Interoperability in BIM prefabricated wood framing house process

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Abstract

Nowadays, "Smart" is closely related to the digitization phenomena occurring in many different industries. In Construction, it receives the name of Building Information Modeling (BIM). In processes aided by BIM software, digital information needs to be exchanged among several tools for the design to be accomplished. During the design phase, because of the multitude of specializations existing in the overall development, it is difficult for a single tool to embrace all necessities. Even after construction, there are other demands to gather and produce information throughout the lifecycle of a building. This leads to the urgency of an open format to exchange information so that there is no need to re-enter data manually at each stage of the project, nor compel the team to work within one single platform (e.g., a collection of different software from a specific company) to smooth the workflow. It is important to highlight that integration between systems or software hardly could be addressed with off-the-shelf solutions. The concept of interoperability is to use these already developed specialty applications and make the information flow through the process autonomously. Beyond the interoperability problem, there is also the cost of integration. Because of that, companies are adopting BIM for just part of the lifecycle of a building, which means they are not harvesting the best gains it can offer. In this context, we propose to analyze the Tecverde Light Wood Frame Co. that designs and builds prefabricated dwellings in Brazil. Aiming in the future to achieve an advantage in the market, this study will provide ideas to promote internal integration between design and fabrication through open BIM processes. The primary objective is to understand how BIM could improve the use of prefabrication in Construction. A business process map for the As-Is and a To-Be design to fabrication processes are drawn based on interviews. The idea is that the identified bottlenecks could be solved without expensive applications, and then the cost of the design will be lowered, and in the future, it is a requisite to employ mass customization. Currently, Tecverde avoids offering many different patterns to its houses because of the expensive design process.

Keywords: BIM, OpenBIM, Interoperability, Prefabrication, Light Wood Frame

1. Introduction

Nowadays, “Smart” is closely related to the digitization phenomena occurring in many different industries, such as manufacturing, and even in the Architecture, Engineering, and Construction (AEC). To design, plan, and construct in advance in the virtual world is an approach that saves money, allows for optimal solutions, and are prone to incur in fewer errors because of early decision processes, and of 3D model coordination between all disciplines (Eastman et al., 2014).

Such processes, known as Building Information Modeling (BIM), are prone to transform the way AEC operate and organize itself. BIM models became a shared database of building information that is increasingly enriched by new geometric and semantic data throughout the entire lifecycle of the building, allowing the reuse of data at any stage. In its collaborative form of work, interdisciplinary project integration takes place from the initial stages of the project, when BIM computational tools become a critical auxiliary source of information for decision making. Besides, the reliability brought by BIM software ability to automatically represent project changes and replicate them by its associated objects made it possible to deliver economy, quality, and safety.

However, BIM professionals are still experiencing interoperability (digital information exchange between software) complications concerning the several specialized tools they need to accomplish a project. Integration between systems or software hardly could be addressed with off-the-shelf solutions. A great deal of study, to represent, and eventually to change current processes, to adopt standards, is part of the solution. Concerning standardization, to mitigate the interoperability problem, buildingSMART[1] association have developed standards, such as the Industry Foundation Classes (IFC) schema that is a neutral schema definition based on the EXPRESS language and is the *de facto* standard used by the industry.

In this work, as BIM adoption has been increasing worldwide, and appears to bring a resurgence in the use of prefabrication and modularization (Salama et al., 2017), we intend to address the integration of design and fabrication through BIM, in the context of the prefabrication of homes in the Light Wood Frame (LWF) building system. We have been mapping current processes, identifying weaknesses, and proposing a different digital workflow to enhance the entire process through widespread BIM implementation. Our work is based on the project workflow analysis at the Tecverde S/A Construction Co., a company devoted to the prefabrication and erection of wooden dwellings through the LWF construction system in the southeast Brazilian region.

Among other timber construction systems, LWF is the most adopted system for its agility and less material consumption (Sotsek & Santos, 2018). However, gains from the adoption of indoor prefab LWF system have yet to be enhanced (Nawari, 2012). The LWF prefab is spreading and, according to Lapointe, Beauregard & D´Amours (2006), since 2003 there has been an increase in the manufacturing of prefabricated components in the United States as well as the preference for prefabricated non-volumetric LWF components, since flat panels are easier to transport, providing this kind of panels a preference among builders when dealing with large-scale constructions. For this reason, LWF, BIM, and prefab have a strong synergy when combined altogether.

2. Perceived benefits of BIM in prefabrication

Manufacturing industries are increasingly dependent on Information and Communication Technologies – ICT (Carr, 2004), and most of their processes, organization, and technologies are intimately linked to it. Specifically, for the AEC industry, BIM processes and software tools create synergy between design and construction, moreover when involving prefabrication, along with management of industrialized

[1] International organization that aims to improve the exchange of information between software applications used in the AEC. Former name: International Alliance for Interoperability.

construction processes. Smith (2011) points out that the future of prefabrication relies on BIM due to its potential to communicate with CAD and CAM stations and, therefore, to Computer Numeric Control (CNC) machines.

However, BIM was developed for the use in a non-prefabricating environment. There are many differences between prefabricated and non-prefabricated design processes and, therefore, BIM tools present some limitations when dealing with prefabricating systems. By analyzing the behavior of many BIM tools concerning the prefab concepts, Yuan et al (2018) point that scholars noted several problems, from few available prefabricated library components (and templates) as well as assembly and connection functions – used in following the Design for Manufacturing and Assembly (DfMA) concept – that should be improved. Another finding was that architects do not master prefabrication techniques so that they tend to handover the design to the prefabricating factory designers. The design process should avoid this split since it reduces communication efficiency among different domains of the project.

Several works have been published focusing on the benefits of BIM to prefabrication. Some are concerned with the interoperability via IFC (Khalili & Chua, 2013), (Sacks et al., 2010), (Nawari, 2012); others address the need to standardized elements and libraries (Lee, Sacks, & Eastman 2006). Design for manufacturing and CAM technology has also been identified as an opportunity to automate the factory production. To Lee, Sacks, & Eastman (2006), BIM suits flawlessly in performing the workflow needed to achieve DfMA design targets, once its capacity to deal with parametric information is native. In this regard, Yuan et al. (2018, p.18) propose an approach to "carry out DfMA analysis to timely integrate the detailed information required by manufacture and assembly stages of precast components into design stage, such as geometry, structure, connection, manufacture process, assembly process, and mechanical equipment." As pointed out by Smith (2011), integrated BIM models thus become the backbone of the prefabrication, not to mention that it can also offer the opportunity of disassembly after use (rather than demolition) and let parts of the building to be replaced instead of being refurbished, similarly to produce parts from the automotive, aerospace and shipbuilding industries.

3. The interoperability issue in BIM processes

Between the elaboration of architectural design, – or its adaptation for a specific building system – structural analysis, and the completion of fabrication details, information produced in different software, by distinct professionals, need to be exchanged. As software internally works with proprietary data formats, in a scenario of open collaboration (between professionals using software of different vendors), files in proprietary formats should be translated temporally in a shared and open standard, so they could communicate and avoid the costs of developing translation between every possible combination of software. Interoperability can be understood as the exchange of information between BIM software from different AEC disciplines to promote the seamless flow of BIM models in proprietary and non-proprietary files. In order to maintain the collaboration within an interdisciplinary team without incurring the re-entry of data and using the same database, stakeholders make use of the interoperability (Corrêa & Santos, 2014). According to Eastman et al. (2014), OpenBIM is the support for multi-enterprise team collaboration applications (being it proprietary or not), providing a data interchanging mechanism, allowing data to flow between software so to complete the design cycle.

IFC is the leading standard of buildingSMART, and since 2013, ISO 16739 (International Standardization Organization, 2013). According to it, IFC is a neutral data description, exchange and information sharing schema (typically within the scope of the AEC) that covers the entire building lifecycle and has been designed to be an extensible skeleton at the level of detail for specific applications.

Nonetheless, many authors report problems in IFC exchange because of difficulties and inconsistencies arising from its data structure. While IFC can accommodate a building component in diverse ways, it might also provide different forms of describing the same part, leading to data misinterpretation between software. According to Venugopal et al. (2012), IFC schema ought to define entities, relationships, and properties in a more cohesive way.

IDM (Information Delivery Manual) and MVD (Model View Definition) are also buildingSMART standards. They were created to address the fact that not all information contained in BIM models in IFC format should be exchanged at the same time, and that for each specific interaction, a particular view of the “model database” should be considered. Despite IDM and MVD being different processes, they seemed to be complementary, and the National Institute of Building Sciences (NIBS) have been responsible for integrating both methods (See, Karlshoej & Davis, 2012).

IDM became ISO 29481 standard (International Standardization Organization, 2016) in 2010 and is a formal document that describes a particular business process, providing detailed specifications as to the exchange of information between agents that perform specific activities, to ensure that the information exchanged is accurate and sufficient to support its operations. To map such activities, buildingSMART recommends the BPMN[2] notation. The BPMN map highlights data information in two types: data models and non-electronic information (external data). Electronic information is then structured into Exchange Models (EM) while non-electronic information needed are also depicted. Once IDM has identified both electronic and external data to be exchanged, the next step is to translate them into a machine-interpretable language, to be implemented on software, which is the MVD.

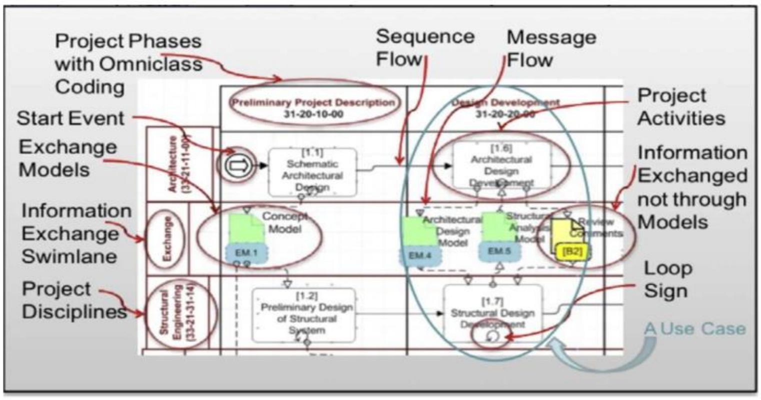

Figure 1: BPMN example. (Venugopal et al., 2012, p. 416).

buildingSMART had published some of these MVDs or “views” for specific purposes such as coordination between distinct AEC disciplines. Such MVD are adequate for the most common exchanges found in the AEC but are far from covering all existent requests, so there is a need to develop distinct MVDs for each exchange case, such as energy or structural analysis, for instance (Corrêa & Santos, 2014).

As to organize the process of identifying and implementing the information exchange required for each particular use of BIM models, NBIMS suggests the following phases (Venugopal et al., 2012): **Phase 1** – Use-Case and IDM: A work team composed by the stakeholders create an IDM and identifies the ERs. The Use-Case defines the exchange requirements between two interested experts (e.g., the architect and the civil engineer); **phase 2 - Model Concepts and MVD:** ERs are structured in Concepts (Model Concepts), as a series of modules. An MVD is a sequence of modules which will further be mapped into a computer-interpretable scheme, such as the IFC. At this stage it is highly recommended to certify the engagement of software developers; **phase 3 - implementation of MVD** by developers, testing and validating through the Use-Case import and export; **phase 4 - MVD** technical and user documentation, to enable users to produce BIM models according to required specifications (ERs).

Identifying the Model Concepts (as shown in phase 2) is of fundamental importance since they reduce the time expended in validating information exchange, by combining them to attend different and new

[2] Business Process Model & Notation. Graphical and semantical notation for representation of business processes, maintained by the non-governmental consortium Object Management Group - OMG.

uses.

4. Tecverde's overview

Tecverde S/A is a Brazilian joint-stock construction company focused on manufacturing, supplying and assembling industrialized buildings in LWF system. The company's competitiveness radius of operation is around 1,000 km from its factory location, and its average productivity is 52 houses per month, employing 18 factory workers. The basic workflow considers two targets at once: the fabrication and the site work foundations, although the site works are carried out by contractors instead of the company's duty. This leads to a disruption in the overall workflow since the bottleneck of production is that the site works do not follow the speed production of the factory, making the company concentrate many efforts on the contractors' sizing and planning activities. We have also detected that the company has recently undergone market strategy changes since they had to stop serving the high-end residential market because of excessive customization problems demanded by customers, causing a costly bottleneck in production. Also, the lack of architects' preparation concerning the LWF system demanded an expensive transfer of knowledge, was the other reason for the company to abandon the high-end residential niche.

The company's system consists of a structural core made up of timber plate framing, disposed of in a vertical position (studs) and the horizontal position (single or double plates). The studs have sizes from 38x90mm or 38x140mm and are spaced in each frame by 30 or 60cm, depending on the role and the structural loads transferred to each wall. The outer sheathings consist of Oriented Strand Board (OSB) on both sides, a water-repellent membrane, and cement boards stapled from the outer side, with its outer joints' treatment made of taping between the cement boards. After jointing and taping, it is also applied an acrylic painting finishing.

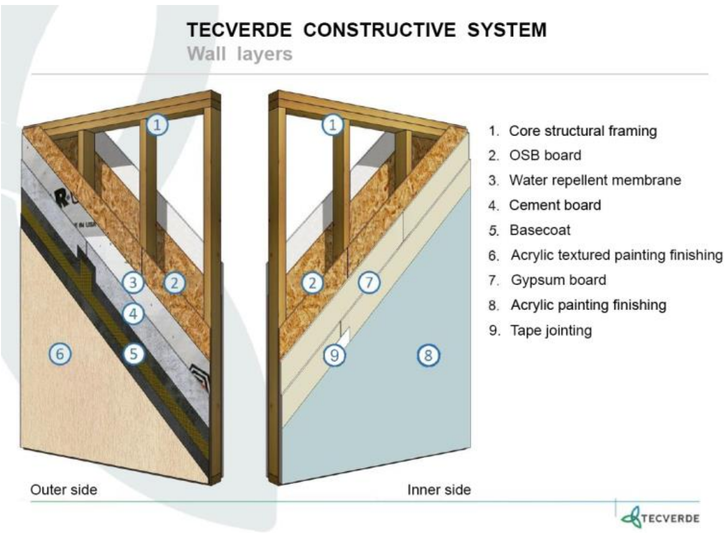

Figure 2: Tecverde´s adapted LWF system (Tecverde Engenharia S/A, 2018)

Floors and stairs are also made of wood. The floors are composed of wood panels, a plastic insulation canvas, and a subfloor layer in a concrete mortar with pre-welded metal screen (20x20cm) reinforcement. The roofs are composed of wooden trusses, produced by an outsourced company and delivered on the site. Some crucial adaptations to the Brazilian market had to be implemented. Concepts such as "control points" and the concrete underlayment executed at the site are practical examples of these adaptations. The "control points" concept arose from the need for flexibilization of assembly concerning the original German system. These are deliberate "slacks" left at some strategic points in such a way as to facilitate assembly. Such clearances are unnecessary in Germany, given the extreme precision of input production as the exactitude of the pre-cut sawn timber available.

5. Tecverde's design-to-fabrication workflow

The design process involves not only Tecverde but also Stamade company, responsible for structural analysis. To gather all the information presented in this article personnel from both companies were interviewed at least once. They were also contacted by phone or e-mail to clarify some points throughout the development of our research. The current design-to-fabrication process can be summarized in the following stages:

1. An architectural BIM model, most commonly performed in Revit® 2018 authoring application tool by Tecverde, is sent to the structural design office (the Stamade Co.);
2. Stamade proceeds to the calculations using the German BIM software Dlubal RFEM specialized in structural systems by the method of finite elements and provides, as a final product, a 2D CAD design executed in AutoCAD;
3. Tecverde then performs the manufacturing design, using the German software SEMA, specialized in industrial carpentry. SEMA is a CAD / CAM application with BIM properties, making it capable of reading CAD files in a variety of formats and create a 3D model based on a previously developed type library within the software. Also, it counts on an operational interface with several CAM languages, which enable it to send cutting, drilling, and other automated operations directly to the CNC machines, down in the shop floor;
4. The manufacturing takes place through the automatic sending of CAM commands considering, however, a few non-automated operations such as inserts of electrical and hydraulic parts among other specificities. These tasks are made by specialized staff and include some electrical and hydraulic assembly parts.

5.1 As-Is process map

The information acquired through interviews was used to draw a process map following IDM methodology so we could identify which and when such data are exchanged.

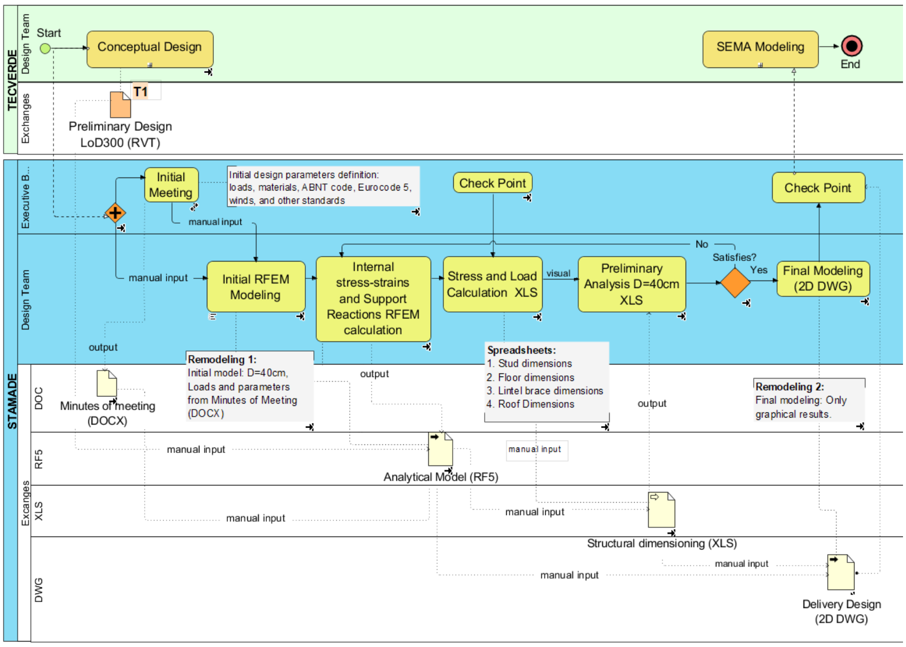

Figure 3: BPMN As-Is process - structural design workflow (the authors).

In the second stage, Tecverde handover its conceptual model to Stamade to develop the Structural Analysis and Structural Design, as illustrated in Figure 3. Stamade currently uses it as a reference for their developing tasks from the very beginning, using specialist software (RFEM). Here, there is a whole re-entry of geometric data causing an issue, as the most time-consuming task is to redraw the entire project into the RFEM software.

The next stage was to unfold the design for the manufacturing process, which is made within Tecverde with the help of the SEMA carpentry BIM software. Once again, it was identified the need for redrawing the whole project, but the most concerning problem was addressed as the design inconsistencies found between the final structural model and the concept model. For some intrinsic misled workflow conduction, these designs do not fit each other in the end.

The critical activities found in the Tecverde's design workflow allows the identification of the information needed in each exchange that occurs in the workflow. The MVD would be developed as the translation of this information (Table 1 represent part of it) in a specific language or data schema, such as IFC.

Table 1: Exchange Model portrayal from Architectural to Structural design (EM.1)

Exchange Model name		**EM.1**: Import model to RFEM software
Phase:		Detailing phase (Omniclass: 1F 20 20 11)
Disciplines:	From:	**Architecture design** (Omniclass: 1D 21 11 11)
	To:	**Structural Design** (Omniclass: 1D 21 31 14)
Description:	Goal:	Provide to the Structural Engineering, the architectural design with the necessary information to execute the Structural Project.
	Content:	Architectural BIM model such that all geometry and materials are defined, as well as walls and floors layers composition.
Mandatory requirements:		**Architectural model already approved by Tecverde, containing:** 1. Company and venture ID; 2. Building´s location and orientation relative to True North; 3. Prevailing winds; 4. All final geometric information; 5. Walls and floors layer specifications.
Level of Detail: (Geometric model)		1. LoD 300 * for: Structural elements, walls and openings. 2. Overall level of detail in architectural design quality. 3. It is desirable to include the structural analytical model, without its loadings.
Level of Information: (Semantic info)		Venture ID;
Related activities:		AT.1 and AT.2

* *Vf. BIMFORUM, 2017.*

Once the tasks have been identified, it is possible to map the ERs so to build the EMs. The Exchange Models can be understood as the connections between two or more activities. The receiving action is the one that imposes the requirements that must be met by the source task to the information to be exchanged.

5.2 To-Be process maps

Aiming to reduce the identified bottlenecks in the portrayed workflow, an initial proposition of a To-Be process, based on integrated BIM workflow was drawn. In Figure 4, data exchanges are mapped in the white swimlanes as with the prefix "R" (stands for Requirement), "M", standing for Model, and "EM", standing for Exchange Model. Requirements are defined as all external data needed as input (eventually either as output data) for a BIM model. Models are defined as BIM authoring software output models, and Exchange Model correspond to exchanged data between authoring tools, which are our focus herein.

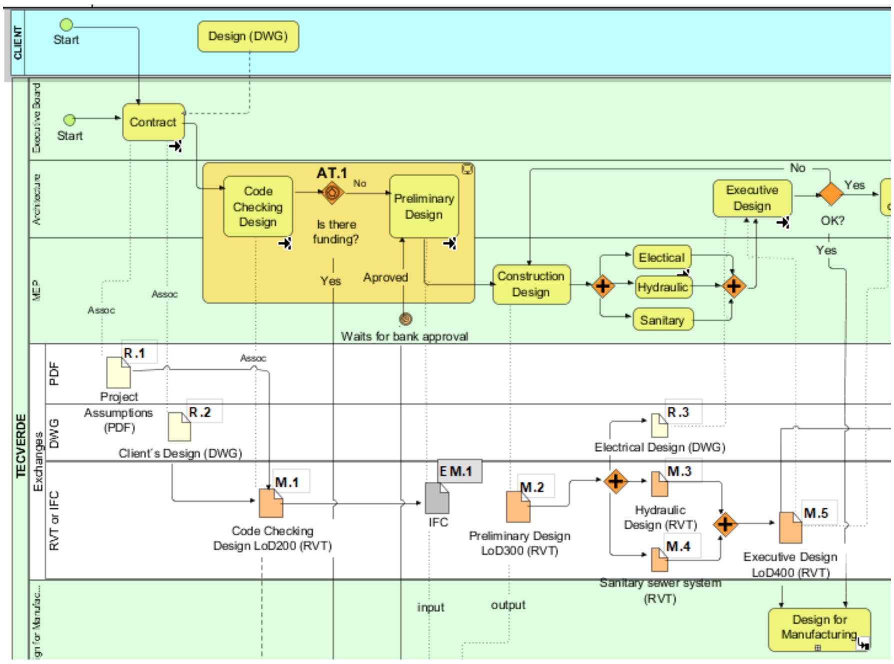

Figure 4: BPMN To-Be process - proposed conceptual architectural workflow (the authors).

We have proposed several improvements in the To-Be processes. The As-Is overall workflow was found to be intricated once there is a need for adaptations in the authoring tool the design team uses. For instance, although the conceptual project workflow is not so threatened since the development of this project is entirely done in Tecverde, we realize that the lack of interaction between project teams (namely, architecture, electrical, hydraulic, and manufacturing design) has development problems since the applications chosen for these design disciplines do not communicate naturally. This requires the design team to adopt alternative procedures for exporting and importing files to work around the problem. These procedures generate errors and extra work for the project teams.

When the structural project comes on the scene, more opportunities for improvement are found as Stamade company currently adopts different internal procedures and this miscommunication leads to data inconsistencies. Often the architectural design, used as the source for the structural design, does not coincide with its basis after its completion. This stems from the fact that some minor changes in structural design are made without communication to the architecture team, as they will not influence the calculation results. However, once this model has been inserted in the context of general interoperability, it will generate new discrepancies in the upcoming activities such as the design for manufacturing. That is, errors are propagated forward and become potentially more hazardous to the design process flow. Another critical point observed was that these tools generated the need to produce extra documentation (drafting, tables, and memorials) for the supply of the other Tecverde departments, such as Purchasing & Bid, and Budget Department, for example. Once again, because they do not communicate.

6. Discussion

Preliminarily, the company design-to-fabrication workflow was mapped using the BPMN language following buildingSMART's integrated IDM / MVD methodology, with information gathering mostly during interviews. Some drawbacks were found in these interviews such as the need to exporting the conceptual BIM model into CAD standards as to deliver it to the Supply and Bid Departments. These branches do not work within the BIM environment yet, causing this issue even within the company's activities.

By mapping the As-Is design process with the use of the IDM methodology, we could highlight when and how BIM information should be exchanged. Based on the As-Is mapping, it was proposed some modifications to accommodate the exchange requirement needed in the Exchange Models (EM). We have found that BIM interoperability indeed fits and shifts the prefabrication principles and, when applied to the LWF, can offer a suitable environment towards the AEC's rationalization.

An intervention was proposed aimed at adapting one of its production bottlenecks (the accomplishment of the detailing design) through the adoption of BIM interoperability (nonexistent today) among the three authoring software used for the development of the design solution. As future work, the IDM will provide information to the MVD implementation in the context of the company.

It is necessary to point out that small companies are not willing to buy additional software modules (plugin to read Revit models directly in RFEM; a particular module of RFEM for timber, instead of creating calculations routines in Excel spreadsheets) to provide better interoperability workflows. Their experience with trial versions of those piece of software do not offer results 100% without errors, so they opt to stay with the basic and spend time instead of money to solve their work. It seems to be the correct decision when working in a business model with few options for clients. If a costly design process could be used to sell the same house many times, it provides economy of scale.

7. Conclusions

The research presented in this article is part of an investigation to understand how the use of information technologies in Construction (of BIM, in particular), combined with industrialized building systems, can contribute to add value to the AEC supply chain. In this article, it was analyzed the potential of BIM in the prefabricated LWF system within a Brazilian construction company, Tecverde. Today, the company faces many issues in sharing information between three specialized BIM applications, causing the need for re-inputting data. A solution to the lack of interoperability is a crucial development, as it harnesses the competitiveness of the company, and threatens its market-share in such a way that Tecverde has chosen not to work with catalog houses due to the costly design development.

IDM / MVD integrated methodology as proposed by buildingSMART indeed enhances performance workflow rates once it identifies the critical activities so to extract the exchange requirements needed to the IFC subset schema to perform BIM interoperability. The highlighted activities disclosure the required information that must be present in each MVD subset in detail. Although this article does not cover the MVD development, it becomes clear how the IDM method lists information in a non-technical way so that stakeholders can perfectly understand and interact with each other to identify the data information pre-requisites to a flexible design workflow between BIM applications. As noted in the BPMN maps, some information comes from non-BIM sources while others are present in BIM models but need to fulfill the exchange requirements to be used properly. Based on the EM, technical ICT professionals will further be able to write the MVD codes and improve them into the authoring software.

When confronting the actual design workflow with the proposed one, the latter method is much more efficient as it eliminates data re-entry manually, so avoiding human error possibility, and speeding up the overall process. According to the interviews, data re-entry is the biggest problem to deal with, making this a crucial issue to be mitigated. For instance, Figure 4 shows that despite all needed BIM data are already present in the conceptual BIM model, structural engineers must redraw it from scratch, not to mention that information required for structural purposes are of elementary geometry, thus making the IFC data subset simple. All professional knowledge could be better applied by solving engineering issues instead of wasting time in redrawing ready-given information.

There are specialized software devoted to prefabricated components, that integrates well with BIM authoring tools. Current practices, however, do not explore all potential in the expected synergy between BIM and prefab/modularization, because of many problems of interoperability that were identified. The cost of this solution is just part of the problem. Lack of technical knowledge plays a more significant role in it.

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