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Integration of BIM in Steel Building Projects (BIM-DFE): A Delphi Survey

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Abstract: This study aims to design a BIM integration model for steel building projects (BIM-DFE). It was developed in the following three phases: (i) theoretical phase, (ii) validation phase, and (iii) statistical analysis for the theoretical phase. A literature review was conducted to study the applications of BIM in steel building projects and to develop an integrated BIM process map for the construction lifecycle of steel buildings. Subsequently, in the validation phase, 32 participants were invited to complete a two-round Delphi questionnaire to validate the BIM-DFE proposal. The participants were classified according to their knowledge level (skilled or expert). Based on the literature review, a process map that integrates BIM in different phases of a steel building project was created. In the first round of the Delphi questionnaire for the validation phase, the various groups studied (skilled vs. expert) were in moderate agreement with the BIM-DFE proposal; however, after the second round, this agreement became better. Therefore, this study contributes to the current body of knowledge by providing a BIM integration model to improve the management of steel building projects as defined by critical stakeholders in the steel industry. In addition, a real-time case is presented to elucidate a part of the research contribution.

Keywords: building information modeling (BIM); steel project life cycle; Delphi; integration model; steel buildings

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1. Introduction

The construction industry, which includes engineering and construction activities, is a fundamental part of the global economy and accounts for approximately six percent of the total gross domestic product, which is equivalent to approximately 10 trillion USD annually [1,2]. Recently, the conventional construction industry encountered a technological revolution that mitigates the classic errors of this industry, such as time delays, cost, and construction quality. An important factor in this technological revolution is building information modeling (BIM), which was developed as a solution to mitigate the errors of traditional construction [3]. BIM is a series of activities that can improve deliverables in the design and construction process [4–6] and is intended to optimize the information transfer processes, which is vital for fluid design and construction. Examples of how BIM can benefit the stakeholders in this industry include the following:

Principal/owner: Control of project expectations from an economic and visual perspective.

Engineers/Designers: Designers can improve the long-term relationships with various stakeholders owing to a better understanding of the different threads for the materialization of construction projects.

Builder/executing engineer: Permit to contribute their knowledge during the design process or update the model during different stages of construction, thus improving pre-execution and on-site planning and gaining a better understanding of the design and building [5,7,8].

BIM can offer different options for construction management as it provides effective design and documentation as well as supports and improves the critical factors of a project [9].

However, there could be issues with regard to the generated data, such as data loss, data inconsistency, errors, and liability for erroneous or incomplete data in 3D BIM models. Adopting a collaborative approach to BIM in certain projects further complicates these issues [10]. BIM management has been attributed to the productivity and cooperation between teams and different materials.

Considering the growth of the global population and increase in industrialized materials, steel has become an essential component for construction [11]; however, its use has increased the complexity of projects, particularly in information management, because it is imperative to present quality information in a timely manner to the different actors involved in the workflow [12]. A steel-building project comprises factory-made components or units that are transported and assembled in a shop or on-site and involves the following phases: (1) planning, (2) design, (3) fabrication, (4) transport, and (5) erection of the structure. An efficient completion of these steps maximizes the benefits of working with steel [8,13]. However, the benefits of using BIM for steel construction projects have not been accurately explored [14].

The use of BIM does not exhibit continuity throughout the phases of a steel construction project; therefore, its benefits are curtailed. In other cases, they are developed in the late phases or within a phase. Therefore, there is a need to investigate, develop, and propose BIM usages that generate continuous communication, coordination, management between phases, and ensure deliverables that conclude with a building that meets the initially established project requirements [8].

This integration is achieved by incorporating BIM in the process map throughout the construction phases of steel buildings. It is then validated by surveying a forum of experts using the Delphi methodology. The aim of this study is to propose a model to improve communication, integration, comprehensible procurement processes, and production processes in this specific area of steel construction. These operating benefits can result in macroeconomic benefits for steel-building projects.

2. Literature Review

A literature review was conducted to analyze the current evidence in the academic community regarding the application of BIM for steel construction and its integration between the phrasing between the different steel construction processes. Fifteen uses of BIM were identified; the observations of each are presented in Table 1. This shows that in steel construction projects, BIM is usually used as a visualization engine that replaces 2D drawings with 3D virtual models to generate a greater compression of the objects materialized during steel construction processes [14–16].

Table 1. The application of BIM based on phases.

BIM (B#)	BIM Utilization	Observation from Literature Review	References
1	3D BIM models to visualize and improve steel processes.	*The 3D model is used as a compression engine that replaces 2D drawings and is used in all phases except the transport phase.*	[14–21]
2	BIM Collaboration for Structural Engineering and LOD.	*Defining the levels of detail (LOD) in BIM models saves time in the design process and reduces the information requirement for stakeholders.*	[17,22–25]

Table 1. *Cont.*

BIM (B#)	BIM Utilization	Observation from Literature Review	References
3	Early integration between design, manufacturing, and assembly based on BIM models.	*Integration between design, manufacturing, and assembly based on BIM models allows incorporating the physical resources of the fabricator, transport, and erector, which results in the reduction in total project costs.*	[20,21,23,25–30]
4	Creating a BIM prior to fabrication.	*The creation of BIM models, including in the manufacturing stages, empowers manufacturers to automate their fabrication processes by connecting computer numerical control (CNC) with the BIM model. It also reduces the time for steel detailing and the fabrication processes.*	[14,16,18,23,26,31–33]
5	Quality control and traceability of the manufacturing and assembly processes using BIM models.	*BIM models in fabrication stages provide the status of each manufactured item, such as painting, welding, assembly, and dispatch status. This imparts traceability to the steel elements.*	[26,27,34–36]
6	BIM and virtual/augmented reality	*The augmented reality application improves decision-making because it allows simulating various scenarios for selection of the one most advantageous for the project.*	[34,37]
7	BIM and IoT	*Controlling the erection of steel structures through BIM and Internet of things (IoT) allows for a transparent relationship between the contractor and subcontractor and an exact follow-up of the assembled elements.*	[30,38,39]
8	Use of API for non-geometric information transfer.	*Application programming interface (API) allows transferring non-geometric information, such as supplier codes and technical specifications, which increases technical communication between stakeholders.*	[35,40]
9	Controlled installation through BIM.	*Controlling the erection of steel structures through BIM allows for an exact follow-up of the assembled elements.*	[22,36,41,42]
10	BIM and laser scanning data.	*The use of laser scanners and BIM models in erection stages allows for the precise erection in a field. It is also generally used to create a BIM model based on existing conditions through point clouds.*	[25,43,44]
11	Cost analysis through BIM models.	*4D and 5D BIM models allow an independent evaluation of each specialty, allowing a better understanding of the scope of work for each bidder.*	[23,24,45–47]
12	BIM for construction management.	*BIM models allow controlling the amount of material used in a project and managing the man-hours assigned in planning to detect deviations in time and materials from an economic perspective at an early stage and make decisions accordingly.*	[21,25,27,28,32,34,40–42,48–53]
13	Structural health monitoring with BIM models.	*The use of microchips along with BIM models allows for the identification of structural failures caused by transportation or poor stockpiling of material prior to assembly.*	[40,53]
14	BIM information to improve site logistics planning.	*The use of BIM models oriented to planning for construction generates a delivery action map of the elements to be assembled in the field; thus, stockpiling and transfer times are optimized.*	[22,28,32,33,52,54–57]
15	BIM for deconstructability and identification of reusable steel materials	*BIM is used to identify reusable materials in the deconstruction stage to reduce construction waste and cost of project materials.*	[37,58,59]

There is limited use of BIM in the early stages of a project, particularly in the planning phase. This prevents the optimization of the benefits obtained by using these models at this stage, including understanding stakeholders who are not part of the construction industry, such as the owners or investors of a project [8].

Studies have demonstrated various forms of BIM usage in the design stage, where early integration is highlighted as a methodology that enables a better understanding of the manufacturer and erector resources to make them available in the design stages [20,21,23,30].

Regarding the manufacturing phase, BIM is presented as a communication amplifier that transforms 3D graphic information from the design to the numerical control machinery (CNC) used to materialize steel structures, such as cutting plasmas and robotic welding machines [14,18,33].

In contrast to the previous phases, the transportation phase provides the least amount of evidence of BIM usage in steel construction [8], highlighting only the incorporation of sensors in steel structures, which allows for the identification of the location of trucks through GPS sensors to improve planning and logistics in the field [49].

Regarding the planning phases for construction and erection, the use of BIM is highlighted as a repository of costs to identify the pricing of machinery and labor to be used in construction [23–25,50], and to control the structural state of the parts arriving from the factory before and after assembly [40–53]. The literature highlights the use of BIM to identify materials with reusable potential in deconstruction stages to minimize the costs of future projects and reduce the carbon footprint in the construction industry [3,37,57].

Although the aforementioned literature review shows the benefits of using BIM in the different phases of steel construction projects, they are either unilaterally considered in the phases or the integration is evident only between two phases (design and fabrication); a collaborative methodology that integrates all phases of the project supported by the BIM methodology remains absent [8].

The BIM usage process map is considered as the first approach in integrating BIM in steel building projects (BIM-DFE) (Figure 1). BIM-DFE consists of five phases and groups of processes. The phases are as follows:

(1) *Planning phase:* The planning phase begins with the need for construction determined by the owner. The type of project is subsequently defined; it can be commercial, residential, or industrial. The following proposed sub-process includes the selection of a design engineer who will fulfill the role of the project manager and accompany the entire steel construction process from design to assembly [20–23]. Once the project manager and designer have been selected, a BIM estimation model is created, allowing early identification of the number of tons to be processed. Finally, this stage is completed with a BIM-DFE act that frames the BIM deliverables of each specialty in the subsequent phases.

(2) *Design Phase:* The proposed design phase begins with the BIM-DFE act from the previous phase, and the next sub-process is the incorporation of the finite element analysis of the structure; the BIM estimation model from the previous phase [27–61] is considered as the starting point. The connection calculation thread is subsequently introduced [23]. Once the design of the structural elements and the connections is complete, it is passed to the next sub-process, which is the selection of the manufacturer and assembler [25]. The design process ends with a BIM-DFE model with a defined structural design.

(3) *Fabrication phase:* This phase begins with the BIM-DFE model from the previous phase. The following thread is the determination of the phases and sequences of the project [57]; the structural details are developed to create the parts and pieces necessary for manufacturing according to the aforementioned phases and sequences. Subsequently, the manufacturing stage begins and is monitored using a BIM model [26]. This phase finally ends with a BIM-DFE model that contains an update regarding the manufacturing status.

(4) *Transport Phase:* This phase begins with the BIM-DFE model updated with the manufacturing information from the previous phase. The prioritization of shipments is then added according to the needs of the project. This phase ends with a BIM-DFE model that contains updated information regarding the shipments from the fabricator to the field.

(5) *Erection Phase:* This phase begins with the BIM-DFE on-site collection model from the previous phase, and the assembly of the steel elements is controlled using a laser scanner in coordination with other specialties of the project [43,44]. Finally, this phase ends with a BIM-DE model that contains updated information on the project assembly status to be shared with the remaining stakeholders.

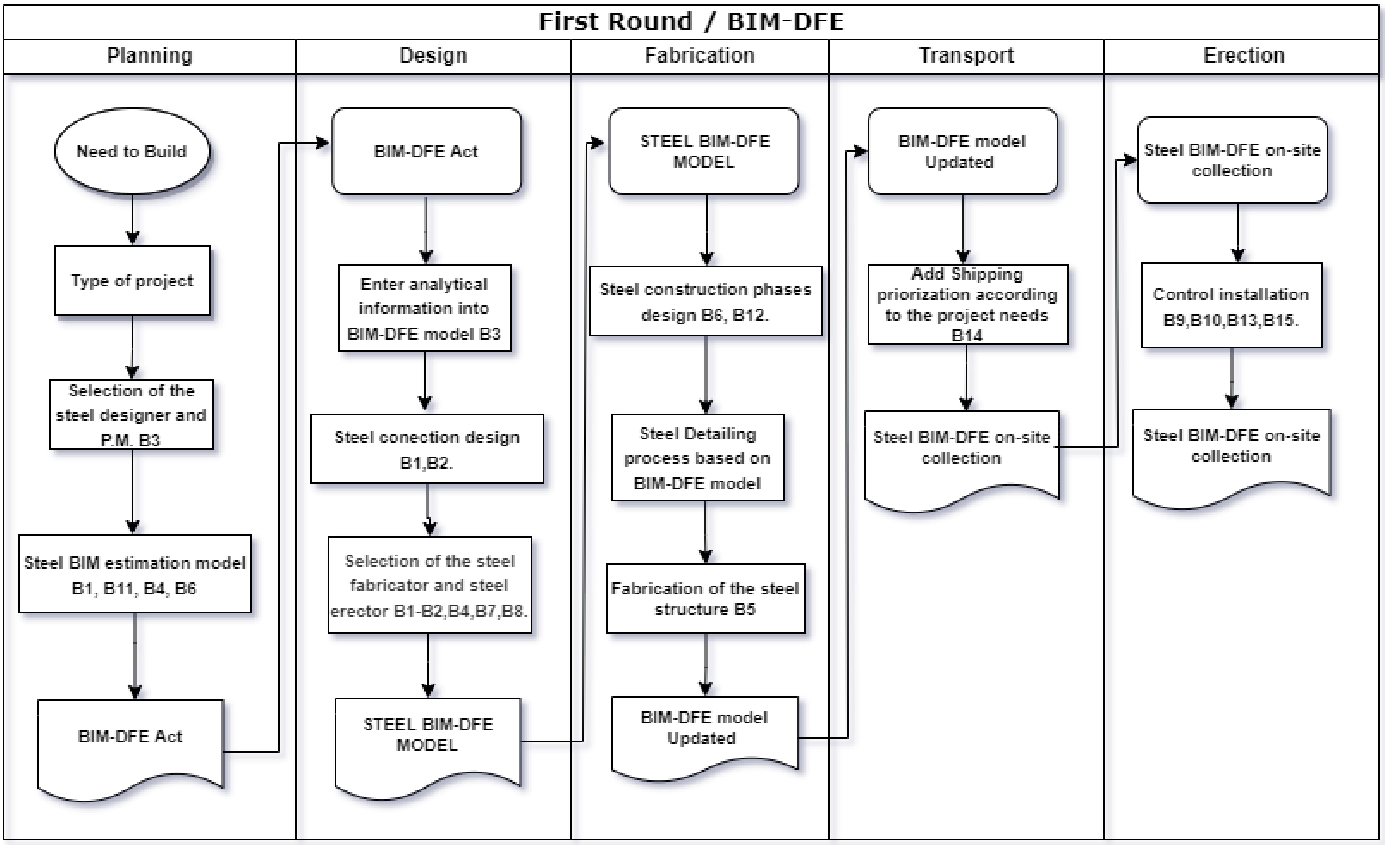


Figure 1. Preliminary integration of BIM in steel building projects (B# indicates the BIM uses from Table 1).

3. Research Methodology

The methodology proposed in this study consists of the following three phases: theoretical, survey, and validation (Figure 2).

3.1. Theoretical Phase

The theoretical phase involved a literature review to determine BIM uses and processes in steel building projects; in addition, the literature review helped identify the lack of BIM integration in steel building projects and in developing a preliminary BIM-DFE proposal (Figure 1).

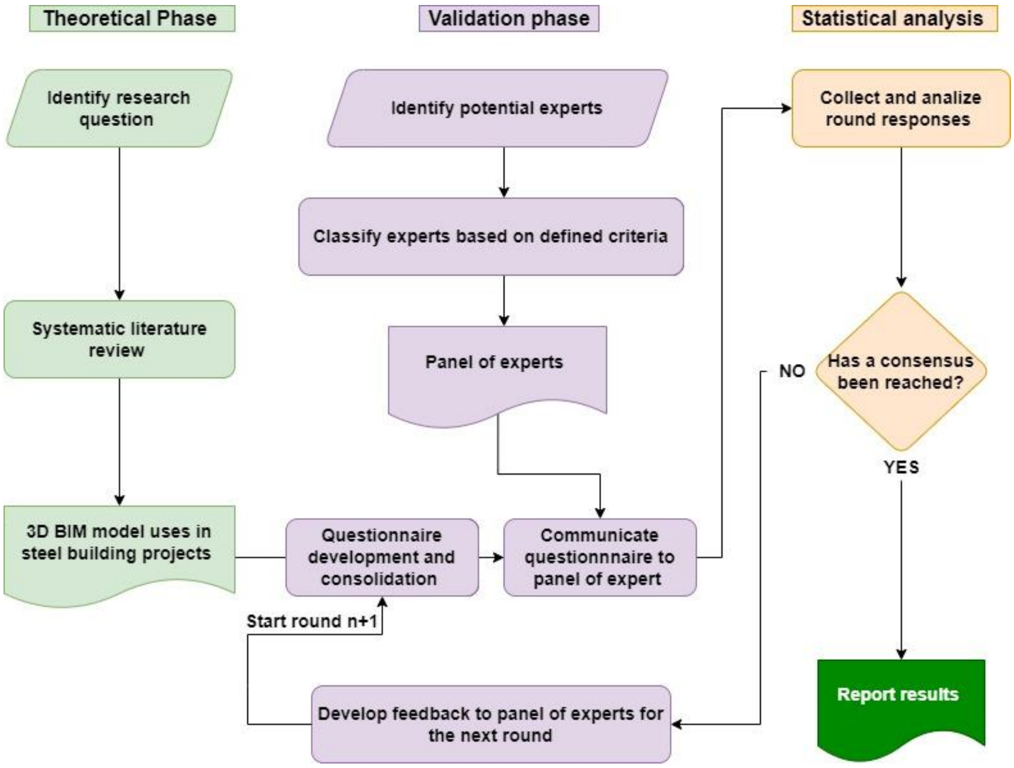


Figure 2. Flow chart of the methodology employed in this study [62].

The literature review included content from peer-reviewed journals, such as the Web of Science (WOS) and Scopus (Table 2). The following search strings were used for the relative articles published between 2012 and 2022: "steel", "building information modeling", "detailing", "construction", "manufacturing", "prefabrication", "steel process construction", "steel BIM process construction", "structures" and "projects performance".

Table 2. Inclusion and Exclusion Criteria [8].

Criteria	Inclusion	Exclusion
1	Articles discussing BIM in a steel building project	Articles not discussing BIM in steel building projects
2	Articles in WOS and/or Scopus	Articles not in WOS and/or Scopus
3	Articles published between 2012–2022	Articles published prior to 2012

3.2. Validation Phase: Modified Delphi Methodology

The Delphi method consists of a systematic and interactive search to retrieve the greatest agreement from a group of experts regarding a specific topic; an underlying definition of the method is provided as follows: "Delphi may be characterized as a method for structuring a group communication process so that the it is effective in allowing a group of individuals, as an entirety, to manage a complex problem". This methodology provides an accurate approach for the search of new information regarding complex topics [63]. The Delphi technique is a structured method used to obtain a consensus from a panel of experts [64,65]; moreover, it presents the advantage of conducting reviews with geographically dispersed experts from various industrial sectors [51,65–71]. This method was used for identifying the integration of BIM in steel-building projects, which was careful not to guide any response through the questions that were presented to the panel of experts; a consensus of the opinions was then calibrated based on the responses from the experts in the rounds of questions [66]. At least two rounds of questions and answers are imperative for correctly using the Delphi method. In this manner, a valid consensus on the hypothesis or questions posed can be ensured. At least seven members of a panel of experts are recommended to answer the questions for this method to be successful [65–67].

Following the literature review, a combination of qualitative and quantitative methods was performed with a panel of experts. This is often referred to as the 'modified Delphi method' (MDM). First, a pilot survey was conducted with four participants (industry experts) to review and validate the factors that helped further specify the questionnaire [65]. All the changes proposed by these four experts were included in the first Delphi rounds. Subsequently, 32 experts were invited to answer the Delphi questionnaire. The selected experts should have the knowledge and competence in the relative subject matter, as well as a significant understanding of the problem. Accordingly, the panel members required to be part of the initial sample were steel building experts. The initial requirements for this included having relevant experience and a significant understanding of BIM and steel building projects; Table 3 demonstrates the qualifications of the panel of experts. The requirements were as follows:

- Expertise in building project management, construction management,
- Designing technical projects, or directing projects.
- A minimum of ten years of experience.
- Participation in at least ten projects worth more than $500,000.
- Transfer experience with at least five collaboration contracts in different phases of steel building projects.

Table 3. Panel of experts.

Country	Specialization	Profession	Development Area	Average Years of Experience
Argentina	Planning Design Fabrication Erector	Civil engineer Building engineer Assembler	Professional Academic	22.5
Chile	Planning Design Fabrication Erection	Civil engineer Mechanical civil engineer Assembler Maker Industrial engineer Building engineer	Professional Academic	18.3
Spain	Planning Design Fabrication Erection	Civil engineer Computer engineer	Professional Academic	21.4
United States	Planning Design Fabrication Erection	Civil engineer Mechanical engineer Assembler	Professional Academic	25.6

The level of agreement in the questionnaire for each steel building phase was based on the 5-point Likert scale: 1 = disagree, 2 = indifferent, 3 = slightly agree, 4 = agree, and 5 = strongly agree. The number of iterations required to obtain the agreement of the experts was determined according to the answers received. Finally, the questionnaire collected personal information from the experts. The authors guaranteed anonymity of the participants [62–66].

3.3. Expert Panel Composition and Classification

A panel of experts was selected based on their knowledge and experience of steel construction projects, including those currently working in universities, research centers, steel manufacturing, steel design engineering, and steel structure assembly. The panel of experts was classified based on years of experience, as follows: (a) one to 15 years (five experts); (b) greater than 16 years (27 experts) (Table 3).

3.4. Statistical Analysis

The agreement level of the experts was determined using statistical tools for the questionnaire techniques, which are presented in the same order as they were used:

a. A Cronbach's reliability test (a) was conducted to validate the reliability of the questionnaire based on the responses. The values varied from zero to one. Values greater than 0.7 were considered acceptable for further analysis [69].
b. The following characterizations were made to define a level of significance based on the average of each question:
    i. "Not important" ($M < 1.5$),
    ii. "Somewhat important" ($1.51 < M < 2.5$),
    iii. "Important" ($2.51 < M < 3.5$),
    iv. "Very important" ($3.51 < M < 4.5$), and
    v. "Extremely important" ($M < 4.51$).
c. Kendall's coefficient of concordance (W) was used to measure the level of agreement within the panel of experts and ascertain the consistency of agreement across the two rounds of the Delphi survey. The value of W ranged from zero (perfect disagreement) to one (perfect agreement). Additionally, the chi-square value indicates the robustness of the consensus with the associated p-value (significance level, 0.05).
d. Interrater agreement statistics (IRA; a_{wg}) were used to analyze and validate the expert agreements among the respondent groups. IRA analysis was performed using the code deduced in [70] as follows:
    i. $0.0 < a_{wg} < 0.30$ "lack of agreement",
    ii. $0.31 < a_{wg} < 0.50$ "weak agreement",
    iii. $0.51 < a_{wg} < 0.70$ "moderate agreement",
    iv. $0.71 < a_{wg} < 0.90$ "strong agreement" and
    v. $0.91 < a_{wg} < 1.00$ "very strong agreement".

All statistical analyses were performed using the SPSS software version Statistics.

4. Results

4.1. Theoretical Phase

Figure 3 illustrates that the largest number of publications relative to this study were presented between 2019 and 2021.

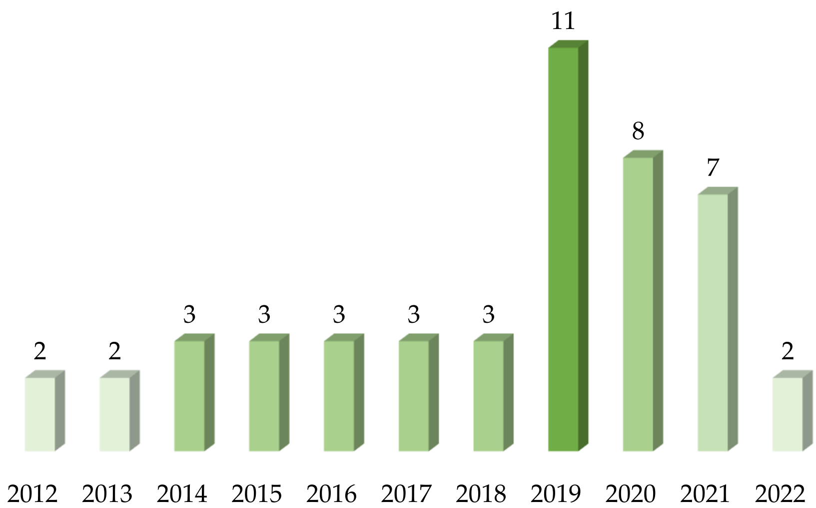


Figure 3. Evolution of the research literature review.

Figure 4 presents the journals with the highest number of publications regarding this topic. The journal of *Automation in Construction* is noteworthy considering 21 articles.

Figure 4. Number of publications per journal.

4.2. Validation Phase: Delphi Methodology: First Round

The Delphi survey was answered by 32 experts, of which (a) five participants had between one and 15 years of experience, (b) and 27 participants had greater than 16 years of experience. To assess the consistency of the survey, the responses were segmented as indicated above. Therefore, the relevant statistical analyses were performed using Cronbach's alpha test and Kendall's coefficient.

Tables 4 and 5 present the statistical analyses performed for the answers provided by the expert panel, which demonstrates a variety of data such as the average, standard deviation, number of experts, value that defines the normality of the sample, as well as Cronbach's alpha value and Kendal's coefficient that endorse the reliability and concordance between specialists, respectively. Kendall's W coefficient was greater than zero for all processes, indicating an agreement among those evaluated.

Table 4 presents the coding of the questions from Appendix A, Table A1. The mean and standard deviation for the panel of experts classified into the following: one to fifteen years of experience, greater than sixteen years of experience, number of respondents, and the statistical data. As a result of the first analysis, the Cronbach's alpha coefficient values that were obtained ranged between 0.795 to 0.55, as the experts were segmented as indicated. The Cronbach's alpha value of all the experts was 0.773, which is higher than 0.7, making it acceptable for further analysis [68].

Table 4. 1st round of Delphi survey-BIM integration in steel construction projects.

EXPERTS ROUND 1						
Code	**All the Experts in the Area**		**One to Fifteen Years of Experience**		**More than Sixteen Years of Experience**	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Q1	4.03	0.822	4.00	0.707	4.04	0.854
Q2	2.59	1.214	2.20	0.837	2.67	1.271
Q3	4.13	0.660	4.00	0.707	4.15	0.662
Q4	4.31	0.738	4.40	0.894	4.30	0.724
Q5	4.53	0.567	4.60	0.894	4.52	0.509
Q6	4.47	0.671	4.60	0.548	4.44	0.698
Q7	4.09	0.777	3.80	0.837	4.15	0.770
Q8	3.75	0.762	3.80	0.837	3.74	0.764
Q9	4.16	0.515	4.00	0.707	4.19	0.483
Q10	3.84	0.808	3.80	0.837	3.85	0.818
Q11	4.25	0.672	4.40	0.894	4.22	0.641
Q12	4.28	0.729	4.60	0.548	4.22	0.751
Q13	4.50	0.622	4.60	0.548	4.48	0.643
Q14	4.03	0.822	4.00	0.707	4.04	0.854
Q15	4.06	0.716	4.00	1.000	4.07	0.675
Q16	4.09	0.777	4.20	0.837	4.07	0.781
Q17	4.03	0.822	4.20	0.837	4.00	0.832
Q18	4.22	0.792	3.80	0.837	4.30	0.775
Q19	4.28	0.772	4.00	1.225	4.33	0.679
Q20	4.34	0.787	4.60	0.548	4.30	0.823
Q21	4.25	0.762	4.60	0.548	4.19	0.786
Q22	4.16	0.628	4.20	0.447	4.15	0.662
Q23	3.94	0.716	4.00	0.707	3.93	0.730
Q24	4.19	0.780	4.60	0.548	4.11	0.801
Q25	4.19	0.859	4.00	1.225	4.22	0.801
Q26	4.16	0.677	4.60	0.548	4.07	0.675
Q27	4.09	0.689	4.40	0.548	4.04	0.706
Q28	4.03	0.782	4.00	0.707	4.04	0.808
STATISTICAL DATA						
Cronbach's α reliability value	0.773		0.55		0.795	
Number of respondents	32		5		27	
Kendall's coefficient of concordance (W)	0.133		0.258		0.127	

Figure 5 presents the results of the IRA analysis and the significance level of the questions for the assessment of the strength of the expert consensus regarding these questions, generating a basis for the second round and defining the status of the first questionnaire. The ranking of the consensus of all the experts was analyzed considering their years of experience. In the first round, "Q2" was the lowest-performing question.

Considering the IRA score and significance level analysis, the results for the other questions provided results ranging from a weak to a strong agreement for the IRA, and from important to extremely important for the significance level with respect to the mean.

Code	EXPERTS ROUND 1								
	All the experts in the area			One to fifteen years of experience			More than sixteen years of experience		
	a_{wg} SCORE	Agreement level	Significance grade	a_{wg} SCORE	Agreement level	Significance grade	a_{wg} SCORE	Agreement level	Significance grade
Q1	0.56	moderate agreement	very important	0.68	moderate agreement	very important	0.52	moderate agreement	very important
Q2	0.26	lack of agreement	important	0.60	moderate agreement	somewhat important	0.20	lack of agreement	important
Q3	0.69	moderate agreement	very important	0.68	moderate agreement	very important	0.68	moderate agreement	very important
Q4	0.54	moderate agreement	very important	0.24	lack of agreement	very important	0.56	moderate agreement	very important
Q5	0.63	moderate agreement	extremely important	-	not applicable	not applicable	0.70	moderate agreement	extremely important
Q6	0.53	moderate agreement	very important	0.60	moderate agreement	extremely important	0.51	weak agreement	very important
Q7	0.58	moderate agreement	very important	0.60	moderate agreement	very important	0.57	moderate agreement	very important
Q8	0.67	moderate agreement	very important	0.60	moderate agreement	very important	0.67	moderate agreement	very important
Q9	0.81	strong agreement	very important	0.68	moderate agreement	very important	0.83	strong agreement	very important
Q10	0.62	moderate agreement	very important	0.60	moderate agreement	very important	0.61	moderate agreement	very important
Q11	0.64	moderate agreement	very important	0.24	lack of agreement	very important	0.68	moderate agreement	very important
Q12	0.57	moderate agreement	very important	0.60	moderate agreement	extremely important	0.57	moderate agreement	very important
Q13	0.57	moderate agreement	very important	0.60	moderate agreement	extremely important	0.56	moderate agreement	very important
Q14	0.56	moderate agreement	very important	0.68	moderate agreement	very important	0.52	moderate agreement	very important
Q15	0.66	moderate agreement	very important	0.36	weak agreement	very important	0.69	moderate agreement	very important
Q16	0.58	moderate agreement	very important	0.47	weak agreement	very important	0.59	moderate agreement	very important
Q17	0.56	moderate agreement	very important	0.47	weak agreement	very important	0.55	moderate agreement	very important
Q18	0.52	moderate agreement	very important	0.60	moderate agreement	very important	0.50	weak agreement	very important
Q19	0.51	moderate agreement	very important	0.04	lack of agreement	very important	0.60	moderate agreement	very important
Q20	0.46	weak agreement	very important	0.60	moderate agreement	extremely important	0.44	weak agreement	very important
Q21	0.54	moderate agreement	very important	0.60	moderate agreement	extremely important	0.54	moderate agreement	very important
Q22	0.71	strong agreement	very important	0.85	strong agreement	very important	0.68	moderate agreement	very important
Q23	0.68	moderate agreement	very important	0.68	moderate agreement	very important	0.67	moderate agreement	very important
Q24	0.55	moderate agreement	very important	0.60	moderate agreement	extremely important	0.55	moderate agreement	very important
Q25	0.45	weak agreement	very important	0.04	lack of agreement	very important	0.51	weak agreement	very important
Q26	0.67	moderate agreement	very important	0.60	moderate agreement	extremely important	0.69	moderate agreement	very important
Q27	0.67	moderate agreement	very important	0.72	strong agreement	very important	0.67	moderate agreement	very important
Q28	0.60	moderate agreement	very important	0.68	moderate agreement	very important	0.57	moderate agreement	very important

Figure 5. Importance rating and IRA analysis of the factors (benefits) of the first round of experts.

4.3. Validation Phase: Delphi Methodology: Second Round

After processing the information provided by the experts in the first round, the results generated new adjustment guidelines for the questionnaire in the second round. Consequently, a new questionnaire (Appendix A, Table A2) with the same number of questions was presented. The second round was conducted with the same experts and total number of participants in this validation phase. As a result of the second round of the Delphi survey, a higher reliability of the data was evident with a Cronbach's alpha value above 0.8, which is excellent. This was replicated for experts with greater than 16 years of experience. The sample experts with one to fifteen years of work experience had a score of 0.743. The Kendall's W coefficient in the participant sample, which indicates the level of agreement among the experts, was higher in the overall round compared to the first round (first round W = 0.133; second round W = 0.140), which demonstrates a better agreement in the second round of the Delphi survey (Table 5).

Table 5. Second round of Delphi survey-BIM integration in steel construction projects.

Code	**EXPERTS ROUND 2**					
	All the Experts in the Area		**One to Fifteen Years of Experience**		**More than Sixteen Years of Experience**	
	Mean	**Standard Deviation**	**Standard Deviation**	**Mean**	**Mean**	**Standard Deviation**
Q1	4.13	0.336	4.20	0.447	4.11	0.320
Q2	4.00	0.672	4.20	0.447	3.96	0.706
Q3	3.97	0.309	4.00	0.000	3.96	0.338
Q4	4.09	0.296	4.20	0.447	4.07	0.267

Table 5. *Cont.*

EXPERTS ROUND 2						
Code	**All the Experts in the Area**		**One to Fifteen Years of Experience**		**More than Sixteen Years of Experience**	
	Mean	**Standard Deviation**	**Standard Deviation**	**Mean**	**Mean**	**Standard Deviation**
Q5	4.53	0.507	4.40	0.548	4.56	0.506
Q6	3.97	0.400	3.80	0.447	4.00	0.392
Q7	4.44	0.504	4.40	0.548	4.44	0.506
Q8	4.09	0.466	4.20	0.447	4.07	0.474
Q9	4.06	0.504	3.80	0.447	4.11	0.506
Q10	4.06	0.435	4.00	0.000	4.07	0.474
Q11	4.50	0.508	4.60	0.548	4.48	0.509
Q12	4.63	0.492	5.00	0.000	4.56	0.506
Q13	4.13	0.609	4.00	0.707	4.15	0.602
Q14	4.28	0.634	4.20	0.447	4.30	0.669
Q15	4.56	0.504	4.40	0.548	4.59	0.501
Q16	4.22	0.608	4.40	0.548	4.19	0.622
Q17	4.22	0.659	4.20	0.837	4.22	0.641
Q18	4.44	0.564	4.20	0.837	4.48	0.509
Q19	4.13	0.609	4.20	0.447	4.11	0.641
Q20	4.31	0.693	4.20	0.837	4.33	0.679
Q21	4.19	0.592	4.40	0.548	4.15	0.602
Q22	4.22	0.553	4.00	0.707	4.26	0.526
Q23	4.22	0.553	4.20	0.447	4.22	0.577
Q24	4.38	0.554	4.60	0.548	4.33	0.555
Q25	4.28	0.457	4.40	0.548	4.26	0.447
Q26	4.09	0.390	4.20	0.447	4.07	0.385
Q27	4.34	0.545	4.60	0.548	4.30	0.542
Q28	4.16	0.369	4.20	0.447	4.15	0.362
STATISTICAL DATA						
Cronbach's α reliability value	0.861		0.743		0.875	
Number of respondents	32		5		27	
Kendall's coefficient of concordance (W)	0.140		0.264		0.139	

Figure 6 presents the IRA results and the significance level of the factors from the second round of the Delphi survey, in addition to the data for the total sample of experts and the ranking of the experts indicated, as shown in the table header. The product obtained in this second questionnaire is more promising and consolidated with respect to the first round, improving the resolution of each question and the result of the reformulated question of code Q2 (Appendix A, Tables A1 and A2). A considerable agreement was observed in the IRA analysis and significance level for the other questions; ranging from a strong to very strong agreement and from very important to extremely important, these factors support the consensus reached by the expert panel after the second round of the Delphi surveys and validate the agreements.

EXPERTS ROUND 2									
Code	All the experts in the area			One to fifteen years of experience			More than sixteen years of experience		
	a_{wg} SCORE	Agreement level	Significance grade	a_{wg} SCORE	Agreement level	Significance grade	a_{wg} SCORE	Agreement level	Significance grade
Q1	0.92	very strong agreement	very important	0.85	strong agreement	very important	0.93	very strong agreement	very important
Q2	0.71	moderate agreement	very important	0.85	strong agreement	very important	0.69	moderate agreement	very important
Q3	0.94	very strong agreement	very important	1.00	very strong agreement	very important	0.93	very strong agreement	very important
Q4	0.94	very strong agreement	very important	0.85	strong agreement	very important	0.95	very strong agreement	very important
Q5	0.70	moderate agreement	extremely important	0.72	strong agreement	very important	0.69	moderate agreement	extremely important
Q6	0.90	strong agreement	very important	0.89	strong agreement	very important	0.90	strong agreement	very important
Q7	0.75	strong agreement	very important	0.72	strong agreement	very important	0.74	strong agreement	very important
Q8	0.85	strong agreement	very important	0.85	strong agreement	very important	0.85	strong agreement	very important
Q9	0.83	strong agreement	very important	0.89	strong agreement	very important	0.82	strong agreement	very important
Q10	0.87	strong agreement	very important	1.00	very strong agreement	very important	0.85	strong agreement	very important
Q11	0.72	strong agreement	extremely important	0.60	moderate agreement	extremely important	0.72	strong agreement	very important
Q12	0.66	moderate agreement	extremely important	-	not applicable	not applicable	0.69	moderate agreement	extremely important
Q13	0.74	strong agreement	very important	0.68	moderate agreement	very important	0.74	strong agreement	very important
Q14	0.67	moderate agreement	very important	0.85	strong agreement	very important	0.63	moderate agreement	very important
Q15	0.69	moderate agreement	extremely important	0.72	strong agreement	very important	0.67	moderate agreement	extremely important
Q16	0.72	strong agreement	very important	0.72	strong agreement	very important	0.71	strong agreement	very important
Q17	0.67	moderate agreement	very important	0.47	weak agreement	very important	0.68	moderate agreement	very important
Q18	0.68	moderate agreement	very important	0.47	weak agreement	very important	0.72	strong agreement	very important
Q19	0.74	strong agreement	very important	0.85	strong agreement	very important	0.71	strong agreement	very important
Q20	0.59	moderate agreement	very important	0.47	weak agreement	very important	0.60	moderate agreement	very important
Q21	0.74	strong agreement	very important	0.72	strong agreement	very important	0.74	strong agreement	very important
Q22	0.77	strong agreement	very important	0.68	moderate agreement	very important	0.78	strong agreement	very important
Q23	0.77	strong agreement	very important	0.85	strong agreement	very important	0.74	strong agreement	very important
Q24	0.72	strong agreement	very important	0.60	moderate agreement	extremely important	0.73	strong agreement	very important
Q25	0.83	strong agreement	very important	0.72	strong agreement	very important	0.84	strong agreement	very important
Q26	0.90	strong agreement	very important	0.85	strong agreement	very important	0.90	strong agreement	very important
Q27	0.74	strong agreement	very important	0.60	moderate agreement	extremely important	0.76	strong agreement	very important
Q28	0.90	strong agreement	very important	0.85	strong agreement	very important	0.91	strong agreement	very important

Figure 6. Importance rating and IRA analysis of the factors (benefits) of the second round of experts.

Figure 7 presents the process map resulting from integrating the BIM model in steel construction projects after two rounds of the Delphi method.

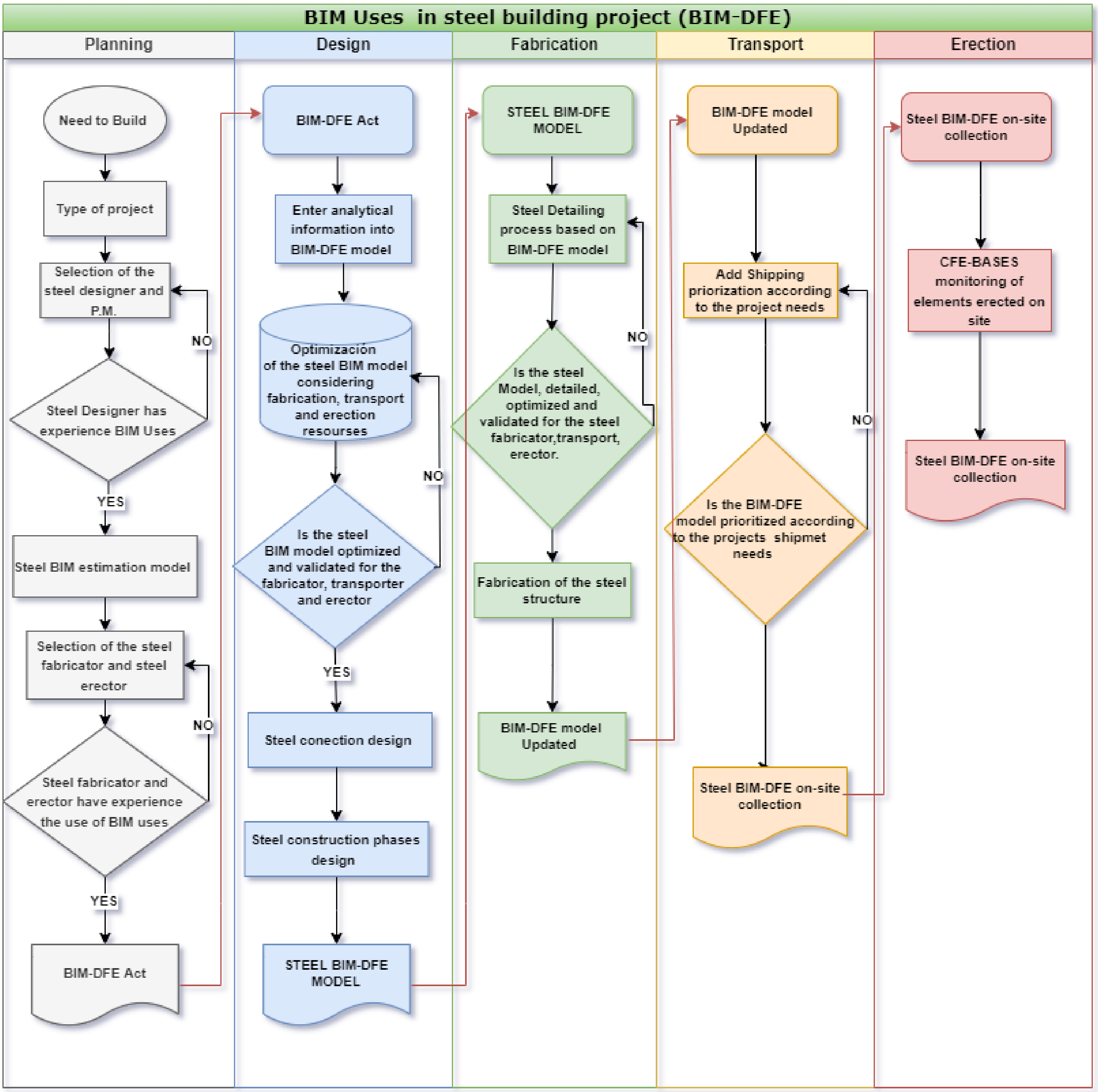


Figure 7. Final consensus of the BIM integration model in steel building projects after the Delphi survey based on expert agreement.

5. Discussion

Following two rounds of the Delphi questionnaire, a consensus among the experts regarding BIM integration applied to steel construction processes was reached.

As indicated in the scientific literature, the need to conduct an early integration through a BIM model is highlighted among experts in the design phase. This early integration is also recommended to be advanced as a steel BIM estimation model in the planning phase, which allows the determination of the amount of steel tonnage to be processed in the planning phase, and is critical because most stakeholders of steel construction projects provide quotes, estimates, and yields based on the indicated tons to be processed. Knowing the value of the amount of steel to be processed makes it possible to select different steel suppliers in the planning stage. This presents repercussions in applying manufacturer resources in the design phase, transport, and erection, which in turn reduces the quotation and execution time of the steel project.

Another outstanding consensus among the experts is the need to have a project manager who accompanies the owner of the steel project during all phases because this is generally outside the construction industry; the role of the project manager is recommended to be obtained by the design engineer, who will ensure that the level of detail described in the BIM models of each phase is met. Therefore, it is recommended that the status of individual processes in each phase is reported through data in a common real-time environment to enable the monitoring and decision-making based on the current situation of a project.

Herein, the results of this study are interpreted based on the expert agreement level in each main phase to fully understand the integration of BIM usage in the steel building process (BIM-DFE). As a reference to the BIM integration in various processes, B# indicates the BIM usages shown in Table 1. In addition, a real case is presented to graphically demonstrate the contribution of this study.

A fish processing plant in Coronel, Concepción, Chile was considered for the real-time project. It was executed and coordinated by the VVL engineering company (Figure 8). More than 80% of this project involved steel construction work. One of the biggest challenges this project presented was the coordination of different specialties because each specialty was represented with different BIM tools. Trimble Connect software was used to conduct the BIM coordination, in which the BIM models were introduced in the IFC format from different specialties. This allowed for the identification and resolution of collisions during the early stages of the project. In the erection and construction stage, this common data environment helped in understanding the progress of the structure, which was used by the remaining stakeholders for payment purposes against the delivery of the assembled structure.

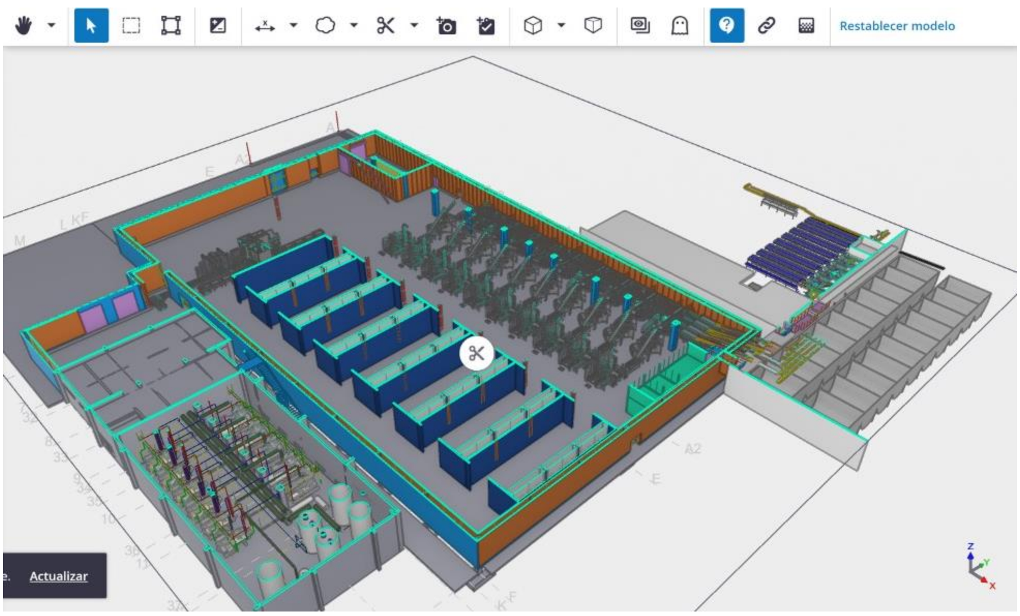


Figure 8. Fish processing plant by the VVL engineering company.

5.1. Phase 1: Steel Planning

The implementation of a BIM model in this early stage was proposed, which in addition to managing the visual expectations of the owner (B1), it provides a preliminary analysis of the costs of the fabrication, transportation, and erection of the steel structure (B11). Thus, the owner can optimize resources, reduce operational costs, and evaluate different alternatives that satisfy construction needs, opting for the most sustainable alternative [20]. To achieve this, the application of BIM and augmented reality is proposed to improve the understanding of the decision-makers [5], especially those unfamiliar with the technical construction terminology (B6). Therefore, the main contribution of BIM in this phase is the visual expectations of the owner. Another target of this phase is to determine the amount of steel required for the project, thus accelerating the quotation response of supplier companies that must be selected in the following process [23], such as steel fabricators and erectors (B3).

Figure 9 presents the activities that were agreed upon by the panel of experts regarding the planning stage of a steel construction project, which is required at the beginning of every type of construction project that needs to be built. Depending on this requirement, the type of steel to be used in the project was identified, which can be industrial or commercial. Subsequently, the next sub-process is the selection of the steel designer and project manager, which is a critical step for the success of the project because these professionals will guide the owner during the entire steel construction cycle. The panel of experts concluded that the role of the project manager would ideally be filled by the design engineer; however it could also be accomplished by another professional with expertise in BIM usage and the type of steel selected for construction in the previous step.

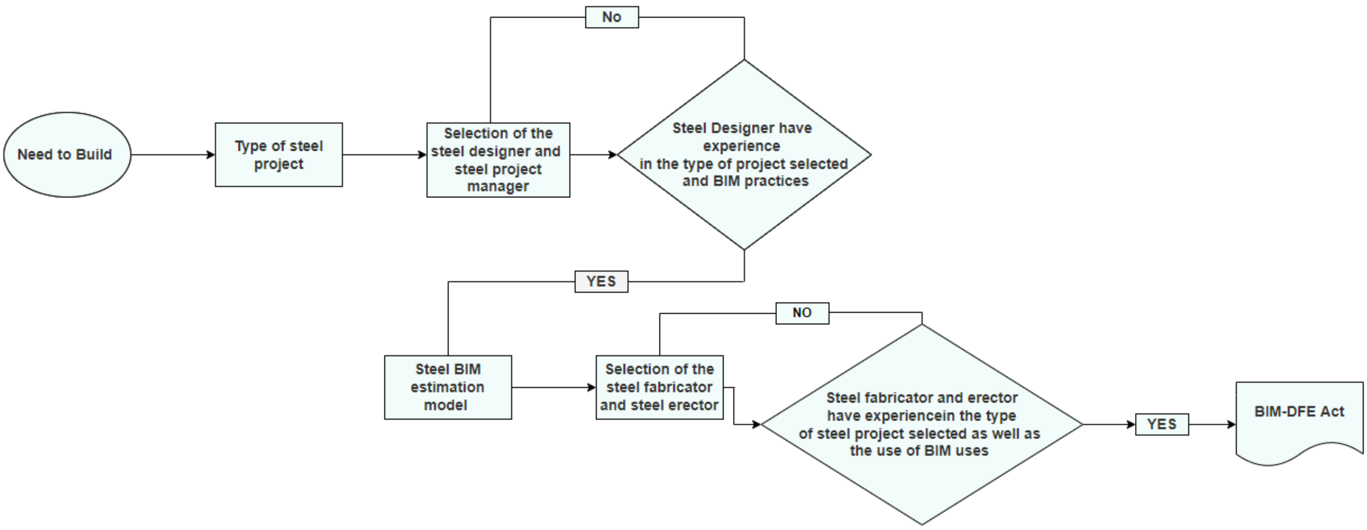


Figure 9. Steel BIM planning process.

The selected design company or professional must have experience in the type of steel project selected (industrial or commercial), the use of BIM [8], and the capabilities necessary to create a preliminary BIM estimation model (Figure 10). This preliminary BIM model can be created using BIM software, such as Tekla, SDS/2, and Advance Steel.

The main objective of this phase is to identify the amount of steel in tons that will be used in the project; therefore, it will accelerate the quotation response of the supplier companies that must be selected in the next sub process, such as steel fabricators and erectors.

This phase ends with the BIM-DFE (3D BIM model and defining the BIM collaboration between the steel designer, steel fabricator, and steel erector), which defines the scope for each specialty, the level of detail for the deliverables of the BIM steel project, and the guidelines for the collaboration and commitment between specialties throughout the steel construction phases.

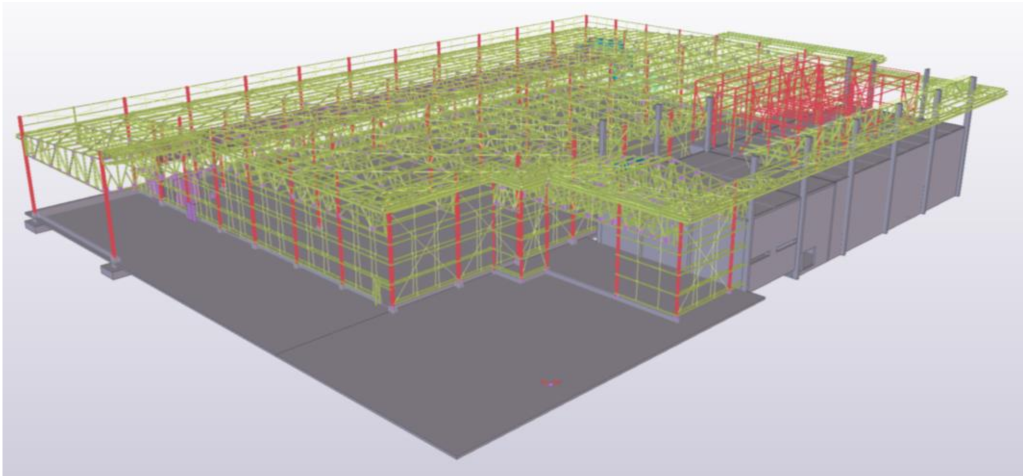


Figure 10. BIM estimation model sample.

5.2. Phase 2: Steel Design

In this stage, the collaboration and validation between the various groups for materializing a steel-building project are generated. The communication between the client and designers, the designer and fabricator, the designer and erector, and the erector and fabricator, ensures the success of the project [21,23,29,67] by reducing time, improving traceability, production control, optimizing transportation, and assembly of the structure (B3, B11). The main objective of BIM in this phase is to develop a BIM model that incorporates the resources of the manufacturer and assembler that were previously selected in the planning phase to expedite future phases.

As shown in Figure 11, this process begins with the guidelines of the BIM-DFE act and adds analytical engineering information to the BIM estimation model created in the previous phase. At this stage, the BIM estimation model is exported to a structural calculation software, such as SAP, ETABS, RAM, or the Industry Foundation Classes (IFC) format for a precise analysis, considering the project requests (live loads, dead loads, wind load, snow load, earthquakes, etc.) [17–25]. Figure 12 presents an example of the ETABS Model.

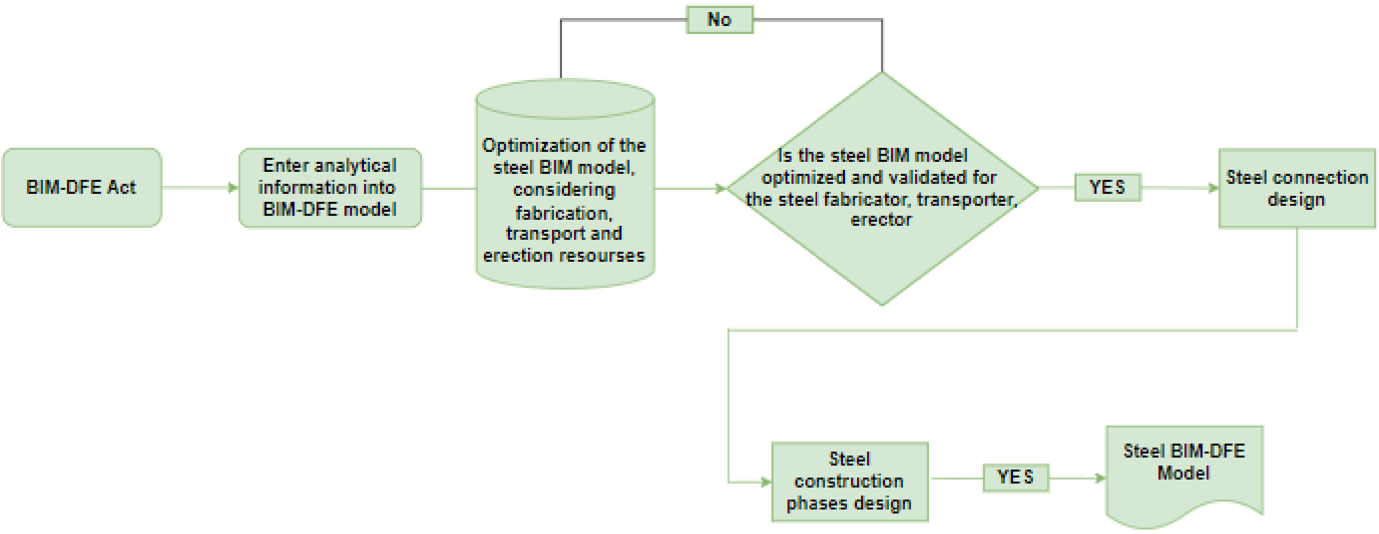


Figure 11. Design process of BIM-DFE.

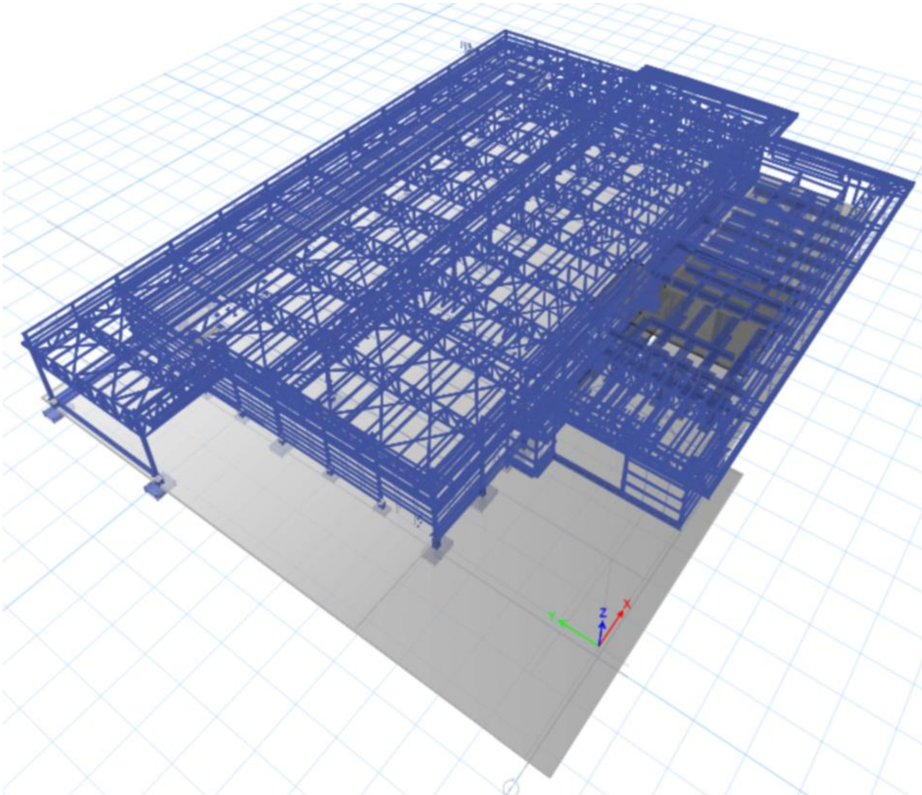


Figure 12. ETABS Model LOD 200—Study sample.

The BIM model is optimized in the following step considering fabrication, transportation, and erection with one of the following specialized software: Tekla, SDS/2, Advance Steel, or a similar software (B1, B3, B11) (Figure 13). At this stage, the resource constraints of the fabricator, transport, and erection of the structure are incorporated into the steel BIM model. Incorporating the fabricator and erector constraints into the engineering design facilitates the flow of production in the fabrication, transportation, and erection processes and provides greater certainty for the entire project; at this stage, the level of detail (LOD) is increased to LOD 400 for a greater efficiency in the transfer of information among all the project stakeholders (Figure 14).

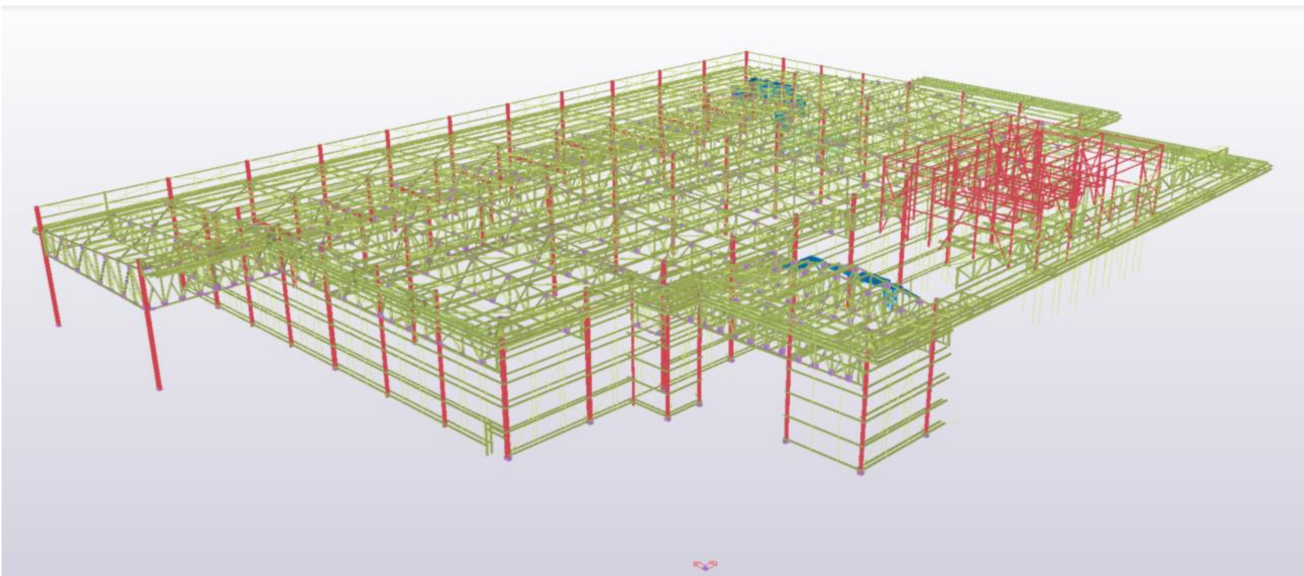
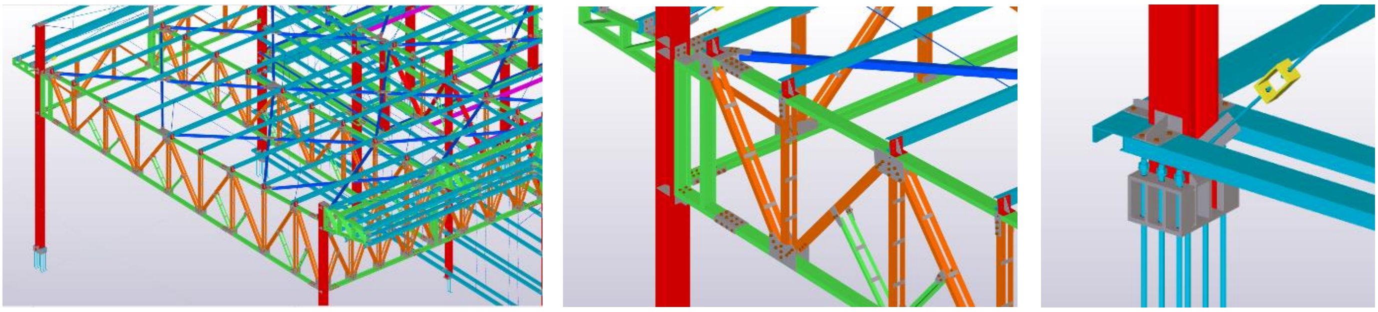


Figure 13. Tekla Model—Study sample.



(**a**) (**b**) (**c**)

Figure 14. Steel BIM LOD 400—Study sample. (**a**) Tekla Model LOD 400, (**b**) Miscellaneous LOD 400; (**c**) Steel Column LOD 400.

The information should be shared with the remaining stakeholders through a common data environment, such as Trimble Connect, to enable all stakeholders to comment on and validate the information exposed in the optimization stage of the project. When the BIM model has been validated, the following process of calculating the connections is implemented.

The main problem between the design team and contractors is the inadequate submission of information related to steel connections. Finding a solution to this problem can initiative the improvement of the design process, which is essential for transferring the information the contractors have regarding the project to the design team in an early stage [71]. At this stage, the connections can be calculated in a calculation software, such as Static Idea, which can be transferred bidirectionally to the BIM model using the IFC format (Figure 15).

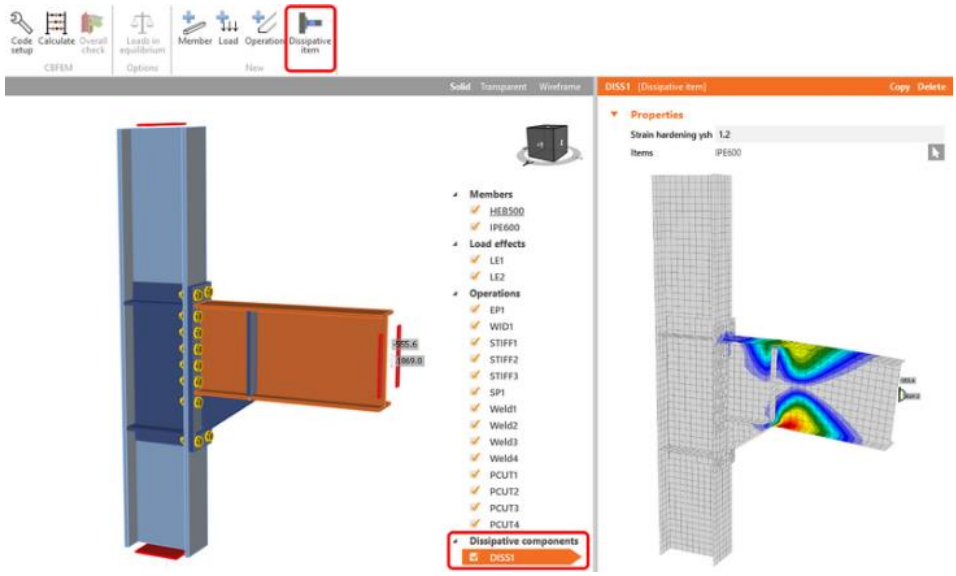


Figure 15. Idea Connection software sample.

The following process continues with the design of the steel construction phases led by the designer and validated by the erector and/or contractor (B1, B3, B4, and B14). Similar to the previous stage, this stage aims to validate the steel BIM model, which will be responsible for materializing on-site. The result of the aforementioned activities is a steel BIM-DFE fabrication model. Defining this new steel BIM fabrication model based on structural engineering generates a deliverable framework with a high level of detail, which ensures the efficient use of resources during fabrication, transport, and erection [8,23,33].

5.3. Phase 3: Fabrication

The main objective of this phase is to accelerate the manufacturing processes, given that the project has already considered the manufacturing resources of the previous phases (Figure 16).

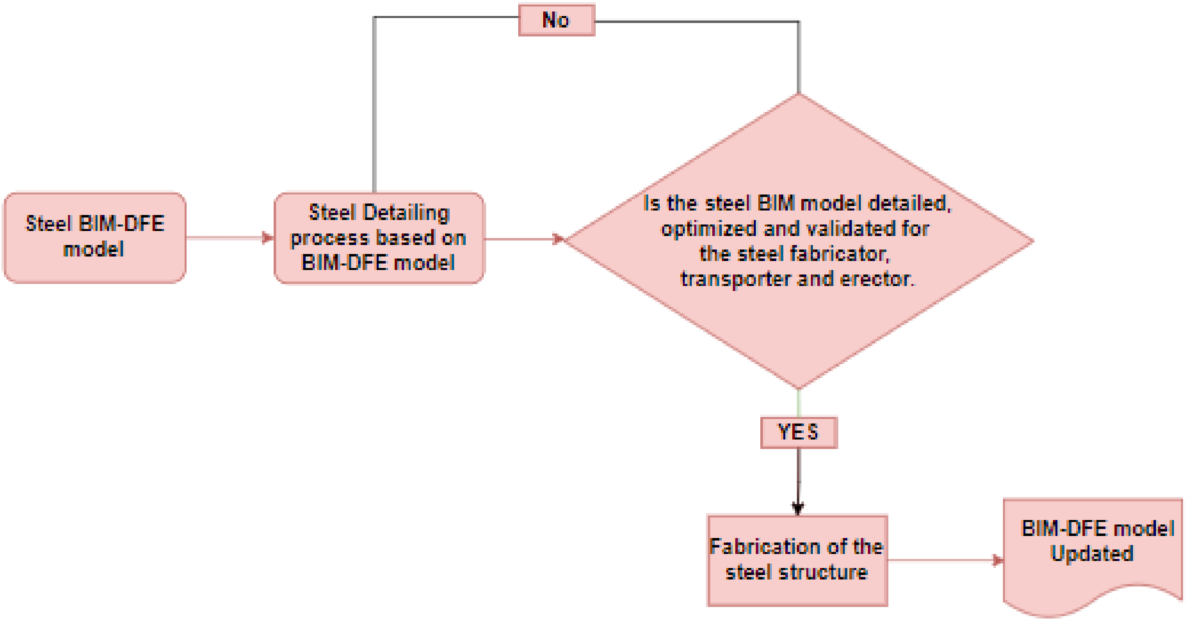
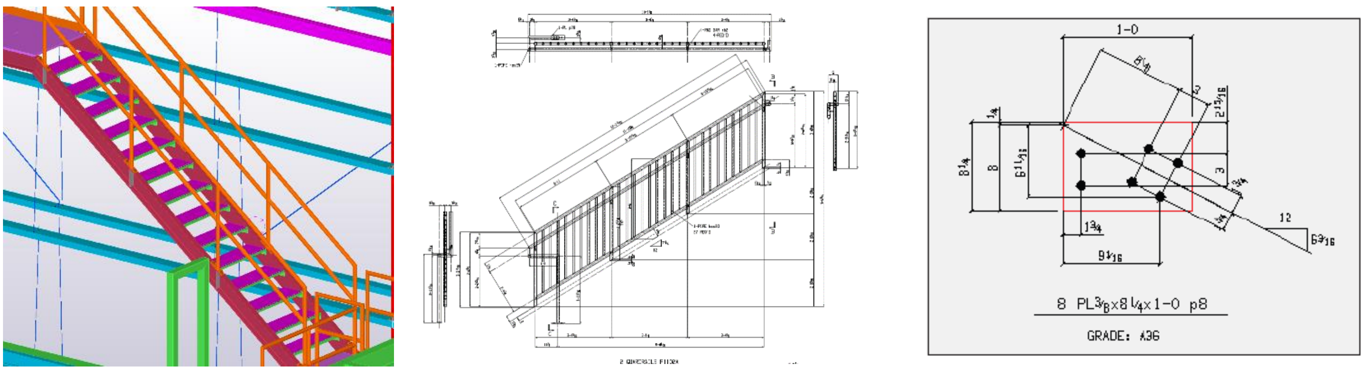


Figure 16. Fabrication process by BIM-DFE.

This phase begins with the steel BIM-DFE process from the previous phase (Figure 16). Experts agreed that taking advantage of the early integration and LOD 400 conducted in the previous design stage is necessary in this phase, not to add more information to the 3D model. It is possible to begin with the planimetric information extraction from the BIM model to manufacture and generate CNC files for cutting, welding, and perforating the steel elements [14,18,23,35]. This can be achieved using BIM visualization software, such as the Tekla visualizer. It is also proposed that the manufacturing status be shared by different stakeholders through a common environment, such as Trimble Connect, to publicize the manufacturing status (Figure 17) (B4).



(**a**) (**b**) (**c**)

Figure 17. Steel BIM Fabrication—Study sample. (**a**) 1Tekla model LOD 400, (**b**) Automatic planimetry extraction, (**c**) CNC extraction.

5.4. Phase 4: Steel Transportation

As shown in Figure 18, this phase begins with the BIM model optimized and nurtured from all the previous stages, allowing the carrier to use this information to classify the elements to be transported (B13), conduct a follow-up, and prioritize the shipment according to the needs of the project [48] (B14). The result of this process is sending the material to the work site and always having the information regarding where, how, and when the elements are to be assembled.

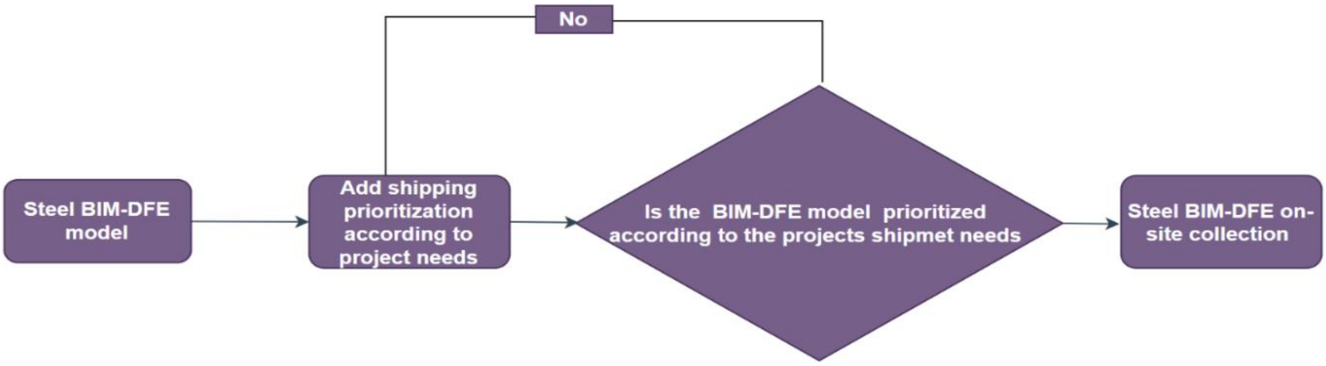


Figure 18. Transportation by BIM-DFE.

This also has a significant impact on the assembly logistics. A common mistake at this stage was the lack of control over the dispatch of steel elements from the factory to the field. In this phase, the expert agreed to take advantage of the information from the manufacturing BIM model and transfer it through IFC files to the software that generates the use of truck spaces to be sent to the field by using algorithms, such as the Fortosi software. This reduces the number of shipments and alerts the factory of any missing elements to be sent (Figure 19).

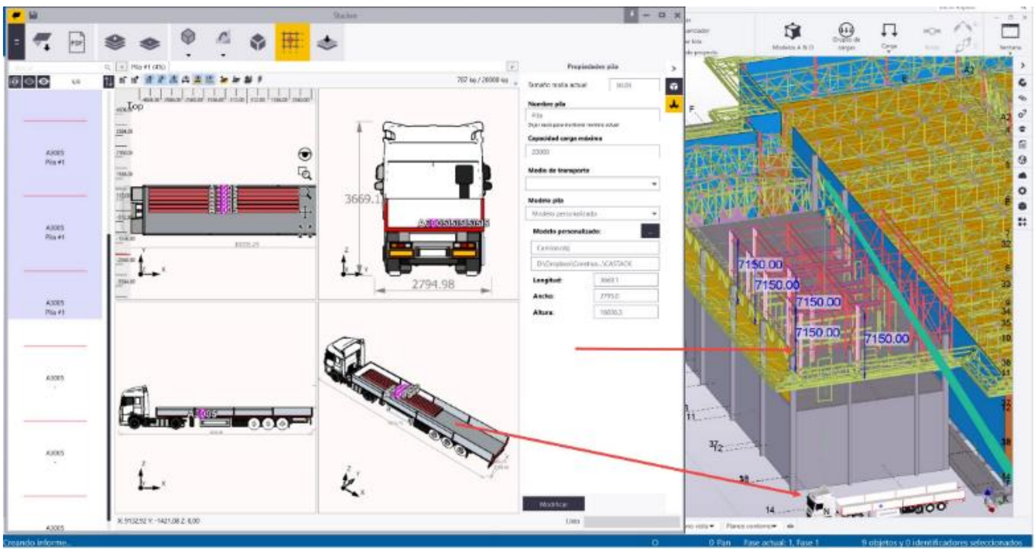


Figure 19. Steel BIM truck loading sample.

5.5. Phase 5: Erection

As shown in Figure 20, this process begins with the steel BIM on-site collection with significant information from all the previous phases, which allows the planning, budgeting, and adequate supervision of the construction and assembly processes of a steel building site. (BU9) (Figure 21). The steel construction progress phase is displayed in real-time, directly and accurately reflecting the hole construction process (B14). The express process includes sensors in the steel structures that allow the identification of failures caused by transportation or stockpiling to prevent the detection of these failures when the structure is already assembled or worse, in the construction operation stage [53]. Finally, combining IoT with the common data environment allows the control of the different stages of the steel section. It reports the steel status of the work site to all the specialties to facilitate the coordination in the fabrication process and make the relationship between the rider and client more transparent regarding the supervision and costs of the work performed (B7, B9, B13).

Figure 20. BIM-DFE Erection.

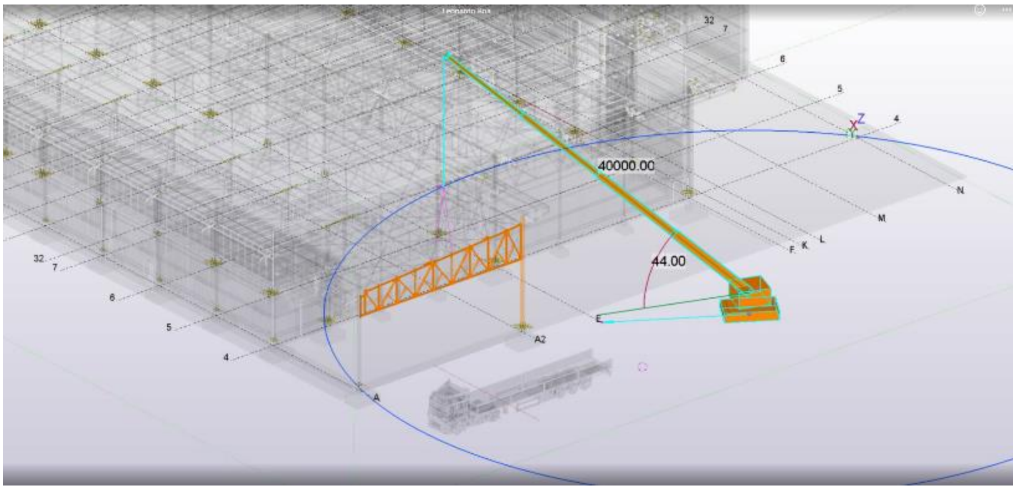


Figure 21. BIM-DFE-Erection model.

6. Conclusions and Future Directions

The use of an integrated BIM, BIM-DFE, is proposed to guide a systematic, efficient, and effective steel construction. The BIM model is to be used for communication between all stakeholders, such as the client and designers, designer and fabricator, designer and erector, and erector and fabricator, to ensure the success of the steel building project. BIM-DFE improves construction plans by determining the most economical and sustainable plan.

After two rounds of the Delphi method, an integrated BIM-use BIM-DFE (BIM for design, fabrication, and erection in steel construction projects) consensus was reached by the panel of experts. BIM-DFE is an integration proposal for using BIM throughout the steel construction lifecycle. The BIM-DFE should be used as a federated BIM 3D model and must be nurtured in different stages; this transfer of information should be through open BIM collaboration files such as IFC.

The use of BIM is most prominent in the planning and design phases, which is highlighted in the preliminary analyses of the costs of fabrication, transportation, and erection of the steel structure, aiming to improve the understanding of decision-makers, especially emphasizing the planning and design phases, and integrating the resources of the remaining stakeholders at the disposal of an optimized design.

Finally, it is imperative to add information related to transport simulation to the BIM models in the design stage. This permits the classification of the elements to be transported to conduct a follow-up and prioritize the shipment according to the needs of the project. Although these are not typically included, they significantly impact the total cost of the project.

6.1. Future Research Directions

Considering that the problems of BIM usage in steel buildings presented in this study can be extrapolated to other building materials, it is proposed for performing a methodological expert consensus for other materials, such as concrete and wood, where the findings of the scientific literature can be integrated into a methodology with the relative consensus of experts in the industry.

6.2. Contribution to Scientific Community

The contribution to the scientific community is the consensus of BIM integration use based on scientific evidence validated by the critical stakeholders in the industry.

6.3. Limitations

The state of the art scientific literature reviewed in this study was limited to the last ten years; only peer-reviewed publications were included, and doctoral theses and proceedings were excluded. Moreover, the experts in this study had experience only in Europe, Latin America, and North America. Furthermore, the investigation was framed only for integrating BIM usage in the different phases of steel building projects.

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Appendix A

Table A1. Questions for the First Round.

Code	Questions	Phase/Software	Subprocess	BIM Uses
Q1	According to your experience, please indicate if you agree whether the following phases are related to the steel building project: planning, design, fabrication, planning for construction, and erection. If so, do you think the last ones could operate in a single phase? Please indicate your level of agreement and explain your answer.	-	-	-
Q2	Considering your experience, please indicate your level of agreement with the statement that the budget process should be the first in the planning stage.	Planning	Project budget	-
Q3	Considering your experience, what is your level of agreement regarding a project manager who also fulfills the role of a design engineer being selected in the planning stages? Please explain your answer. Ref: planning process map.	Planning	Selection of the steel designer and P.M.	-
Q4	Considering your experience, what is your level of agreement regarding that a BIM estimation model should be created in the planning stage prior to the design and analysis phase to determine the number of tons to process prior to the selection of steel, transportation, and assembly suppliers? Please explain your answer. Ref: planning process map.	Planning	Steel BIM estimation model	B1, B4, B6, B11.
Q5	What is your level of agreement regarding that the planning stage should end with communicating the guidelines and level of detail of the BIM models that will be developed in the following stages? Please explain your answer. Ref: planning process map.	Planning	BIM-DFE act.	-
Q6	What is your level of agreement regarding the design stage beginning with an act that frames the scopes and types of BIM deliverables of the project in the design phase? Ref: Design process map.	Design	BIM-DFE act.	-
Q7	What is your level of agreement regarding the next sub-process being the entry of analytical information into the BIM estimation model to accurately determine the structural steel sections to be used? Ref: Design process map.	Design	Enter analytical information into the BIM-DFE model	B3.

Table A1. *Cont.*

Code	Questions	Phase/Software	Subprocess	BIM Uses
Q8	What is your level of agreement regarding that in the design phase, following the design analysis subprocess, the steel connection will be made with a software that can process the connection types considering the inputs of the BIM model in the previous stage? Please justify your answer. Ref: Design process map.	Design	Steel connection design	B1, B2.
Q9	What is your level of agreement regarding that the response in the quote of the potential suppliers (manufacturers, assembler) can be accelerated using the BIM model from the previous stages and that this influences the decision-making of the selection of suppliers? Ref: Design process map.	Design	Selection of the steel fabricator and steel erector	B1, B2, B4, B6.
Q10	What is your level of agreement regarding this phase ending with selecting the manufacturer, assembler, and a BIM model with the connections defined before manufacturing? Ref: Design process map.	Design	Steel BIM-DFE Model	-
Q11	What is your level of agreement regarding the manufacturing stage beginning with the BIM model from the previous phase? Do you think this increases the speed and rigor in the manufacturing stage? Ref: Fabrication process map.	Fabrication	Steel BIM-DFE Model	-
Q12	What is your level of agreement regarding the following thread determining the manufacturing and assembly phases in the BIM model according to the needs of the project? Ref: Fabrication process map.	Fabrication	Steel construction phases design	B6, B12
Q13	What is your level of agreement regarding the following thread detailing the structure to generate the parts and pieces for manufacturing and assembly? Please explain. Ref: Fabrication process map.	Fabrication	Steel detailing process based on BIM-DFE model	-
Q14	What is your level of agreement regarding the next sub-process being the fabrication of the structure and using the BIM model as a tool for portability in the manufacturing processes? Ref: Fabrication process map.	Fabrication	Fabrication of the steel structure	B5
Q15	What is your level of agreement regarding the manufacturing process ending with a BIM model that obtains all the information based on the state of the manufactured process, and this is shared with the transporter and assembler? Please explain. Ref: Fabrication process map.	Fabrication	BIM-DFE model updated	-
Q16	What is your level of agreement regarding the transport phase beginning with the BIM model resulting from the previous phase? Please explain. Ref: Transport process map.	Transport	BIM-DFE model updated	-
Q17	What is your level of agreement regarding the following process in the transport phase prioritizing shipment according to the needs of the site? Ref: Transport process map.	Transport	Add shipping prioritization according to the project needs	B14
Q18	What is your level of agreement regarding a BIM model being used to optimize the shipment according to the truck type to be used in the same previous process? Ref: Transport process map.	Transport	Add shipping prioritization according to the project needs	B14
Q19	What is your level of agreement regarding this transportation phase ending with a BIM model with all the information on the shipping priorities according to the needs of the project and transportation resources? Ref: Transport process map.	Transport	Steel BIM-DFE on-site collection	-
Q20	What is your level of agreement regarding the planning and erection phase beginning with the BIM model fed from the previous stages? Ref: Erection process map.	Planning for C. and Erection	Steel BIM-DFE on-site collection	-
Q21	What is your level of agreement regarding the next sub-process in the planning stage for erection being the simulation of the assembly structure considering the resources available in the field? Ref: Erection process map.	Planning for C. and Erection	Control installation	B9, B10, B13.
Q22	What is your level of agreement regarding the assembly stage ending with a BIM model that has significant information regarding the project, reflects the final state of the steel elements, and is shared in real-time by all the stakeholders? Ref: Erection process map	Planning for C. and Erection	Steel BIM-DFE on-site collection	-

Table A1. *Cont.*

Code	Questions	Phase/Software	Subprocess	BIM Uses
Q23	Based on your experience, what is your level of agreement regarding the BIM tools that are most used in the planning phase are the following: Revit, SDS/2, Tekla, Advance Steel, and CYPECAD? If you do not completely agree, please explain your answer.	Software	-	-
Q24	According to your experience, what is your level of agreement regarding the BIM tools that are most used in the design phase are the following: SAP2000, Tekla Structural designer, ETABS, and RAM? If you do not agree completely, please argue your answer.	Software	-	-
Q25	According to your experience, what is your level of agreement regarding the BIM tools that are most used in the manufacturing phase are the following: Tekla, SDS/2, Strumis, and Tekla PowerFab? If you do not completely agree or if you consider that certain software is missing, please comment and explain your response.	Software	-	-
Q26	According to your experience, what is your level of agreement regarding the BIM tools that are most used in the transport phase are the following: SDS/2 Fortosi and Tekla Track loading? If you do not completely agree or if you consider that certain software is missing, please comment and explain your answer.	Software	-	-
Q27	Do you feel it would be helpful to have a BIM model in the erection stage that reflects the physical state of the elements prior to erection?	Software	-	-
Q28	Based on your experience, what is your level of agreement regarding the BIM information exchange format between the different phases being IFC? If you do not completely agree or if you consider that there is another software extension, please comment and justify your answer.	Software	-	-

Table A2. Questions for the Second Round.

Code	Questions	Phase/Software	Subprocess
Q1	According to your experience, please indicate your level of agreement with the following statement: The phases of steel building projects are planning, design, fabrication, and erection.	-	-
Q2	Considering your experience, please indicate your level of agreement regarding the planning process beginning with the need to build, followed by the selection of the type of project (industrial, commercial, etc.)? Ref. Planning process map.	Planning	Type of project
Q3	Considering your experience, please indicate your level of agreement regarding that a project manager should be selected in the planning phase? This project manager can be one of the project stakeholders with experience in BIM usage for steel construction and the type of project selected. Ref: planning process map.	Planning	Selection of the steel designer and P.M.
Q4	Considering your experience, please indicate your level of agreement regarding a BIM estimation model being created in the planning phase prior to the design and analysis phases to determine an approximate number of steel tons to process prior to the selection of the steel fabricator, transportation, and erection suppliers in this phase.? Please explain your answer. Ref: planning process map.	Planning	Steel BIM estimation model, Selection of the steel fabricator and steel erector.
Q5	Please indicate your level of agreement regarding the planning stage ending with a BIM-act that would provide the communication guidelines and level of detail of the BIM models that will be developed in the following phases? Please explain your answer. Ref: planning process map.	Planning	-
Q6	Please indicate your level of agreement regarding the design stage beginning with a BIM-act that frames the scopes and types of BIM deliverables of the project in the design phase? Ref: Design process map.	Design	BIM-DFE act.

Table A2. *Cont.*

Code	Questions	Phase/Software	Subprocess
Q7	Please indicate your level of agreement regarding the next sub-process being the entry of the structural design information into the BIM model from the previous stage selected in the previous phase, and that in this design stage, the resources of the suppliers selected in the previous stage are also considered? Please explain. Ref: Design process map.	Design	Enter analytical information into the BIM-DFE model
Q8	What is your level of agreement regarding that in the design phase, following the design analysis subprocess, the steel connection will be made with a software that can process the connection types considering the inputs of the BIM model in the previous stage? Please justify your answer. Ref: Design process map.	Design	Steel connection design
Q9	What is your level of agreement regarding the erection sequences of the project being defined in the following sub-process in this phase?	Design	Steel construction design
Q10	What is your level of agreement regarding this phase (design) ending with selecting the fabricator, erector, and a BIM model with the connections defined prior to fabrication? Ref: Design process map.	Design	Steel BIM-DFE Model
Q11	What is your level of agreement regarding the fabrication phase beginning with the BIM model from the previous design phase? Ref: Fabrication process map.	Fabrication	Steel BIM-DFE Model
Q12	What is your level of agreement regarding the following sub-process detailing the steel structure (optimized and validated for the steel fabricator, transport, and erector) to generate the parts and pieces for fabrication and erection information? Please explain. Ref: Fabrication process map.	Fabrication	Steel Detailing process based on BIM-DFE model
Q13	What is your level of agreement regarding the following thread manufacturing the structure with the detailed documentation of the BIM model of the previous subprocess? Ref: Fabrication process map.	Fabrication	Fabrication of the steel structure
Q14	What is your level of agreement regarding that the BIM model would be used as a quality control tool in the steel fabrication process?	Fabrication	Fabrication of the steel structure
Q15	What is your level of agreement regarding the manufacturing process ending with a BIM model that obtains all the information regarding the state of the manufactured process, and would be shared with the transporter and erector? Please explain. Ref: Fabrication process map.	Fabrication	BIM-DFE model updated
Q16	What is your level of agreement regarding the transport phase beginning with the BIM model resulting from the previous phase? Please explain. Ref: Transport process map.	Transport	BIM-DFE model updated
Q17	What is your level of agreement regarding the following dub process in the transport phase being prioritized for shipment according to the needs of the site? Ref: Transport process map.	Transport	Add shipping prioritization according to the project needs
Q18	What is your level of agreement regarding that in the same previous process, a BIM model is used to optimize the shipment according to the type of truck to be used? Ref: Transport process map.	Transport	Add Shipping prioritization according to the project needs
Q19	What is your level of agreement regarding this transportation phase ending with a BIM model with all the information on shipping priorities according to the needs of the project and transportation resources? Ref: Transport process map.	Transport	Steel BIM-DFE on-site collection
Q20	What is your level of agreement regarding the planning and erection phase beginning with the BIM model fed from the previous stages? Ref: Erection process map.	Planning for C. and Erection	Steel BIM-DFE on-site collection
Q21	What is your level of agreement regarding the next sub-process in the planning stage for the erection being the simulation of the assembly structure considering the resources available in the field? Ref: Erection process map.	Planning for C. and Erection	Monitoring of the elements erected on site
Q22	What is your level of agreement regarding the assembly stage ending with a BIM model with significant information that reflects the final state of the steel elements and it being shared in real-time by all the stakeholders? Ref: Erection process map.	Planning for C. and Erection	Steel BIM-DFE on-site collection

Table A2. *Cont.*

Code	Questions	Phase/Software	Subprocess
Q23	Based on your experience, what is your level of agreement regarding the BIM tools that are most used in the Planning phase are as follows: Revit, SDS/2, and Tekla? If you do not completely agree, please explain your answer.	Software	-
Q24	According to your experience, what is your level of agreement regarding the BIM tools that are most used in the design phase are as follows: SAP2000, Tekla Structural designer, ETABS, and RAM? If you do not completely agree, please explain your answer.	Software	-
Q25	According to your experience, what is your level of agreement regarding the BIM tools that are most used in the manufacturing phase are as follows: Tekla, SDS/2, Advance Steel, Steel Project, Strumis, Power Fab. If you do not completely agree or if you consider that certain software is missing, please comment and explain your response.	Software	-
Q26	According to your experience, what is your level of agreement regarding the most used BIM tools in the transport phase are as follows: SDS/2 Fortosi and Tekla Track loading? If you do not completely agree or if you consider that certain software is missing, please comment and explain your answer.	Software	-
Q27	Do you feel it would be helpful to have a Tekla, Revit, SDS/2, Naviswork, or Trimble Connect BIM model in the erection stage that reflects the physical state of the elements prior to erection? Please explain.	Software	-
Q28	Based on your experience, what is your level of agreement regarding the BIM information exchange format between the different phases being IFC? If you do not completely agree or if you consider that there is another software extension, please comment and justify your answer.	Software	-

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