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Smart Manufacturing for Industrialized Construction 2021

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Research Article

IDM for the Conceptual Evaluation Process of Industrialized Timber Projects

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Interest in industrialized timber construction systems, in particular light-frame systems, has increased worldwide due to its various benefits. However, it is very important for projects executed under the off-site construction system to consider the different manufacture and assembly requirements in their design, following the design for manufacturing and assembly (DFMA) concept. It is fundamental that these requirements and assumptions for manufacture and assembly be considered in a conceptual evaluation during the early stages of the project, as these have an impact on stakeholder decision making, detailed design, production, and sourcing strategies. To accomplish this, the use of building information modeling (BIM) has simplified the different processes and tasks required in the development of these projects, in addition to the synergy between both methodologies. However, it is vital to be clear about the information requirements of each process to properly use the BIM methodology. This paper presents the proposal of a BIM standard, the information delivery manual (IDM), which identifies the associated process map and the information parameters required for early evaluation, which were validated with local prefabrication companies as well as compared to the property sets present in the IFC standard.

1. Introduction

In recent years, prefabricated timber-based building systems have shown a positive trend and steady growth worldwide [1]. This is due to the multiple benefits of using these methods that are based on off-site construction and industrialization of projects, such as less waste generation on site, increased project quality, shorter work time on site, and reduced risk of accidents [2, 3].

Light wood frame construction is the most used timber system in Chile, with respect to its variants platform frame, balloon frame, and others, and has become quite relevant thanks to the implementation of new industrialization process technologies [4]. Similarly, this system is widely used in countries such as Canada, the United States, and New Zealand, especially for residential construction due to its simplicity, ease of manufacture, and assembly [5].

Because of the advances in processes and technologies for industrialization in construction, the design for manufacturing and assembly (DFMA) concept aims to ensure that designers consider the manufacturing and assembly requirements of prefabricated projects from the design stage so that these projects have good manufacturing and assemblability [6].

Due to these multiple criteria and design requirements, having a commercial evaluation becomes relevant for decision making in early design stages, especially when all aspects and definitions of the project are not yet known in detail, where factory, transportation, and assembly constraints—typical of off-site construction—must also be incorporated [7]. Along these lines, the commercial evaluation in conceptual design phases is strategically relevant, as it defines not only the guideline and scheduling of the next phases of the project [8] but also determines the sourcing strategy and its influence on detailed design stages [9].

In addition, building information modeling (BIM) and off-site construction are highly related, and by applying them together, it is possible to maximize the benefits of both methodologies for this sector of the industry [10]. The adoption of off-site construction and the trend towards the industrialization of projects simplify the creation of digital models used in the BIM methodology, since, for example, the solutions for prefabricated building elements can be modeled as BIM objects within a library to be reused in other projects [10].

Furthermore, both BIM and off-site construction are closely associated with product and process perspectives, where BIM serves not only as a tool for parametric design but also as a philosophy for the off-site construction process [10]. In this way, the use of BIM methodology has been promoted as part of the industrialization process itself, since it uses and requires digital models that allow connecting the different links and subprocesses of the supply chain of these projects [10].

At the same time, BIM has eased and supported the different processes associated with off-site construction, since through the use of information models, it is possible to coordinate the different specialties of the project, improve the visualization of its components, analyze thermal and structural performance, and simplify the processes of cost estimation, assembly sequence, manufacturing, logistics, etc. [11, 12].

Based on this background and the synergy between the implementation of BIM methodologies and industrialization, it is very important to be clear about the specific requirements to include in the development of each BIM standard to support each of the subprocesses and activities associated with the development of off-site construction system projects. In particular, this is relevant for timber-based projects, which have not been studied well enough to establish a sufficient level of maturity for implementation [13].

Due to these reasons, the objective of this research is to develop and propose an information delivery manual (IDM) which captures and specifies the processes and information flows required for the commercial evaluation of industrialized light-frame timber projects under the platform frame system.

This research addresses the gap within the early evaluation process of industrialized wood projects associated with the lack of a standard that establishes the workflows and the information exchange requirements that support and improve this process, taking into consideration the multiple criteria, assumptions, and peculiarities of this type of project. Thus, this work contributes to the body of knowledge inside the industry by proposing a standard information model based on the BIM methodology, which supports the decision-making process during the early evaluation phase of industrialized timber projects.

2. State of the Art and Practice

2.1. BIM Standardization. Building information modeling (BIM) is based on the generation and management of building or facility information through the development of digital models that support the different phases of the project [14]. For the development of these models (known as building information models), various tools are used to enable collaboration between the different stakeholders and users involved in each phase of the project.

To obtain a successful implementation of BIM, it is important to capture all relevant data in the BIM model and achieve a successful exchange of data between the different project participants [13]; so, one of the key factors in achieving BIM success is the efficiency of interoperability solutions that enable the flow of information between the different project disciplines [15].

In response to the challenges of interoperability, various methodologies and standardized formats have been developed to facilitate the exchange of data between the different specialties and phases of a project, where various BIM tools are used. An example of this is OpenBIM, an approach to building design, execution, and operation based on open standards and workflows [16], developed by BuildingSMART in collaboration with software vendors.

OpenBIM includes the industry foundation classes (IFCs) format, an open international standard (ISO 16739-1: 2018) based on an object-oriented data model that allows the digital description of the elements or assets present in the BIM model [17]. It is possible to use the IFC standard to support a full range of BIM data exchanges between different disciplines and BIM applications. Each domain within the industry adopts the part of the IFC data model schema that allows it to represent the BIM model for that particular discipline. This subset of the IFC schema is known as model view definitions (MVDs) [18].

Under this line, BuildingSMART has proposed an integrated process to design, implement, certify, and use standard information exchanges for the transformation of the needs of each area within the industry into operational solutions and thus achieve a good implementation of the BIM methodology. This process includes four distinct phases:

(1) Development of an information delivery manual (IDM): this phase defines the process and the information to be exchanged between the stakeholders and their software applications.

(2) MVD concepts and mapping: the MVD documents the subset of the IFC model that is required for the information exchanges defined in the IDM.

(3) Implementation and certification of the application: once the MVDs are documented and published, technical support is required to implement these results in the software solutions and obtain certification of the application.

(4) BIM data validation: this stage allows the end user to verify that a BIM model exported from a certified software application complies with the requirements defined in the original IDM and MVD for information exchange.

In other words, the MVD is generated based on the information exchange requirements (ERs) specified within the IDM standard; since, conceptually, the MVD integrates these information requirements coming from the different IDMs to the most logical model views that will be compatible and implemented in the various software applications used within the BIM methodology [13].

Furthermore, the International Standard ISO 29481 establishes that the IDM is made up of two main components. The first component is the process map, which aims to describe the flow of activities within a process, as well as the roles played by the stakeholders and disciplines involved, together with the information required and produced. The second component is associated with the set of exchange requirements (ERs), which define the information that must be exchanged to support the process at a specific stage of the project [19]. To define the ER, the use case concept is employed, which defines a scenario of information exchange between two roles defined for a specific purpose, within a particular phase of the project life cycle [20].

Consequently, the development of a well-defined IDM and MVD plays a key role in the successful exchange of information throughout a construction project [18]. Therefore, various disciplines and areas within the construction industry have advanced in the establishment of these standards (IDM, MVD, etc.) intending to simplify data exchanges between the different tools used in the BIM. The following section presents the progress associated with the development of these standards for different domains and industry sectors.

2.2. BIM Standards in Different Industry Sectors. Various sectors and domains within the construction industry have developed and advanced to different extents in the definition of standards associated with the BIM methodology, which have made it possible to facilitate the exchange of information that takes place during the development of projects. For example, the CIS/2 format, from the steel industry, is the first computational data model for structural steel developed by CIMsteel [21], which allows software developers to make their applications compatible with each other.

Moreover, the construction operations building information exchange (COBie) standard format has taken care of the transfer of digital information from the design and construction process to the management, operation, and maintenance of the asset [22]. This format is a data exchange specification based on the neutral IFC standard, which describes the exchange of information between the construction and operations phases of a project [23].

Also, LaNier et al. [24] developed a specific MVD for precast concrete known as the MVD for precast concrete exchanges, which defines the data exchanges necessary for various design, engineering, and manufacturing tasks of precast concrete elements [25]. Before this development, the work done by LaNier et al. related to the IDM for precast concrete addressed all the information exchanges associated with the main tasks of the manufacturer when interacting with other relevant stakeholders. This IDM defined four workflow cases associated with the precast concrete process: *architectural precast, precaster lead project, precaster as subcontractor*, and finally the common flow of *fabrication and erection* [24].

Regarding other materials and disciplines, there are currently several projects, research, and organizations dedicated to the development of MVD and BIM standards associated with different areas and sectors within the industry [26], for example, information exchanges based on the MVD for the simulation of building energy performance [27]; specific MVD for structural analysis, cost estimates, requirements for thermal simulations; and even MVD for the proposal of the bridge inspection process [28]. Likewise, the research conducted by Gentry et al. [21] presented the development of a BIM data model for the masonry construction system, where information is specified for masonry pieces and walls manufactured with this system [21].

It is important to mention that the description of the research and proposals of the different MVDs are available on the IFC solutions factory site [26], and BuildingSMART also hosts a database with the different proposals and research under development associated with both IDM and MVD proposals available on its website [29, 30].

In relation to advances in BIM standards associated with timber construction, UF-DCP-010 and UF-DCP-02 projects [26] aim to research the development of said standards for masonry and timber construction. Within these projects is the research conducted by Nawari [31], which proposed to use an IDM and a MVD in the design and structural analysis of timber structures, devising the functional requirements for the development of a BIM standard to support the design process of timber structures [13]. This research took the first step in the development of the IDM and the MVD for structural timber systems, which provides a basis for the standardization of BIM information flows in the structural timber domain [13]. However, it is important to mention that this proposal did not consider within its scope the process of prefabrication of timber structures nor the standardization of information flows to facilitate the exchange of data within this particular process.

Furthermore, with respect to prefabrication and industrialization processes and their advancement in BIM standardization, the research conducted by Nawari [13] covered the development of an IDM and addressed the advances and need for advancing the BIM standard in off-site construction [31]. In this case, the workflow definitions of this IDM were linked to an overall process and addressed different use case exchanges within off-site construction. This IDM incorporated information exchanges between architects, engineers, manufacturers, and general contractors and subcontractors, along with other exchanges geared towards the procurement phase [31].

The work of Ramaji and Memari [32] also presented a method for standardizing information exchanges in industrialized modular projects, developing an IDM based on the method proposed in the national BIM standard (NBIMS-US) and incorporating the concept of product architecture model (PAM) to address the additional needs that exist in the development of modular buildings. The product architecture model, as the authors mentioned in their research, is defined as a way in which the functional elements of a product are assigned to the various physical components of the project and how they interact. In this context, the product architecture model is the crucial element in the method proposed by NBIMS to look at this type of project from the production point of view and is used as the core for the whole BIM standardization proposal [32].

Despite these great advances in the work on standardization in BIM information flows and proposals for the IDM and MVD, it is worth mentioning that the use of timber and off-site construction has not been treated in an integrated manner. This implies difficulty for the implementation of BIM for this sector of the industry since there is no standard definition of the data flows and information requirements to carry out the off-site construction process for timber building projects based on the use of BIM methodology.

Due to this, the main objective of this research is to develop and propose an IDM that captures and specifies the processes and information flows required for the early evaluation of prefabricated timber projects. To achieve this, the following specific objectives are proposed:

(i) To identify the main activities and exchange models within the development of prefabricated timber projects.

(ii) To propose the information exchange requirements (ERs) associated with the early evaluation model through a list of information parameters.

In particular, this paper emphasizes the prefabrication system of timber buildings based on two-dimensional panels of the platform frame type.

3. Research Methodology

Figure 1 shows the research methodology of this paper, identifying the activities and corresponding methods associated with each objective.

As part of the deliverables and components of an IDM, the first specific objective was to generate a process map that describes the flow of activities and information when developing prefabricated timber projects. In order to meet this first objective, 3 activities were proposed. First, a general survey of the stakeholders, phases, and activities associated with the development of prefabricated timber projects (1.1). Second, mapping the required information flow associated with this process (1.2), and finally, validating the mapping (1.3).

The methods used to carry out the activities in the research methodology were mainly based on an iterative process associated with 3 interviews (A, B, and C) conducted with representatives of different prefabrication companies. Table 1 shows the description of the companies and representatives that participated in the interviews described above.

The second specific objective was to propose the information exchange requirements (ERs) associated with the exchange model of the early evaluation subprocess of prefabricated timber projects. These information parameters (ER) were identified and proposed (2.1) based on the active participation of the main author in a prefabrication company, and then, based on this proposal, the relevant parameters necessary for the early evaluation process of these projects were filtered and validated (2.2). Subsequently, the relevant parameters identified were compared with the standard IFC model (2.3) to finally propose the final set of attributes that will be relevant to the early evaluation process of prefabricated timber projects (2.4).

Regarding the methodology implemented, as mentioned, there was an initial approach with the group of representatives of the different prefabrication companies (Table 1). From this first approach, the necessary information was gathered to generate a first deliverable of the process map proposal (activities 1.1 and 1.2). Also, in parallel to this process, the main author had an active participation in company 4. This participation lasted 8 months and was carried out in the engineering and design area, where the main role was to generate the different deliverables necessary for the development of the project, both to execute the production of the elements in the manufacturing plant as well as for the onsite assembly tasks, i.e., manufacturing planimetry, 3D models, assembly sequences, transport design, etc. At the same time, in order to relate the existing knowledge with the work done in the company, the authors decided to use process maps from the literature related to industrialization and timber construction as references to achieve this activity. For example, research that included a general process map for off-site construction [33] and a process map for wood construction [13].

Subsequently, for the validation of the process map, the iterative process of interviewing company representatives was continued (Table 1) In this case, this validation was achieved through a structured interview (detailed interview B) and carried out independently for each participant, in order to obtain a consensus on the mapping proposal. For this, interview B contemplated the validation of seven aspects present in the process map: (i) participating disciplines, (ii) process phases, (iii) tasks and subprocesses, (iv) relations between activities (flow of activities), (v) deliverables of each activity or subprocess (documents, models, etc.), (vi) decision-making points within the flow, and (vii) open question to identify requirements or special aspects within the mapping.

In the case of the second specific objective, the process was similar to the one described above, that is, based on the author's participation in company 4 and the iterative interview process, activity 2.1 was carried out, in which the main parameters associated with the industrialization process of timber projects were identified based on the different information exchange models present in this process. Subsequently, the attributes identified in activity 2.1 were

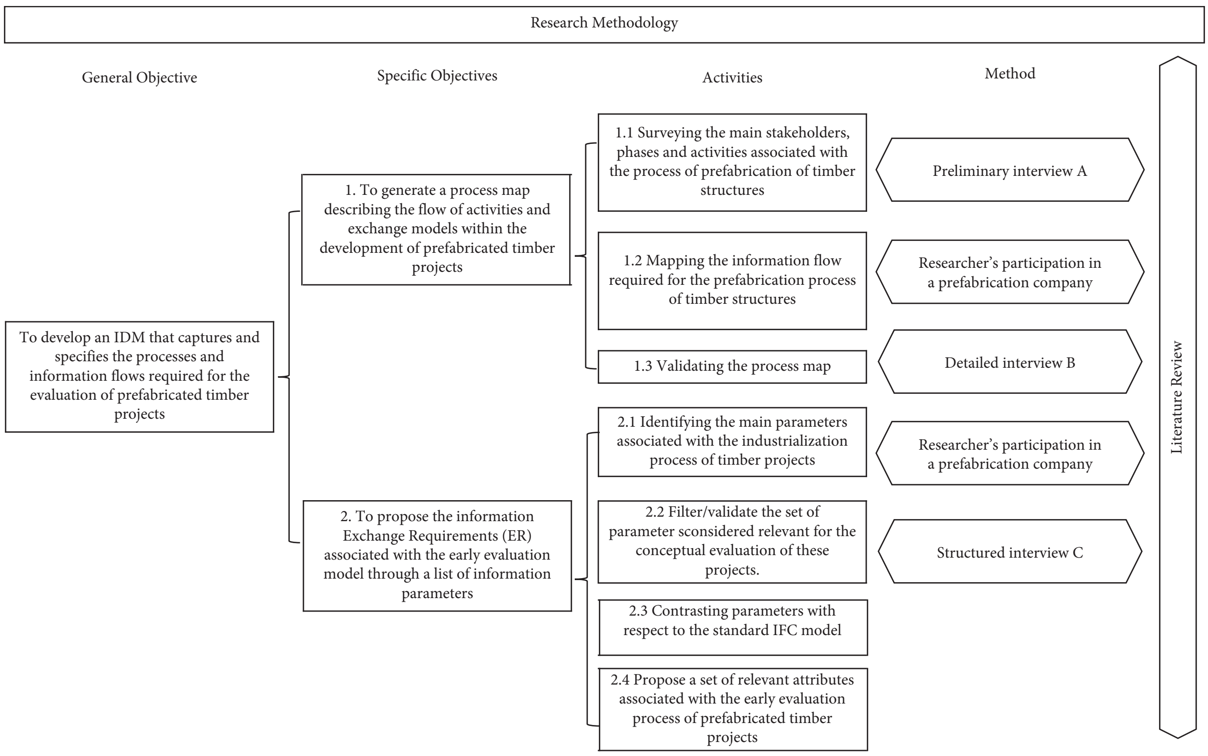

Figure 1: Research methodology.

compared to the parameters and properties present in the IFC standard (2.2).

Then, based on the focus of this research and the result of activity 2.1, the parameters considered relevant for the early evaluation of these projects were filtered and validated (2.3). This was done through a structured interview (interview C), in which a list of all the identified parameters was presented and those that were necessary and relevant for the early project evaluation process were classified. The same representatives of companies 3 and 4 in Table 1 participated in this process. However, for companies 1 and 2, experts associated with the project evaluation process participated in interview C.

Lastly, a final proposal was made for the set of relevant attributes associated with the early evaluation process of prefabricated timber projects that should be present in the exchange model of this subprocess (2.4). In this way, the IDM standard proposal was obtained, which allowed capturing and specifying the processes and information flows required for the evaluation of prefabricated timber projects.

4. Workflow Associated with the Industrialization Process of Timber Projects-Process Mapping

One of the main objectives in the development of an IDM is to simplify the workflow within a process by identifying and specifying the data required to develop each of the tasks or subprocesses needed within the workflow. Thus, if the information is available and of good quality, the process itself is greatly improved [19].

Likewise, the purpose of the IDM is to show the definitions of the functional requirements of the data or information exchanges between each of the tasks or subprocesses executed by the different stakeholders in a given phase, which are known as exchange requirements (ERs). This information exchange is performed by means of exchange models, which define the functional content of the information to be exchanged in a use case. A use case defines the data required in each information exchange scenario between disciplines within a workflow [20].

This section presents the produced results associated with the first specific objective, in accordance with the research methodology presented in Section 3. This section presents the process map obtained, as well as the breakdown and description of each of the main components associated with this mapping: phases, activities, participating disciplines (stakeholders), flow of activities, and exchange models.

4.1. Disciplines Involved in the Industrialization Process of Timber Projects. The main disciplines involved in the process of industrialization of timber buildings are presented and described below.

(i) Client: person or entity for whom the project is executed.

(ii) Architecture: discipline responsible for the planning and design of buildings and structures by applying the knowledge of design, construction procedures, zoning regulations, building codes, and materials [34]. In the context of this research, this discipline

Table 1: Description of the companies and representatives participating in the iterative interview process.

Companies	Countries	Company descriptions	Interviewee's profession	Position in the company	Interviewer's years of experience
1	Chile	This company offers housing solutions based on a modular system. It has a catalog of already defined solutions for housing and spaces according to different requirements (offices, houses, etc.)	Civil engineer	Head of civil specialty	18
2	Chile	This company is specialized in off-site construction that provides services in manufacturing, assembly, and dispatch of interior and exterior walls of houses that are part of various real estate projects associated with the company	Civil structural engineer	Development manager	5
3	Chile	This is an off-site construction company of timber projects based on a CLT panel system	Engineer	Project manager	20
4	Chile	This company is dedicated to the design and production of industrialized construction systems based on timber structure panels. It has an automated numerical control production line	Civil engineer	Head of engineering and design	8

participates in several stages of the project life cycle, as its knowledge of the good use and function of spaces together with the construction processes is used to define the design of the building and make the necessary adaptations to build under the off-site system.

(iii) Structural engineering: discipline that deals with the design of structures based on the load demands or stresses of the building; it is responsible for ensuring that the structure is designed to withstand these loads [34].

(iv) Off-site construction company: discipline specialized in adapting building projects to the off-site construction system.

(v) MEP: project specialists associated with mechanical, electrical, and plumbing installations.

(vi) General contractor: discipline that performs onsite assembly work for the project. It is in charge of the supervision and proper execution of the tasks on site. Examples: a construction company, assembler, etc.

It is important to mention that these disciplines respond to the current national context based on the interviews conducted with companies participating in this research. Having said that, depending on the context, country, or even the company or regulations, there could be other disciplines (or activities) involved in the process such as master builder, planner, landscape architect, and green building consultant. This work presents the most relevant disciplines involved in the general development of industrialized timber projects.

4.2. Phases Associated with the Industrialization Process of Timber Projects

(i) Conceptual design phase: this corresponds to the conceptual design phase of the project in which the client, architecture, engineering, and the off-site construction company participate. This phase must ensure that the project concept can be implemented. The early involvement of the architecture and engineering disciplines allows the preliminary design to be based on the information provided by the client. Likewise, in this phase, the project evaluation is carried out, in which all relevant variables must be considered in order to execute the project under the off-site construction system and evaluate its feasibility. Given this, it is important to highlight a relevant activity performed by the off-site construction company, which the research team decided to incorporate into the process map. This activity consists of a process of optimization and improvements that the off-site construction company performs in early stages and that the designer (architect) can consider at the conceptual design stage.

This early input from the off-site construction company not only allows for information associated with the process to be carried out in the plant but also allows for a more accurate evaluation of the project by having more information associated with the production process.

(ii) Design phase: once the project is approved by the client, the more detailed design phase of the project begins. During this phase, the architecture and engineering disciplines are mainly involved in defining the design detail of the project. Coordination with MEP specialties is also incorporated into this design. Finally, a relevant activity is executed which consists of adapting the result of the detailed design into a design suitable for manufacturing. Since many companies work with automated production lines, it is necessary to incorporate all the details and configurations in the design so that the elements (panels) can be produced in the factory.

(iii) Off-site manufacturing and assembly: finally, the off-site manufacturing of the project is executed in these phases (in the production line from the result of the detailed design) to finish with the assembly of the elements at the project site.

4.3. Activities and Models of Exchange Associated with the Development of Industrialized Timber Projects. The following is a description of the most relevant activities and subprocesses that are part of the workflow associated with the industrialization process of timber projects:

(i) Project information distribution: this activity consists of the client providing the main information associated with the project to be executed. For example, type of building, location, regulatory requirements, and preliminary planimetry.

(ii) Schematic design: this subprocess consists of the architectural schematic design of the project in which the spaces of the building are defined. In this subprocess, the wall thicknesses are also preliminarily defined according to the construction solutions based on the regulatory requirements.

(iii) Improvements and optimization: this subprocess arises as a result of activities 1.1 and 1.2 according to the research methodology. It is an optional activity suggested by the companies, which consists of the early participation of the off-site construction company, with the objective of taking into consideration the production process project design conditions. The result of this task allows for making improvements to the project design that are in accordance with the manufacturing and operation processes of the off-site construction company, as well as identifying the particular characteristics of the project with respect to its manufacturing.

Regarding the improvements and optimization processes before the detailed design of the project, they may relate to different aspects of the project. One of these is to minimize the number of panels required (either horizontal

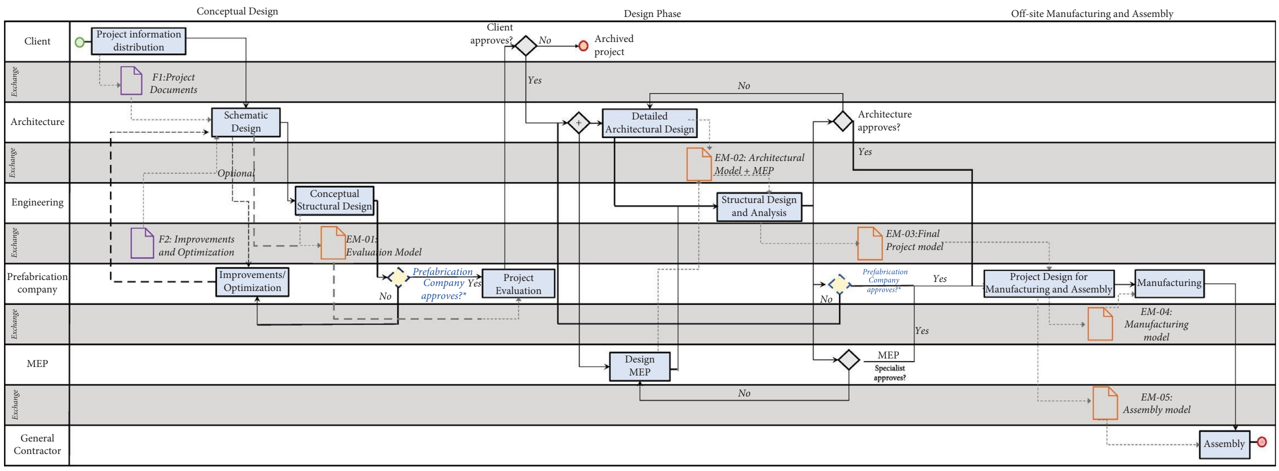

Figure 2: Process map associated with the development of prefabricated timber projects.

or vertical) and thus reduce assembly times; however, there are several restrictions associated with this task such as structural requirements, geometric restrictions associated with the dimensions of assembly tables and manufacturing plant facilities, geometric restrictions of transportation, and lifting operations of the elements, among others.

Also, another type of optimization to be considered is to minimize the manufacturing costs of the off-site construction company, i.e., material costs, plant fabrication time costs, etc., where the constraints are due to the different performance requirements of the project (acoustic and thermal insulation and fire resistance) and structural compliance checks.

Along the same lines, another important task associated with the industrialization process of timber projects, particularly for the panel system, is that prefabrication companies seek to make the maximum use of the panel assembly tables according to the dimensions of the construction elements of the project, i.e., to form the so-called multiwall systems. This system consists of manufacturing more than one panel on the same assembly table, which has a fixed and standard length. The configuration of this multipanel system for manufacturing can take into account several assumptions and considerations according to the characteristics of each project, for example, panel assembly sequence, order and priorities in transportation, and similarity in dimensions between different panels.

Accordingly, the development of these activities also allows for a better commercial evaluation process of the project; since it is possible to have more precise information regarding the project's manufacturing, a better estimate of the time required for manufacturing as well as of the costs associated with the detailed design and manufacturing of the project.

(i) Conceptual structural design: this activity advances in the conceptual structural design of the project, i.e., it preliminarily defines the dimensions of the construction elements (walls, flooring systems, etc.) as well as the type of connections required for both manufacturing and assembly, in order to obtain a more accurate cost estimate.

(ii) Project Evaluation: in this subprocess, the commercial evaluation of the project is performed. The project costs and deadlines are estimated in order to determine whether the execution of the project is profitable and convenient for the parties involved, and this proposal is submitted to the client.

(iii) Detailed architectural design: in this activity, the detailed design of the architecture of the project is carried out, in which the positions of openings, spaces, wall thicknesses, etc., are definitively determined. In general, this activity is carried out in parallel and in coordination with the following activity.

(iv) MEP installation design: in this activity, the design of the project's installations, whether electrical, mechanical, or plumbing, is carried out. This activity is very important since it is necessary for the coordination of specialties.

(v) Structural design and analysis: once the architecture and design of the installations are defined, the structural design and analysis of the project are carried out. From this activity, the final design of the construction elements (walls, floor timber, ceilings, etc.) is obtained, specifying the dimensions of the framing, fabrication, and site connections, together with the results and calculation report of the project.

(vi) Project design for prefabrication and assembly: this activity consists of preparing the various specifications associated with the manufacture and assembly of the project. It also includes all design specifications to be carried out, from the factory to operations, i.e., the scope of prefabrication, specific fabrication details, preassembled elements, procedures to be executed on site, etc. The same applies to the case of assembly, i.e., transport and logistics specifications, detailed assembly sequences, assembly connections, on-site procedures, etc.

Table 2: Information exchange models and requirements of the process map.

Exchange models (according to use case)	Names of exchange model	Exchange requirements (ERs)
EM_01: Architecture and engineering: off-site construction company	EM_01: Conceptual evaluation model	Volumetric model of the project, contains the general characteristics in terms of architecture and geometry based on volumes of the proposed constructive solutions, with the allocation of estimated costs
EM_02: MEP architecture and design: engineering	EM:02: MEP architecture and design model	Coordination model, contains the details of the architectural and installation definitions approved by the project client
EM_03: Engineering, architecture and MEP: off-site construction company	EM_03: Final project model	Detailed final model with architectural and installation definitions, with the incorporation of structural definitions
EM_04: Engineering: off-site construction company	EM_04: Fabrication model	Project model used to generate the information associated with panel fabrication, multiwall configuration, and parameters associated with the fabrication process. This model verifies the information associated with the nailing and cuts to be made during manufacturing, as well as the details and special procedures to be considered during panel assembly
EM_05: Off-site construction company: general contractor	EM_05: Assembly model	Construction model of the project that incorporates the information associated with the assembly process, i.e., the placement of connection hardware, screws, construction sequences, details of connections, etc

Table 3: Information exchange.

Information exchanges	Use case	Descriptions
F_01: Project documentation	Client: architecture	The main background of the project, such as type of building, location, and initial planimetry
F_02: Optimization information	Off-site construction company: architecture	Information that the off-site construction company provides to the designers in the early stages to achieve a more accurate evaluation of the project. This information can consider the quantification of the project's panels, the configuration of the assembly tables, and all the appraisals that the off-site construction company visualizes as a specialist according to the project's background

Table 4: Minimum geometric parameters associated with the development of prefabricated timber projects.

Parameters	Descriptions	Exchange models (EMs)
Length	Minimum geometrical definition: it is also relevant to identify the lengths of the sole plates, to optimize the production tables, and the assembly of the packages for transport	EM_01–EM_05
Thickness	Minimum geometric definition. Like the previous attribute, it is also used for the configuration of the assembly tables in multiwalls	EM_01–EM_05
Height	Minimum geometric definition. Like the previous attribute, it is also used for the conformation of the reinforcement tables in multiwalls	EM_01–EM_05
Anchorage position	Relevant to perform in the manufacturing of the panels. In addition, it is a definition that involves the structural capacity of the panel according to its design	EM_03–EM_05
Position additional studs	Defines the position within the panel geometry relevant for correct panel assembly	EM_03 to EM_05
Panel floor	Location of the panel within the project (level). This information is relevant not only because it defines the position of the panel within the project but also because its correct assignment allows the control of the order and logistics on site, especially in large scale projects (midrise buildings, hospitals, etc.)	EM_01–EM_05

In this activity, the associated exchange model allows obtaining the different deliverables, both for the manufacturing of the project and for its assembly. For the former, it is possible to obtain the necessary files to execute the automated processes in the numerical control (CNC systems) machines that the off-site construction company may have. For the latter, the exchange model also contains the information associated with the assembly of the project, which will be required onsite, for example, assembly sequences, connections, procedures, and planimetry.

(i) Fabrication: the project is manufactured according to the off-site construction company's production line. This activity varies among the different prefabrication companies as they respond to the characteristics, restrictions, and conditions of each company according to its production process.

(ii) Assembly: the project is assembled and built on site, according to the specifications generated in the project design for prefabrication and assembly activity.

Figure 2 shows the result of the process map associated with the development of prefabricated timber projects. It shows the different components described above and how they are related. In this case, the business process modeling notation (BPMN) was used. Likewise, this map also shows the information exchanges, either through exchange models (EMs) or other documents, which are described in Tables 2–4.

After obtaining the results associated with the process map presented in Figure 2, it is important to mention that the workflows of prefabrication projects depend on the internal tasks and flows of each prefabrication plant. These flows are also adjusted according to what is most appropriate for each project; however, the objective of this research is to focus on information exchanges in an illustrative manner through a general process and not to present this proposal as a prescriptive process.

Finally, it is important to mention that two "control points" included in Figure 2 (*) made by the Prefabrication Company were not a part of the results of the interviews, although it was included in the process map as a preferable situation to get a better design and model project with good manufacturing and assemblability. Also, this was a recommendation of some companies that emphasized the relevance of the continuous participation of the prefabrication company during all the process.

5. Information Exchange Requirements (ERs) Associated with the Conceptual Evaluation Model

5.1. Main Parameters Associated with the Industrialization Process of Timber Projects. As a result of activity 2.1, according to the research methodology, this section presents a general list of the main information parameters that are involved in the development of industrialized timber projects. Tables 5 and 6 show the list of these attributes, their description, and the exchange model to which they belong.

It is important to mention that the main entities of the exchange models (EMs), which contain the information parameters associated with the industrialization process, correspond to vertical panels (wall panels) and horizontal panels (floor timber panels or flooring systems). Thus, the parameters presented in the following sections belong to the entity IfcWall in the case of wall panels and IfcSlab in the case of flooring systems panels.

5.2. Contrast with IFC4 ADD2 TC1 Data Model (Publication in ISO 16739-1:2018). The abovementioned list of the main parameters associated with the development of prefabricated timber projects (Table 6) was compared with the IFC data model version 4 ADD2 TC1, which corresponds to the latest ISO publication. Table 7 shows the comparison made with respect to the attributes and set of properties that are present

Table 5: Minimum nongeometric parameters associated with the development of prefabricated timber projects.

Parameters	Description/Uses	Exchange models (EMs)
Panel construction solution ID	Identifies the type of construction solution designed for the panel, i.e., the configuration of its timber core (cross section, spacing, and structural grade) and the rest of the cladding layers of the solution (e.g., bracing plates, termination plates, and insulation)	EM_01–EM_05
Panel weight	Relevant for panel loading control and to be able to quote the correct equipment, relevant for the analysis of lifting systems and logistics	EM_01–EM_05
Anchorage specification (hold down or the anchorage system)	Parameter that may be relevant in case the logistics of the anchorage elements is the responsibility of the manufacturing plant and requires information on their specification. The importance of this parameter lies in assuring that the CNC machining to be performed on the panel correctly installs the anchor according to the project design	EM_01–EM_05
Panel has MEP installations	Identifies whether the panel in question has electrical, mechanical, or plumbing installations	EM_02–EM_05
Panel assembly location	Defines where the panel is to be assembled, either in the factory or on site	EM_03–EM_05
Number of additional studs	Relevant for correct panel assembly	EM_03–EM_05
Interior and perimeter plate nailing pattern	Relevant for material quantities, cost estimates of the off-site construction company, and correct execution of the patterns in plant according to the design specifications	EM_03–EM_05
Cost per square meter of panel	Relevant for cost estimation and financial evaluation of the project	EM_01
Panel ID	Relevant for the identification, management, and control of the panel to be manufactured	EM_01–EM_05
Panel fabrication table ID	Relevant for plant planning and production capacity. Obtaining this parameter involves a process of analysis and optimization during the design phase of the project	EM_01–EM_04
Transport identifier code	Code identifying the package and/or truck where the panel in question will be transported	EM_04–EM_05
Identifier code to indicate the company/shift that manufactures a panel	Identifies the team responsible for manufacturing the panel	EM_04–EM_05
Identifier code of procedures/details at the factory	A code or description associated with a procedure or detail to be performed in the manufacture of the panel (reinforcement with screws, insulation placement, etc.) is defined	EM_04
Site/assembly procedure identifier code	Indicates if the panel requires a special procedure on site or during assembly, e.g., special lifting requirements and reinforcement	EM_05
Panel assembly sequence identifier code	Code specifying the order in which the panel is assembled on site	EM_04–EM_05
Wood structural grading	Specifies the structural grade of the wood used on the panel	EM_02–EM_05
Type of treatment applied to the wood	Specifies if the wood used for the panel considers a specific treatment	EM_04
Acoustic, waterproof, or fire seals ID	Indicates if the panel requires the installation of special seals, either on site or at the plant to ensure regulatory requirements	EM_04–EM_05
Storage conditions	Specifies if the panel requires any special storage	EM_04–EM_05
Equilibrium moisture in plant	Specifies the equilibrium moisture as the condition in which the panel was manufactured	EM_05

Table 6: Minimal nongeometric attributes and their contrast in IFC.

Parameters	IFC4 ADD2 TC1			Proposals
	Present in IFC	Property sets in IFC	IFC attribute names	
Panel construction solution ID	Yes	Pset_ManufacturerTypeInformation	ModelReference	—
Panel weight	Yes	Qto_BaseQuantities	GrossWeight	—
Anchorage specification (hold down or the anchorage system)	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Panel has MEP installations	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Panel assembly location	Yes	Pset_ManufacturerTypeInformation	AssemblyPlace	
Number of additional studs	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Interior and perimeter plate nailing pattern	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Cost per square meter of panel	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Panel ID	No	Pset_ManufacturerOccurrence	SerialNumber	—
Panel fabrication table ID	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Transport identifier code	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Identifier code to indicate the company/shift that manufactures a panel	Yes	Pset_ManufacturerTypeInformation	Manufacturer	—
Identifier code of procedures/details at the factory	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Site/assembly procedure identifier code	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Panel assembly sequence identifier code	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Wood structural grading	Yes	Pset_MaterialWood	StrengthGrade	—
Type of treatment applied to the wood	No	Does not exist	Does not exist	Incorporate in Pset_MaterialWood
Acoustic, waterproof or fire seals ID	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Storage conditions	No	Does not exist	Does not exist	Handle in property set of timber prefabrication
Equilibrium moisture in plant	Yes	Pset_MaterialWood	MoistureContent	—

Table 7: Relevant information for exchange model EM_01 associated with the project conceptual evaluation.

Parameters	Types	Importance of the parameter in EM_01
Length	Geometric	These minimum geometric definitions associated with the wall panel or flooring systems allow not only to define the geometry and volume of the element but also to identify whether the panel can be prefabricated within the production plant, according to its restrictions, or even if it is convenient to assemble the panel on site due to other difficulties such as variable heights and double height panels
Thickness	Geometric	
Height	Geometric	Likewise, as previously mentioned, length and thickness are key geometric parameters for the configuration of the multipanel system, since within the same table it is convenient to combine panels with the same height and thickness to avoid conflicts in the automated system associated with the CNC machines
Floor	Geometric	Early knowledge of this information allows for a better estimation of the costs and time associated with manufacturing and the tasks to be performed on site
Panel construction solution ID	Nongeometric	Knowing the type of construction solution associated with the panel is very important for the commercial evaluation performed by the off-site construction company, since it defines the materials to be used to manufacture the panel (coatings, insulation, framing, type of membrane, etc.). This is relevant not only to establish the unit prices of the solutions but also to quote their availability in the market
Panel weight	Nongeometric	It provides the order of magnitude of the project load and the identification of the most critical panels for the selection of lifting tools and machinery (and associated costs). Likewise, this information is relevant for configuring the loading of the panels on the transport trucks from the production plant to the project site
Anchorage specification (hold down or anchorage system)	Nongeometric	The cost of anchors is an important direct cost of the project, so knowing their specification at an early stage allows for their quotation and market availability study, and thus obtaining a much more accurate evaluation of the project cost
Cost per square meter of panel	Nongeometric	Basic information that allows quantifying the overall direct cost of the project, and it is associated with the parameter of the panel's construction solution. Sometimes, various modification factors are applied to this parameter to quantify an increase in cost due to difficulties or particularities that the panel may have, for example, openings, installations, and special geometry
Panel ID	Nongeometric	It allows the identification and quantification of the project's panels in addition to managing the information in a more organized manner
Panel fabrication table ID	Nongeometric	Although this attribute takes on greater relevance and is required in later stages of the evaluation, since it is key for the programming of factory production, the result of this research showed that knowing the configuration of the assembly tables is an important input that the improvement/optimization subprocess carried out by the off-site construction company can provide to the designers in early stages. This input is important because it allows for the estimation of the production time and costs associated with the project. It is also possible to make better decisions regarding production planning, which has a significant impact on costs during all phases of the project (production planning, transportation, assembly, etc.)

in the IFC standard and that could be related to the attributes identified for the industrialization process of timber projects. In case there is no correspondence of the identified attribute within the standard, the last column of Table 7 shows a proposal for managing the parameter.

From the results presented in Tables 6 and 7, it is possible to affirm that only 6 of the 20 minimum (general) nongeometric parameters associated with the development of industrialized timber projects have a corresponding attribute within the IFC data schema. This implies that the standard IFC data model somehow does not allow to properly managing the information associated with the development of industrialized timber projects. Consequently, the BIM workflows associated with this process are made difficult and are carried out in a nonstandardized and disorganized manner.

Also, since many of these attributes are not present in the IFC standard, this research proposes to manage these parameters in a specific property set associated with the process of prefabrication of timber projects. Just as there is a Pset_PrecastConcrete within the IFC standard, which responds to the information requirements for the precast process of concrete elements, there should be a property set that responds to the data requirements of the process of prefabrication of timber buildings.

5.3. Parameters Associated with the Conceptual Evaluation Exchange Model EM_01. According to the results presented in Table 6, this section details the specific minimum parameters that are required in the conceptual evaluation exchange model for prefabricated timber projects (EM_01). The following table shows those attributes relevant to the exchange model EM_01 and the relevance and usefulness they have within this model.

6. Conclusion

The standardization of information flows within the context of the BIM work becomes important in order to face, mainly, the challenges of interoperability. Given this, many domains within the industry have advanced in the definition of standards based on the development of the IDM and MVD. This research presents a proposal of the IDM standard associated with the development of industrialized timber projects under the light-frame panel system. This paper focused on defining the information exchange requirements associated with the conceptual evaluation model (EM_01) for this type of project.

Based on the results of this research, one of the most relevant conclusions is that at present, the standard IFC model does not have a structure or information parameters that meet the information requirements of this process. As can be seen in Table 7, approximately 70% of the minimum relevant parameters associated with the development of these projects do not have a counterpart within the IFC standard.

According to the abovementioned, this causes those workflows and data associated with this process to be executed without a standard of information exchanges, which may imply disorganized management, with losses of information and an inefficient BIM implementation. Given this, the present research proposes to manage these attributes within property sets specific to the process of industrialization and prefabrication of timber projects, similar to the case of prefabricated elements in other materials (e.g., concrete). This research also contributes to the knowledge of IFC, proposing new entities and information parameters that are necessary inside the IFC standard to develop this type of projects in a more efficient way during the early evaluation phase.

In summary, this research contributes to the body of knowledge by proposing a standard information model based on the BIM methodology through an information delivery manual (IDM) proposal by first presenting a workflow to identify the principal actors, activities, and information flow. Second, this work contributes to the body of knowledge by identifying the necessary information parameters (contrasting with the IFC standard) which support the decision-making process during the early evaluation phase of industrialized timber projects.

In relation to the industrialization process and the process map presented in this research, a relevant conclusion is that from a project management perspective, industrialization and prefabrication are considered a specialty and discipline in project development. This implies that the coordination processes required in the design of these projects require a lot of attention, where the early participation of the prefabrication plant is also essential to identify improvements, optimize the processes, improve the commercial evaluation of the project, and increase its manufacturing and assembly capacity in order to obtain all the advantages that the use of the off-site construction system implies.

Also, with respect to the results obtained in this research, it is relevant for future research to evaluate the impact of this BIM workflow proposal in the project evaluation processes, for example, to identify if the evaluation is more assertive or efficient and if the information requirements are sufficient, to execute this activity properly.

Future research should study in detail the other exchange models present in the proposed IDM: EM_02, 03, 04 and 05, with the objective of identifying their information exchange requirements in order to advance in a BIM flow standard in all stages of the industrialization process of timber projects. Finally, this work contributes to the first step to developing a model view definition (MVD) standard, which would be referenced in the development of software and use case to make the workflow of commercial evaluation of industrialized timber projects more efficient.

Data Availability

Data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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