline (e), the ND3 DMU step (c), the ND4 DMU step (d), and the detail of the shared files (f).

3.4 Experiment and develop exchanges (Phase D)

We took as support for the experimentation a common project of the architects and the carpentry firm which has been already made with the usual process. The architects work with ArchiCAD and carpenters work with cadwork. The only file extension that can be exported and imported with these two software programs is the IFC format. Therefore, we chose to make all our exchanges tests with IFC files.

3.4.1 The reference project

The support of our experimentation is an individual house project, originally drawn in 2D (Autocad). The construction of this house is now completed (12.2015). The house is build with wood-frame walls and a masonry garage separated of the house by a small winter garden. To achieve our goals, the project was re-drawn in 3D (ArchiCAD). We chose this project for our experiment, because a particular mistake occurred during the construction process. The carpenters made confusion between the use of the '%' character and of '°' character in the frame design. The architects didn't noticed the mistake because of the lack of information on the carpenters' plans. One of our objectives is to determine if our method may allow to avoid such a mistake. The house has been re-modelled with ArchiCAD during the internship in the agency in order to have a DMU support for the experiment.

3.4.2 Architects to carpenters exchange

We made a first IFC export of this 3D semantic model with ArchiCAD with the default settings. When we imported the geometry in cadwork, some parts of the model were critically damaged, and we lost information during the exchange process: some walls and roofs are missing and walls are no longer connected to roofs (c.f. fig. 5).

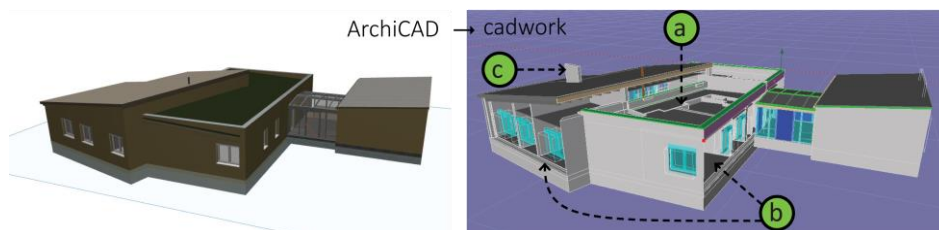


Figure 5. Result of our first IFC exchange test. Some roofs (a) and walls (b) are missing, and a wall lost its connection with the roof (c)

We made then three hypotheses concerning the reasons of this loss of information:

- 1 - The house was not modelled properly
- 2 - Cadwork doesn't read the file properly and deleted unreadable information
- 3 - ArchiCAD doesn't export the file properly.

1 – For the first hypothesis which concerns the modelling techniques, we made a set of tests to check the impact of some modelling practices as the manner the wall is modelled, its composition, the type of roof, etc. We noticed that the geometry is damaged when the walls are connected to roofs. The tests showed that the way we model a wall (clockwise or counter clockwise) and its composition (simple or composite) impacts the quality of the exported IFC file even when it is invisible and unnoticeable in ArchiCAD (c.f. fig. 6).

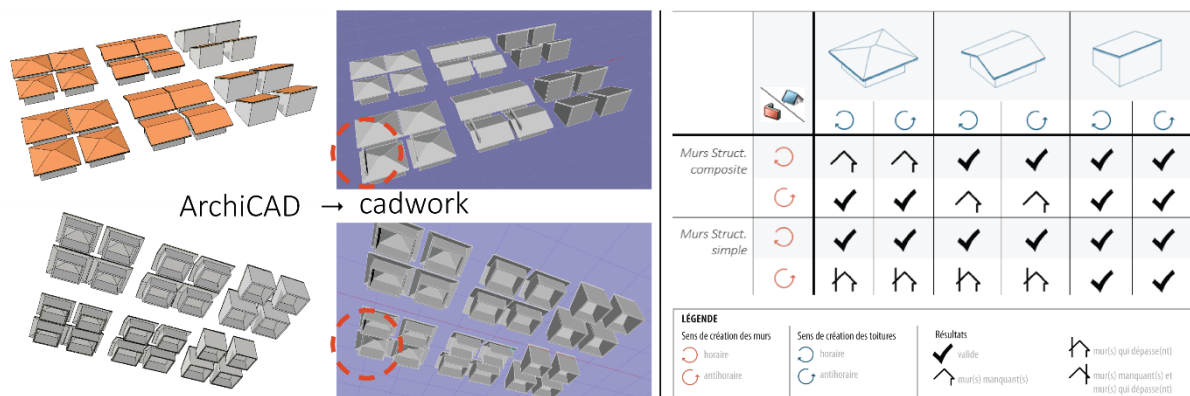


Figure 6. Results of the tests made for the hypothesis 1

2 – Then, after checking the quality of the file, we tried to identify if the problem comes from cadwork import functions. It's important to specify that cadwork is not certified yet by BuildingSMART for IFC2x3 import. We opened the same IFC file with different software programs: cadwork, Revit, Solibri Model Viewer (SMV), and Tekla Bimsight and compared the different obtained visualizations. None of these programs revealed the same damages on the same file. That means that cadwork, Revit and Tekla Bimsight aren't able to read this IFC file properly. The best importation of the IFC file was made by SMV: there is no difference between the visualisation of in SMV and that in ArchiCAD (c.f. fig. 7 and fig. 5).

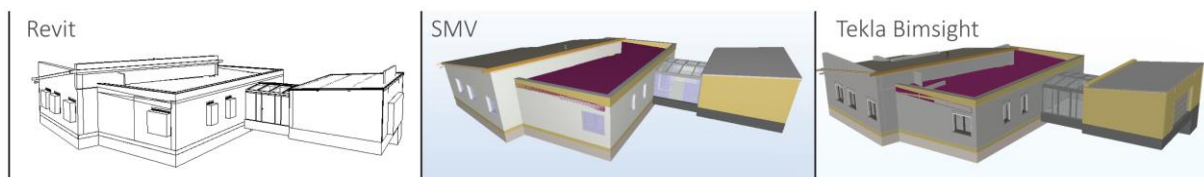


Figure 7. Visualization of the same IFC file in different software programs

3 – Finally, we checked the most essential factor: the IFC export profile settings in ArchiCAD. ArchiCAD is certified by BuildingSMART for IFC2x3 import and export. In this software, the IFC file export profile can be configured. Our tests showed that the IFC export profile has an important impact on the quality of the imported geometric information in cadwork.

Information handover– Cadwork and ArchiCAD work in a total different way. ArchiCAD allows architects to make an Object Oriented Model, whereas in cadwork carpenters work with panels and volumes. There is only five non-geometric data that can be recovered from an IFC file in cadwork: IFC class, global ID, name, building storey and layer of an object. These data are sufficient for carpenters to realize their work. In cadwork, the carpenters usually model only structural parts of a wall and use simple volumes as basis to define the whole structure of wooden framework of house.

3.4.3 Carpenters to architects: interoperability problems

A BIM exchange process is profitable only if the 3D model can go back and forth between the two companies. Now let us determine how the architects can exploit the carpenters' detailed model.

As previously explained, the actual exchange process contains a delicate step: the information exchange for the architects compliance check. Currently, this work is done using paper plans. Nonetheless, both companies don't

need the same information. They don't use same graphical conventions for representation or measurement and thus the files become hardly readable by each other.

A way to decrease this issue is to translate the carpenters' model with IFC standard concept, and to overlay it with the architects' model either in their BIM software (ArchiCAD), or in an other software program, in order to detect possible errors or differences. This method immediately showed an error, and made it easier for architects to check technical compliance of the projects.

An IFC file was exported from cadwork, and then imported in ArchiCAD. Groups in cadwork are converted into building storeys in ArchiCAD and then disrupt the architect's work model.

4. RESULTS AND FINAL PROCESS (PHASE E)

4.1 Solutions found

4.1.1 Architects to carpenters: exporting settings recommendations

Export profile – We created a new IFC export profile in ArchiCAD that explodes and converts all the geometries into Breps. With this method, we lost a lot of information, but it made possible to keep geometric information we needed. We observed no more wall or roof removal, but a new visualization problem appeared. It seems that faces overtake edges boundary in convex edges (c.f. fig. 8).

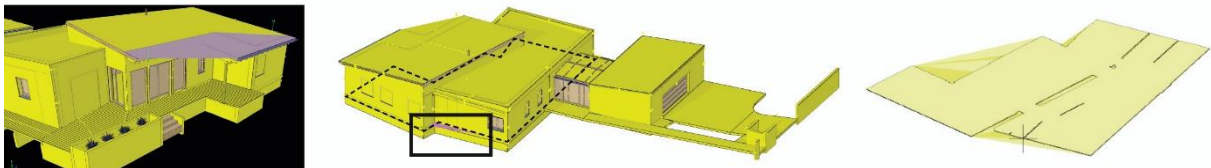


Figure 8. The house imported in cadwork: IFC import coming from ArchiCAD with our exporting profile.

Information handover – To deliver to carpenters a model that only contains the structural parts of the walls in order to not overload the IFC file, a selection must be made by the architects before the IFC file export. They have to check the “only structural parts” option in the model visualization in ArchiCAD (c.f. fig. 9).

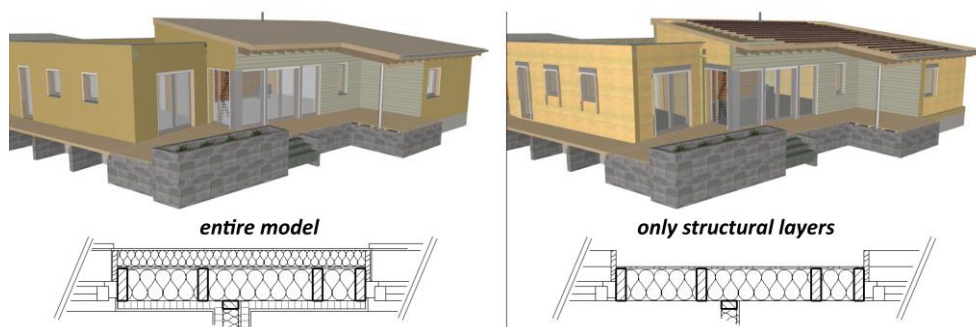


Figure 9. Selection of information in ArchiCAD before the IFC export

Unfortunately, the bad quality of the imported geometry (in breps) doesn't allow carpenters to use it directly to define the house structure. They can only use the imported file as a background base for re-modelling clean basic volumes. However, it makes it possible to carpenters to avoid units reading errors.

4.1.2 Carpenters to architects: an alternative to interoperability problems

We chose to realize this task by using the freeware Tekla Bimsight (c.f. fig. 10.). We decided to use this specific tool and not overweight the manipulations in the architects' software (ArchiCAD). This particular tool allows an easy overlay of many IFC models.

On the figure 10, we can first observe on the left the architects' IFC model with only the global volumes of the construction elements, a wall in this case. Then in the middle is the IFC model detailed by the carpenters with all structural parts constituting the wall. This model is generated from the model drawn by the architects. Lastly, we can see on the right of the figure the two models overlay. In this case, they overlap perfectly and this shows that the architectural conformity is fulfilled.

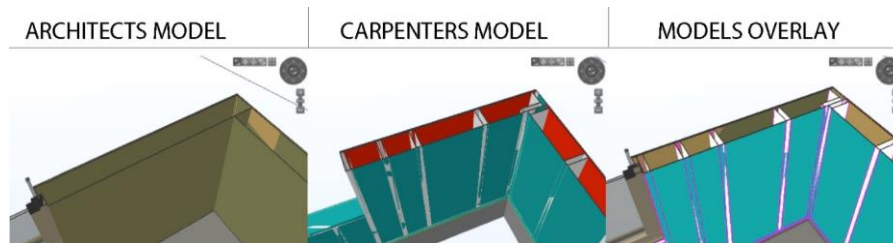


Figure 10. Models overlay done

The modelling process has an influence on the possible exploitations of the model. Sometimes, to ensure a correct geometrical representation, it is necessary to adapt the modelling process. On the opposite, get a proper 3D model to share with partners may alter the geometrical side. This mutual impact of both stakes prevents the development of their full potential and requires an adaptation of the initial goals.

4.2 Final Process

As what we supposed before the experiment, we had to adjust our objectives to fit the possibilities of the software programs used instead of defining new infrastructures. The practical problems today stay linked to interoperability and to the ability of software programs to read and write IFC files. But there is one important step missing in our method: it would be useful to check the quality of the IFC file before it is shared, to see if the DMU matches with the expected LOD, and if no error is detected in the file.

5. CONCLUSION

It is quite rare to get the opportunity to realize an experiment with two SMEs in collaboration with a research laboratory. Our work demonstrated the importance of taking into account usual practices in SMEs in order to implement a BIM exchange process.

This experiment allowed us to set up a first draft of a method for BIM implementation in SMEs. For that, new notations and new practices for architectural conception and construction process have been tested and the relevant information of the DMU that can be shared between the concerned actors has been determined and described.

Notwithstanding the interoperability problems we experienced, carpenters spontaneously asked architects to send them a partial DMU in IFC standard after the end of experiment. The actors are satisfied by the experiment results: they are now ready to invest time and money to set up new changes and integrate more advanced BIM uses. This is an indicator that makes us conclude that implementation is accepted and that “freeze” happened.

This common master student work is resulting in the beginning of two theses about BIM practices integration in SMEs. The first one concerns intelligibility of architectural processes and procedures, and the second one is about usage and technology changes.

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