Hindawi
Advances in Civil Engineering
Volume 2019, Article ID 8452461, 16 pages
https://doi.org/10.1155/2019/8452461

Research Article

Methodology for Building Information Modeling (BIM) Implementation in Structural Engineering Companies (SECs)

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Received 19 September 2018; Revised 31 December 2018; Accepted 30 January 2019; Published 21 February 2019

Guest Editor: Tatjana Vilutiene

Structural engineering companies (SECs) currently have a series of deficiencies that hinder their processes and interactions, decreasing their productivity, lacking collaborative and interconnected processes, not including current work methodologies such as building information modeling (BIM). The BIM methodology seeks to integrate processes and professionals involved in engineering tasks by working on platforms with coordinated and intelligent 3D virtual models. BIM has great potential for structural engineering companies (SEC) and solves their most salient problems. This paper defines a methodology to implement BIM in the SEC, focused on solving the complexities of the design phase, those that make the implementation of BIM in these offices a nontrivial task. Characterized by the optimization of resources, flexibility, and adaptability, the methodology proposed for BIM implementation within SEC clearly and objectively identifies the resources and expectations of the organizations, sets out the requirements necessary to develop the BIM methodology, and provides practical and technical recommendations for planning and monitoring the implementation.

1. Introduction

In a building or infrastructure project, the structural design, materialized in the analysis, design, and documentation of structures is a complex and dynamic process that undergoes constant modifications and restrictions during the life-cycle of the project on the orders of the client, the architect, and/or contributions from other professionals [1]. In structural engineering companies (SECs), interactions between both professionals within and outside the organization and the workflows tend to situations that decrease productivity, interaction problems among different professionals, inefficient delivery of information, and inadequate communication channels, reworks, and recurrent changes, among others [2].

Building information modeling (BIM) is one of the most important and promising changes in the architecture, engineering, and construction (AEC) industries, as it represents a paradigm shift in the conception and gestation of projects, allowing for the development of a detailed virtual model for the different phases of a project life-cycle. Improving collaboration and harmony and achieving higher levels of efficiency, BIM allows integration in the AEC industry, which is usually characterized by fragmentation [1]. Currently, with complex and large engineering projects, these methodologies and technologies are enabling the management and processing of the generated data [2–4].

The structural design phase represents one of the most complex and dynamic tasks in the life-cycle of a project, given that structural behavior must be rigorously analyzed in adherence to a series of regulatory provisions, not to mention professional practices. This significance makes the structural design phase an essential component of the generation of the BIM model [5]. In addition, modern architectural designs increasingly include complex geometric configurations of buildings [6], which make structural analysis of buildings more complex [7]. Notwithstanding the above, there is still not a unanimously accepted method for information transfer at the structural design stage, and so it continues to be the weak link in BIM model workflows [8]. It is therefore essential to be able to solve this latter barrier and efficiently incorporate structural area processes into the work chain of typical projects, taking advantage of the fact that the success of BIM depends, to a large extent, on the efficient exchange of information generated by different disciplines [9]. BIM implementation within a structural engineering company is not a trivial task, as it represents a complete evolution of the way the work process develops [10].

The main goal of this document is to revise and provide a solution to the current problems within traditional industry standards, developing a methodology for BIM implementation in structural engineering companies (SEC), including procedures, interactions, and workflows [11]; recommendations for computer programs and communication networks; and other variables necessary for success.

This paper is structured on the basis of a robust bibliographic review of scientific journals in the area, together with studies of expert recommendations that define the problems of the structural design phase and the potential of the BIM methodology. This methodology is structured on the basis of six sections: company analysis, reformulation of the BIM objective in the company, requirements for the adoption of BIM, determination of the "implementation gap," strategies and planning for implementation, and finally, the assessment and monitoring.

2. Literature Review

Current procedures in structural engineering companies are dynamic and iterative. The analysis and design of structure is based on trial and error processes, until the convergence of structural models and defines and designs the various elements that make it up [12]. This process is also constantly fed by changes coming from the senior structural engineer and/or the architect, generating recurrent revisions of the design that must be studied again. In addition, the interactions between the various professionals in this phase are high but poorly systematized and not optimized, establishing artisan communication channels, which causes lack of information and disconnection [1]. These situations entail a series of interaction problems, both within the company and with external professionals, which translate into productivity losses, in addition to the fact that they have not incorporated collaborative work methodologies to optimize their processes [2].

Building information modeling (BIM) is a collaborative work methodology that seeks to connect people, processes, and digital models in building and infrastructure projects, thereby allowing fluidity in the transfer of information and communication [1]. Thus, with a digital graphic representation of the physical characteristics and functionality of the project, it is sought to manage the phases of design, construction, and administration throughout the life-cycle, considering relevant the information associated with the graphic representation, which allows its work and use for various functions [13].

The need for BIM in the early stages of the project is very relevant [14]. The MacLeamy time-effort distribution curve in Figure 1 shows how capacity to influence costs and changes of a project is greater at the design stage and decreases significantly as the project enters the operation phase (curve 1). At the same time, the cost of making changes is very low during the design phase and quite high in the operation phase. Curve 3 shows traditional design behavior, while curve 4 shows how performance shifts to the left when using BIM technologies, allowing for greater ability to make changes at lower costs [15]. It should be noted that displacement of the curve necessarily involves interactions between all phases of the project; this is where BIM and nD modeling have great potential for industry integration [16].

Specifically, BIM has been demonstrated to facilitate communication and information transmission between professionals from different disciplines during the structural design process, allowing greater accessibility and constant updating of information, even in real time [17]. BIM enhances knowledge sharing management, reducing the time and cost of solving problems related to constructability and projects coordination [18]. In addition, it allows architects and structural engineers (bidirectional flow) to visualize modifications and conflicts and assists immediate decision making, significantly reducing rework and optimizing project times and costs [8]. Also, by detecting errors in advance and automating variables that were traditionally used in "manual" processes, BIM also enhances automation of detail engineering and documentation processes, reducing work times and increasing project quality [19, 20]. The possibility of integrating structural and nonstructural elements into the model controls performance of the whole. Once structural analysis has been carried out and member sections have been verified, BIM allows SEC to monitor how structural behavior affects nonstructural elements and/or other components of the project (considerations that would otherwise be too complex without the use of this type of tool). Thus reductions in costs for repairs when the structure is used differently, or when affected by adverse natural effects (earthquakes, hurricanes, among others) [7].

The correct exchange, quality information extraction and storage, are relevant to the success of BIM. There, the importance of universal archives, such as IFC format, is relevant to the achievement of these objectives [21].

In spite of the above lack of agreement, there are methodologies or guidelines for BIM implementation, mainly from developed countries such as the United States, Holland, and the United Kingdom, among others. These lists of recommendations for BIM are structured around project development [22], the roles included, and the tasks, objectives, and responsibilities of each of the participants in the process [23]. However, the steps for implementing BIM in companies remain to be defined: plans, training, studies, progressive changes, etc.

It is important to clarify that BIM implementation does not modify design criteria or standards, but rather restructures the way professionals and processes develop and interact with each other. Thus, each team member becomes aware of the importance and objectives of the process, has

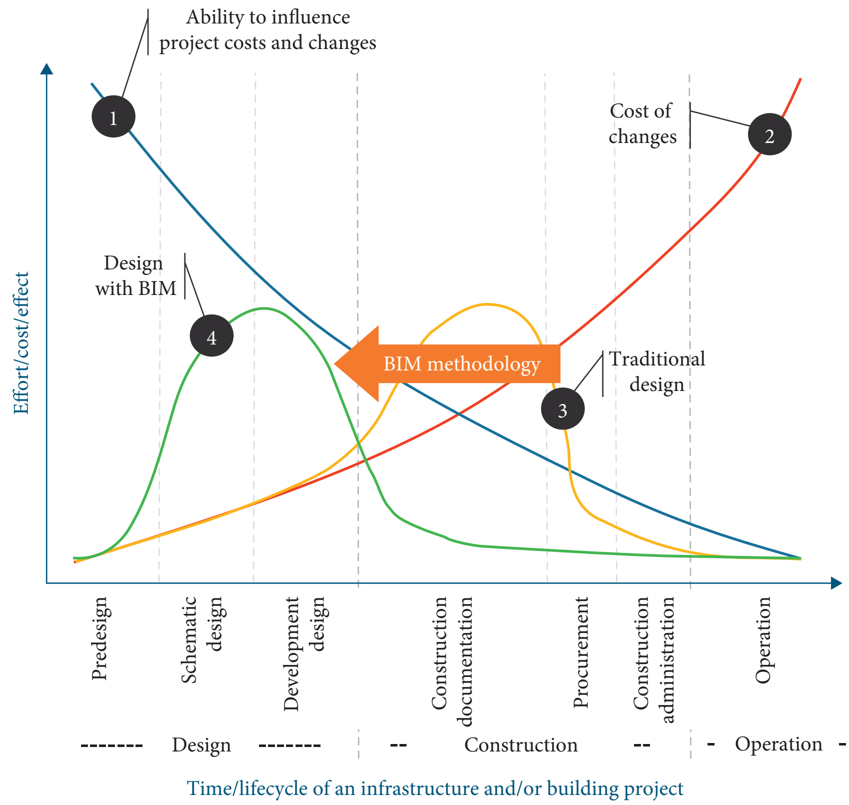


Figure 1: MacLeamy time-effort distribution curves in construction [15].

well-defined roles and responsibilities, and acquires knowledge of the requirements for skills, competencies, processes, and interactions needed for project success. Furthermore, the implementation plan serves as a guide for new professionals to join the task at hand and is a reference for future evaluations of success in the company [10].

3. Methodology for BIM Implementation in SECs

The BIM implementation methodology for structural engineering companies (SEC) has different stages, as shown in Figure 2. The methodology maintains implementing manual principles from leading authors, methodological recommendations, templates, and guides of the "BIM Handbook" and the "Project Execution Planning guide" [23, 24] while expanding and adapting the same for SEC. It is mainly characterized by clear and flexible processes for company requirements, objective evaluations of resources and processes, real implementation requirements identified, and maximally optimized costs.

The requirements for an implementation methodology necessarily include recognizing the objectives, expectations, and approaches that a given company wishes to achieve when incorporating BIM methodology; identifying roles, teams, and functional structures; planning gradual scales and speeds of implementation and training; and identifying the alignment of management and staff, along with a detailed program of action, according to experiences reflected in various research documents [25–27]. In addition to the above recommendations, the model in the present paper has additional components to generate a more complete and flexible implementation methodology, summarized in six major sections: company analysis; reformulation of the BIM objective in the company; requirements for the adoption of BIM; determination of the "implementation gap"; strategies and planning for implementation; and finally, assessment and monitoring.

Below, each section of the methodology as shown in Figure 2 is detailed.

3.1. Business Analysis and Diagnosis

3.1. Business Analysis and Diagnosis. In order to refocus company activities using BIM methodology, it is necessary to understand how the organization works, what resources it possesses, and its expectations and projections for the future. In this way, the implementation will be aligned with the objectives, vision, and mission of the company, will take advantage of available resources, and will generate the most suitable plan. From the very first contact with the company, management staff must be instructed on BIM in order to bring them closer to the methodology and show them its potential. Afterwards, in order to carry out a complete study of company operations and characterize its needs, all the necessary information points below are to be developed.

3.1.1. General Information. General, information on the organization is to be collected, which is useful for identification of the company and future management. The

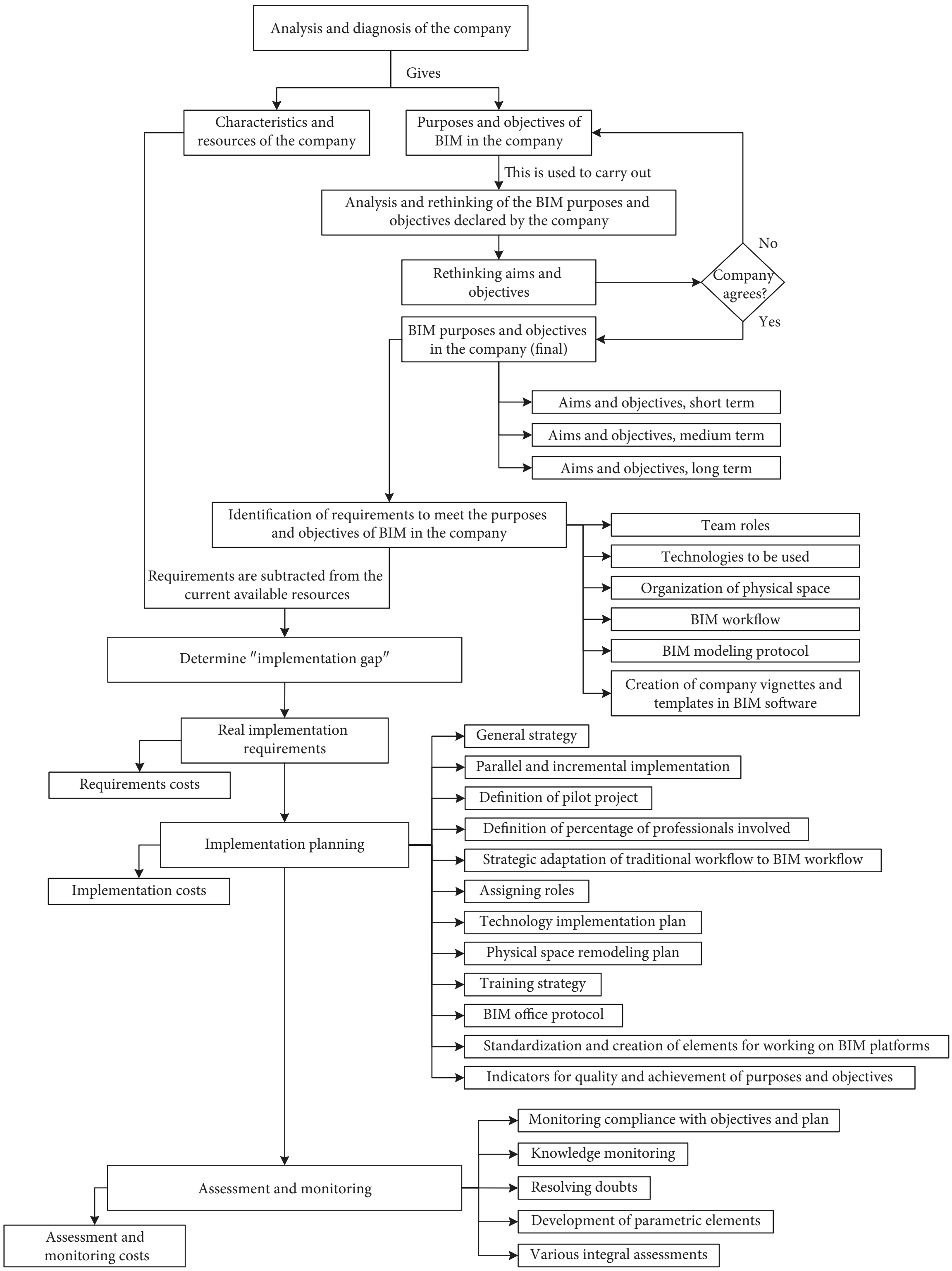


Figure 2: Methodological model for BIM implementation in structural engineering companies (SEC).

following is requested: name of the company, address, contact, professional contact, organizational chart, number and type of professionals, working hours, and timetables available for training sessions.

3.1.2. Focus and Expectations of the Company. The implementation plan should be aligned with company vision, mission, and the objectives it seeks to achieve through BIM implementation. Thus, three perceptions should be defined:

(1) vision of the organization; (2) target market and projects developed; and (3) purpose of BIM implementation.

Identifying the vision and mission of the company implies understanding its own definitions of how it was conceived, how it has acted, and how it projects itself towards the future. Respondents should be ready to answer how BIM will help meet these institutional objectives.

The organization should be explicit about their target market and the size, type, and approximate duration of the project it is developing in order to timely inform requirements and provisions for respective contractors in alignment with BIM deliverables.

The organization must also state the objectives for which it wishes to adopt BIM. These may include lower costs, improved project quality, reduced time, participation in new markets, and/or regulatory requirements, among others. The organization delivers these objectives expressed in expectations of concrete goals (tasks and dates).

3.1.3. Evaluation of Available Resources. Available resources are evaluated through three categories: (1) human resources; (2) technological resources; and (3) physical space and office furnishings. For each of these, it is necessary to know investment, renovation, and/or plans for expansion in order to identify previously assigned resources and align some implementation costs.

The human resources available are evaluated to obtain information regarding capabilities and competencies, with technical and personal skills such as: technical competencies (TC), personal and collaborative work skills (PCWS), mentality and willingness to change (MWC), and alignment with the vision and development of the company (AVDC). In order to obtain high levels of veracity during consultations, self-assigned scores from each professional (Pp) should be weighted against the evaluation of their direct supervisor (Ps), at the discretion of the evaluator. Table 1 shows the skills and abilities that should be consulted with company employees. Items should be added or removed for specific computer programs, depending on the context of the company. The list shown, while not exhaustive, includes the most frequently found programs in offices surveyed.

Table 1: Items for measuring human resources.

Item		Competencies
TC	1	Mastery SAP2000
	2	Mastery ETABS
	3	Mastery of SAFE
	4	Mastery AutoCAD 2D
	5	Mastery of AutoCAD 3D
	6	Advanced mastery EXCEL
	7	Mastery of the programming program (MatLab, other)
	8	Mastery structural robot
	9	Mastery of advance steel
	10	Mastery advance concrete
	11	Mastery of tekla structures
	12	Master and other structure programs (please specify)
	13	Mastery revit architecture
	14	Mastery revit structure
	15	Mastery revit MEP
	16	Mastery archicad
	17	Mastery of navisworks
	18	Mastery of "working in the cloud" (please specify)
	19	Mastery of other BIM programs (please specify)
	20	Mastery standards of structural design
	21	Mastery of plan detailing standards
	22	Mastery of BIM methodology
PCWS	23	Leadership
	24	Collaborative work
	25	Management control skills
	26	Problem solving skills
	27	Creativity
	28	Conflict management
	29	Ability to persuade
	30	Communication skills
	31	Negotiation skills
	32	Sense of discipline
MWC	33	Quality orientation
	34	Self-study capability
	35	Flexibility to change
	36	Readiness for training and new studies
AVDC	37	Organizational sensitivity
	38	Alignment with company vision
	39	Alignment with the company's mission
	40	Commitment to the company

Inventory of the company's technological resources should include hardware and software; all software or virtual tools and/or platforms used should be accounted for. Thus, at least 3 broad categories of these media items are available: equipment (brand, model, processor, video card, RAM, hard disk, and video adapter); software and/or virtual platforms (name, developer, local provider, type and cost of licenses, description of use); and local and/or "cloud" servers (brand, model, capacity, and description of the network).

BIM implementation requires fluid interaction among project team members, and it is essential that the physical workspace within the company allows for this type of interaction [24, 25]. This is why the organization must submit its plans for the existing physical facilities, detailing locations of facilities, networks, furnishings, and people in order to understand staff interaction conflicts within the office and to propose restructurings adapted to the current scenario during BIM implementation.

3.1.4. Analysis of Current Deliverables. The company should report current deliverables. The need to know the characteristics of organizational deliverables lies in the fact that the product achieved through BIM implementation must align with current indicators.

Any deliverable an organization currently has should be included in a document called the "Traditional Design and Drafting Practices Manual," which details development of the plans made under traditional work methodology and standardizes work done within the SEC. The aim is for the organization to clarify three characteristics: (1) minimum regulatory framework required; (2) standards set by the SEC above regulatory requirements; and (3) established checkpoints for verifying information at all levels of project development to prevent the spread of errors and to seek timely correction. Many companies already have this document for office criteria, so its identification should not be complex.

3.1.5. Evaluation of Current Processes. Evaluation of current processes (and components thereof) within the organization is developed along three lines: current workflow and processes; programs used in each activity; and current problems. Workflow and processes within the organization are to be identified for all types of resources and deliverables. In general, companies in the field do not formally define processes; however, professionals usually do have a clear definition. The evaluator then translates the declared processes into a workflow template. For each of the activities declared within the workflow, any programs used to develop or support work should be indicated. This helps to identify current problems in the organization. To this end, Muñoz [2] published a nonexhaustive set of 25 common problems that occur in structural engineering offices, which are reproduced in Table 2.

Table 2: Typical problems in structural engineering companies (SEC) [2].

Interaction	No.	Problems in SEC
I-E	1	Various returns of the projects to architecture
	2	Delay in return of plans from architecture, protested by the SEC
	3	No notification or specification of changes in plans from architecture
	4	Inefficient communication channels with architecture
	5	Few direct coordination meetings with architecture
	6	Lack of initial coordination (defining channels, means for working, and feedback) in early architecture-engineering interactions
	7	Differences in modeling criteria between architecture and SEC
	8	Delays in deliveries due to questioning of calculations based on differences in design criteria between project review offices
	9	Projects returned to the SEC due to doubts/errors identified during the construction phase
	10	Postdelivery changes to total costs of bulk work (reduced costs)
1-E/I-I	11	Loss of information from central source (architect, client) when passing across the desks of senior engineers, coordinators, up to the executing project engineer
	12	There is no logbook/record of project modifications
	13	Presence of downtime in projects
I-I	14	The exchange of information between the engineer-designing draftsman is "manual" (handwritten plans, verbal indications, etc.)
	15	Large number of reworks by the designing draftsman due to recurring changes
	16	Errors in final structural plans
	17	Excessive work for designing draftsmen because of large amount of detail in the projects
	18	Redrawing of architectural plans to structural plans
	19	Changes in analysis models (partial or global) due to project modifications
	20	Identification of errors and/or omissions in near-completed projects
	21	Low internal control of ongoing activities and projects
	22	Decreased efficiency due to multiple jobs performed in parallel by one professional
	23	Excessive rework by the project engineer
	24	Large number of spreadsheets (excel, etc.) that make the design process slow and cumbersome
	25	Many projects with similar deadlines as all clients want their projects to be completed quickly (everyone needs theirs "yesterday")

3.2. Analysis and Rethinking of the Purpose and Objectives of BIM as Stated by the Company. The statement of objectives that the organization seeks to achieve by incorporating BIM in some cases may come from partial or misconceived knowledge of, rather than the full potential embodied in, BIM. In view of this, once company objectives have been defined and placed within the framework of its characteristics (size, resources, etc.), the objectives to be achieved through BIM must be reconsidered in order to optimize resource use for investments, or to place concrete goals on the expectations raised. The fulfillment of objectives should also be distributed throughout the short, medium, and long terms.

3.3. Requirements for the Adoption of the BIM. The implementation plan identifies all the requirements necessary for an SEC to work with BIM by considering the important contributions from current organization attributes and resources.

3.3.1. Team Roles. Since the implementation plan in this paper focuses on SEC, it is necessary to adapt traditional generic BIM roles to the development of structural design and calculation under BIM methodology [28–30]. The construction of BIM roles for the work team expands and adapts the four roles and 15 competencies from the BIM role matrices as proposed by both the Dutch BIR [31] and Chilean BIM Plan [25], given that they propose in a simple and complete way the generic roles that must be assumed in the BIM methodology. In addition, the BIM approach of the United Kingdom [E] has been studied, pioneers in BIM worldwide, considering the articulation of tasks and roles that they include, focused on aspects of training and skills that must be assumed. It is important to note that BIM roles assign responsibilities and functions to different members of the work team; they are not necessarily related to specialties or positions, and moreover, they can be developed by more than one person or allow one person to exercise more than one role. Table 3 shows the five roles the current SEC BIM plan considers: BIM coordinator, BIM modeler, BIM reviewer, BIM project engineer, and BIM leader. In addition, the skills and abilities of the roles detailed by the Chilean BIM Plan and the Dutch BIR have been adapted to numerical parameters in order to quantitatively establish requirements for the different attributes and capabilities for professionals assuming a specific BIM role. Table 4 shows

Table 3: Characteristics of BIM roles.

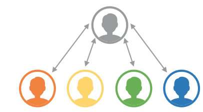
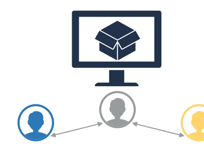
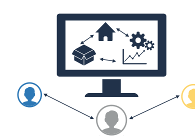
Role	Main characteristics	Model
BIM leader	Responsible for commanding BIM implementation in the organization, defining protocols, and guiding the BIM execution plan (BEP). Must have extensive knowledge of BIM methodology.	
BIM reviewer	Responsible for verifying that the modeling is correct, based on technical and normative aspects and according to organizational protocols.	
BIM coordinator	Articulator of the BIM process in the organization, responsible for model validation and coordination. Serves as a point of contact among different modelers and specialties—must comply with the BEP and be fully aware of BIM standards, mandates, and regulations.	
BIM modeler	In charge of developing BIM models, including 3D visualizations and information associated with the elements. Must have a broad mastery of the related computational tools and a broad knowledge of the discipline modeled.	
BIM project engineer	Professional who performs modeling, analysis, and structural design, but who has acquired skills to partially or totally develop such work under BIM methodology and computational platforms.	

Table 4: Competencies and capacities a professional must have to assume a certain BIM roles.

No.	Skills	BIM leader	BIM reviewer	BIM coordinator	BIM modeler	BIM project engineer
1	Leadership	5	2	3	1	3
2	Training	4	4	4	4	4
3	Collaborative work	5	4	5	3	4
4	Management control	5	3	3	1	3
5	Problem analysis	5	3	5	2	5
6	Creativity	5	3	4	3	4
7	Organizational sensitivity	5	2	3	2	3
8	Vision	5	3	3	3	3
9	Conflict management	5	3	4	1	2
10	Persuasion	5	3	4	1	1
11	Negotiation skills	5	2	3	1	2
12	Communication skills	5	3	4	1	3
13	Quality orientation	5	5	5	5	5
14	Sense of discipline	5	4	4	4	4
15	Constant self-learning	4	4	4	5	4
16	Flexibility to change	4	3	4	4	3
17	Industry needs and challenges	5	1	1	1	2
18	BIM methodology	5	3	3	3	3
19	BIM implementation strategy	5	2	2	2	2
20	BIM execution plan (BEP)	5	2	2	2	2
21	BIM standards and norms	5	4	4	4	4
22	Structural design and calculation	2	1	1	1	5
23	Use of structural calculation program	2	1	1	1	5
24	Using the BIM structural calculation program	2	1	1	1	5
25	Use of BIM modeling software	2	5	5	5	5
26	Use of BIM coordination program	2	5	5	3	2
27	Use of BIM communication platform	5	4	5	4	5

this quantitative measure of skills on a scale of 1 to 5, where 1 represents a low competency level required and 5 high.

3.3.2. Technologies to Be Used. Software interoperability chosen for working in BIM environments is important to the success of the workflow proposed by BIM methodology. While industry foundation classes (IFC) look to be a universal language to connect many software programs in BIM environments, the technology is not yet fully resolved; the only 100% effective way to correctly connect models from different platforms is currently through the use of native programs, i.e., from the same provider or with partner providers. In addition, in view of the variety of options offered by the market, it is necessary to choose the specific tool that best solves objectives sought, weighed in favor of its scale of use and interoperability.

Each BIM professional will have different uses for each computer program [32], and thus differing levels of mastery to successfully perform tasks (though further training is not to be disregarded) within the framework of company-defined objectives. By accounting for these variables, it is possible to optimize and plan training resources.

BIM software requires greater computing power. The recommendations given in Table 5 correspond to specifications provided through consensus among program brands and expert user opinions [33, 34]. Required hardware capabilities are closely related to the size of the projects to be modeled; thus, these are specified to reduce equipment costs that, in the short or medium term, would not be used to maximum potential. Five evaluation categories are defined: operating system, processor, hard disk, RAM, and video card. Table 5 shows general hardware requirements and provides recommendations according to project size. “Type I” projects are considered to be single-family houses and small residential buildings; “Type II” projects are considered to be medium-sized and large residential buildings, and medium-sized office buildings and complex works (e.g., medium-sized clinics); and “Type III” projects are considered to be large skyscrapers and complex works (e.g., large hospitals, airports, etc.).

Since the core of BIM is the connection of processes, files, models, and professionals, a network (server) is required to connect all office team member computers. For example, working under the “Windows Server” platform (Microsoft) has several security advantages and cloud storage capabilities. In addition, visualization and coordination of models must be possible from any physical location. To this end, the use of cloud computing environments, such as A360, BIMsight Key, or Solibri Model Viewer, among others, is recommended to allow interconnected work on the Internet with the rest of those involved in a project. In the future, when there is a project with a large amount of data, computer supports will be necessary to manage it. Optimizing the Big Data of the projects will be relevant for its management [35, 36].

3.3.3. Organization of Physical Spaces. The distribution of physical spaces directly affects how professionals develop their activities, even more so within a collaborative environment such as BIM. To achieve greater and better interactions, it is necessary to remodel the workspaces within the company. Field observations were made to 10 structural engineering companies in Chile, noting that in all of them, the engineers were separated from the modelers. In addition, the professionals declare that there are communication problems between engineers and modelers, mainly because of how the jobs are distributed, having to move from place to consult the projects. Based on field observations made in various companies in the area, a physical arrangement called “3 pairs” is proposed (Figure 3). This arrangement has professionals together at the same time in 3 types of pairings: engineer-modeler (blue-yellow interaction); modeler-modeler (blue interaction); and engineer-engineer (yellow interaction). Thus, engineers are able to communicate directly with modelers, and engineers as modelers (designer draftsmen) are able to provide feedback to each other, etc.; in short, each may directly consult technical and theoretical doubts of their profession with the colleague next to them. It is recommended that there should be more experienced professionals at the ends of the “chains,” where there is only one professional left without a paired colleague, since they will make fewer consultations with their colleagues, spending less time overall.

At the same time, the professional BIM modelers and coordinators must be in an integrated collaborative workspace linked to the integration of other specialties (besides the engineering-designer calculation work) in what has been termed the “extreme collaboration environment” [37]. Figure 4 shows how this room should be organized. The use of a big room is useful, to bring together the owner and the other disciplines, achieving an integrated collaborative process [39].

Here, professionals can work from their personal computers and view a central model on screen. In addition, the extreme collaboration environment serves as a meeting and decision-making room for all project members (including architects and builders) to identify errors or ways to construct the models. In this room, real physical collaboration is achieved among the different professionals involved in the project, with real-time visualizations of how decisions are materialized (in 3D).

3.3.4. BIM Workflow. Figure 5 shows the ideal SEC BIM methodology workflow diagram. The proposed BIM methodology workflow provides fluid communication and document generation processes and facilitates model revision, reducing time spent overall. This workflow is an adaptation of generic BIM flows proposed in the project execution planning guide [22] and is based on professional interactions in a central model: the BIM platform for a given SEC (Revit, for example) will contain volumetric models, reinforcement steel or other structures, as appropriate, and detailed designs and drawings [40]. Thus, all the models may be “superimposed” in order to visualize conflicts and optimize interaction. The workflow also proposes coordination meetings among all the professionals to advance criteria and/or agree on changes.

Table 5: Hardware recommendations for use of BIM software as of 2018.

No.	Item	General characteristics		Recommendation, by type of project
1	Operating system	The use of Microsoft® Windows® (not Linux or Apple), higher than 7, 64-bit version, is recommended.	I	Microsoft® Windows® 10, 64 bits
			II	Microsoft® Windows® 10, 64 bits
			III	Microsoft® Windows® 10, 64 bits
2	Processor	Single or multicore Intel® Pentium®, Xeon®, or i-series processor or equivalent AMD processor (with SSE2). Select version with the highest possible speed.	I	Intel® core I5
			II	Intel® core I7
			III	Intel® core Xeon
3	Hard disk	Preferably solid state disks (SSD) or traditional HDD disks of 750 GB or higher. 5 GB of free disk space is required.	I	Traditional 1 TB HDD disk
			II	128 GB SSD + traditional 1 TB HDD disk
			III	500 GB solid state disk SDD
4	Ram	RAM of 8 GB or more.	I	8 GB RAM
			II	16 GB RAM
			III	32 GB RAM
5	Video (or graphics) card	NVIDIA Quadro cards: 2000 (1024 MB), 4000 (2048 MB), 5000 (2560 MB), 6000 (6144 MB), k-series and above, or similar to the above. The video (or graphics) card must be dedicated, not integrated. AMD counterparts (less recommended) may be used.	I	Dedicated NVIDIA graphics card
			II	Dedicated NVIDIA graphics card
			III	Dedicated NVIDIA graphics card

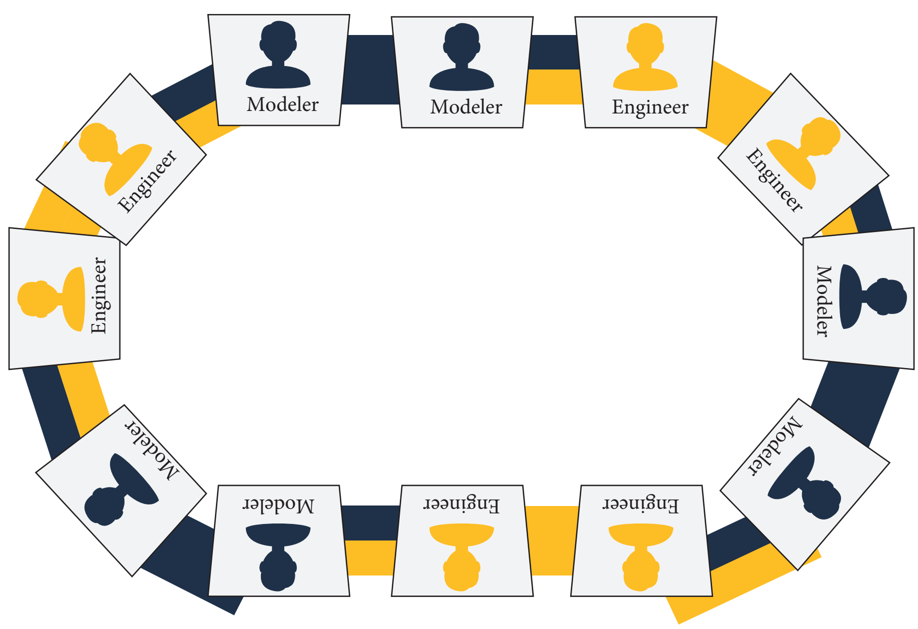


Figure 3: Organization plan for the ideal BIM physical space, “3 pairs”.

3.3.5. BIM Protocol. The structural design companies have their own manuals of procedures and standards that define the work they do, which are based on the standards and national design codes. Currently, based on the documented CAD-2D drawings (complemented by three-dimensional analysis models), companies are guided by 2D design manuals and drawing practice manuals to standardize their design and detail outputs. Now, to work in BIM, counterpart document should be generated for documentation under the BIM methodology, to be called the “BIM Protocol.” This will contain the minimum regulatory framework required, standards established by the SEC (over and above the regulatory requirements for modeling, according to the objectives defined with BIM), and the control points for verifying information at all levels of project development in order to prevent the spread of errors and seek their timely correction. This should be aligned with the BIM execution plan (BEP) and look to standardize model generation on BIM platforms, establish work platforms, define channels, and connect models and professionals. It will be a dynamic document, adaptable to regulatory requirements and technological changes. Table 6 shows recommendations for BIM Protocol content.

All information from the BIM Protocol that reiterates that of the Traditional Design and Drafting Practices Manual should be explicitly incorporated in this protocol (ideally referencing the traditional standard as a user guide).

In addition, office project plans should explicitly indicate any particular characteristics of the deliverables generated, so as to check that the work is being properly standardized,

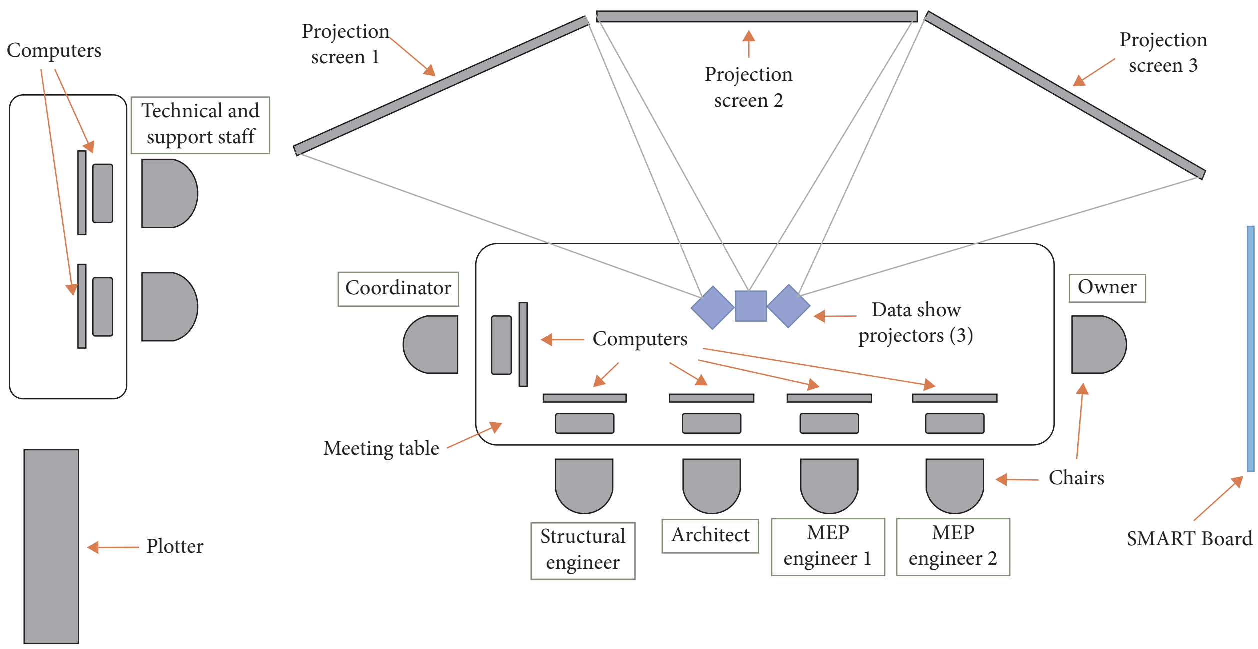


Figure 4: Extreme collaboration environment [38].

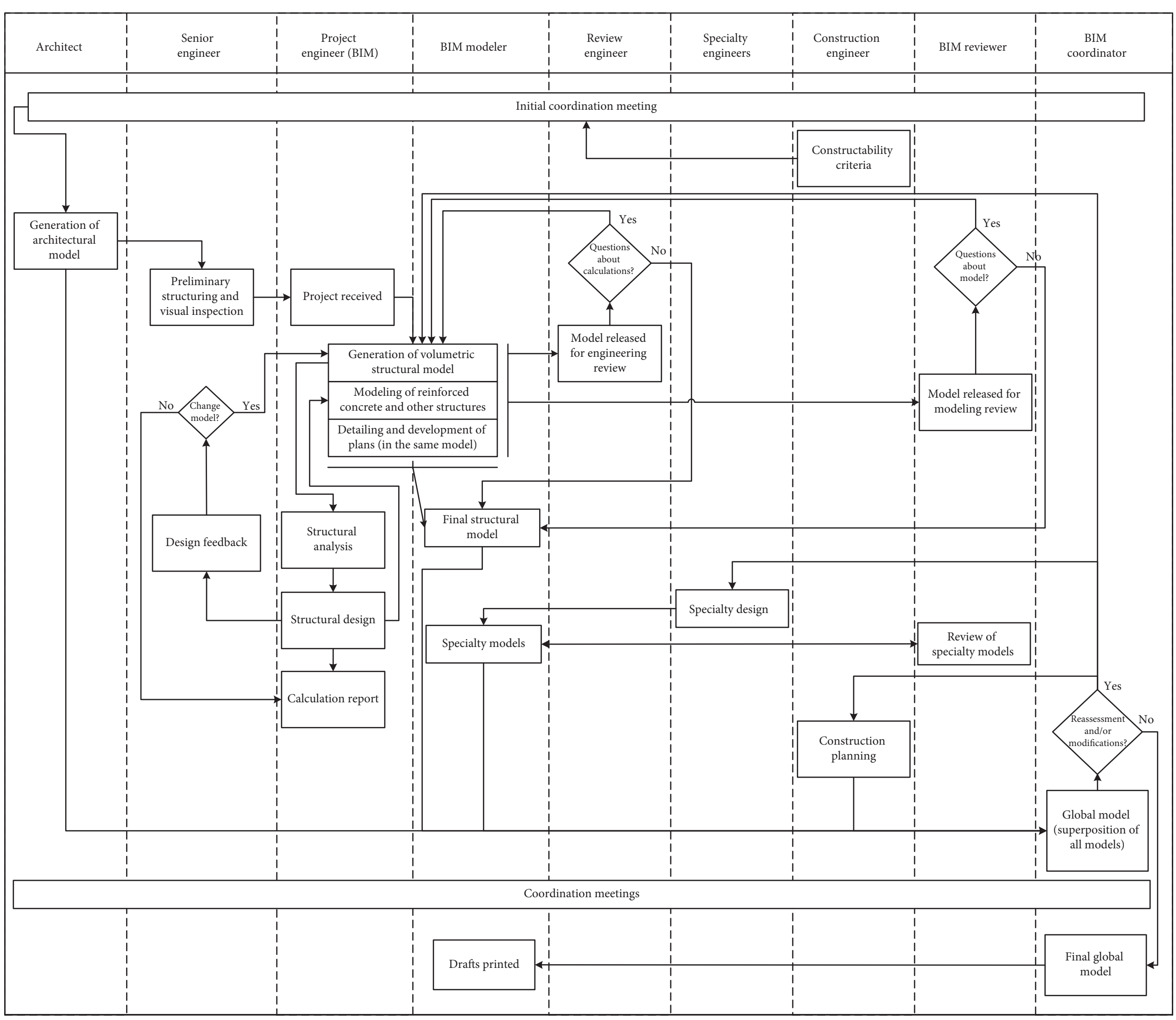


Figure 5: Workflow under the BIM methodology.

Table 6: Recommendations for BIM Protocol.

Item	Description
Responsibilities	Commitments, staff in charge, implementation, supervision, and compliance responsibilities are identified, established, and assigned.
Project development and workflow	All the phases of a project, input documents, and the deliverables of each (background, calculation report, models, documented) must be indicated. Workflows between internal and external professionals are detailed.
General terms, definitions, and characteristics	General aspects of the deliverables must be made explicit according to the criteria of the company in particular. Define: formats, bullets, updates and revisions, scales and work units, dimensions and sizing, among other characteristics.
Basic modeling elements	Basic aspects of modeling should be pointed out regarding how certain actions should be developed in these BIM platforms. Detailed design references, program commands used, characteristics of parametric elements, types of annotation, among others, are indicated.
Contents of plans	The final plans, which will be produced in coordination with the BIM model, must comply with the traditional specifications of the SEC, so their content and characteristics do not vary from those specified in the company's Traditional Design and Drafting Practices Manual.
Definitions and considerations for BIM	The team must be contextualized in the new work methodology, according to the following aspects: single work model (a cloud-based file in which several elements are simultaneously combined), model transcendence (where any modeling must be useful "upstream" during later stages), LOD and LOI (levels of detail and information in the models), IFC and interoperability, importance of fluid communication, BIM computational tools, interconnected work "in the cloud," among others.
BIM modeling strategies and recommendations	Clarify recommendations such as: general structuring of the modeling (partitioning the model into levels and specialties, in order to improve workability), generation of phases (organizing different temporal states of the project, e.g., demolition, construction), construction considerations (replicating the modeling as it is built in reality), considerations for material take off, model coordination, order in the project environment, subdivision by system colors, among others.

especially in the initial stages of the project. Once the first models have been generated, examples of these should be attached to serve as a guide for future professionals and/or for queries regarding how particular complex situations were modeled.

This protocol is meant to be flexible and may be modified in the future provided that there is progress in BIM objectives. For example, this protocol may incorporate new planning or construction tactics (when a construction model is generated, for example).

3.3.6. Business Requirements for BIM Software. It is assumed that the company will currently have a "design" of how it structures and delivers its products (drawings), as detailed in its "Traditional Design and Drafting Practices Manual." In view of this, it is necessary to generate all the templates used in BIM program documentation, in such a way that the office professionals only use models from previously created templates. These resources should be made available in the initial phase of implementation and handed over to the office for free use.

3.4. Determining the Implementation Gap. BIM implementation undoubtedly represents an important cost for the company, which is why it is necessary to optimize the use of current resources, i.e., to refocus and adapt them to the work under the BIM methodology. After identifying objectives and establishing the tools to be used, BIM methodology proposes that current resources should not be ignored; on the contrary, they should be considered as the starting point for implementation. From there, the resources missing to reach the total requirements should be established. This establishes the concept of the implementation gap, as shown in Figure 6.

Thus, BIM requirements (in terms of job roles, technologies, physical space, BIM workflow, modeling protocols, and templates) must be subtracted from currently available company characteristics and resources in order to implement only those missing requirements. In other words, technological implementation does not start from zero; the company will already have equipment that can be totally or partially reused, from which it is sufficient to acquire parts or improve systems to meet the requirements of BIM.

By determining the implementation gap, it will be possible to identify the costs of the actual implementation requirements. The economic cost of the latter will be lower than would be requirements that do not consider the current resources of the company and thus would be less impressive for company managers looking to program future investment.

3.5. Implementation Planning. Implementation planning should clarify, specify, and contain details of the actions that

Figure 6: Determining the “implementation gap”.

will be carried out. The general guidelines provided must be adapted to the particularities of the company. The points discussed in this section should be contained in the BIM execution plan (BEP), which guides the successful development of BIM projects. Essential planning points are discussed below, and details of the objectives and contents that each section seeks are given.

The recommendations outlined below have been based mainly on the methodological recommendations of the “BIM Handbook” [24] and the templates and guides of the “Project Execution Planning Guide” [23], together with recommendations for implementation experiences declared in the literature [25–27]. All of them declare themselves considering the specific processes that are developed in the structural engineering companies, focused on the work, professionals, and dynamics of structural engineering companies.

3.5.1. General Strategy. The general strategy should be the initial motivating impulse for the entire work team, with the company’s vision and mission strongly present. It should indicate the objectives of the BIM (previously defined with the company), the scope of the implementation plan, and a general timeline indicating the actions required to achieve the goals.

3.5.2. Parallel and Incremental Implementation. A parallel and incremental implementation is to be developed in the company. On one hand, the implementation will be incremental; that is, there will be training and stages for implementation (or uses) that, once successfully completed, will allow for the company to proceed implementing the next. In this way, quality will be assured in the fulfillment of small objectives, avoiding dragging errors downstream. On the other hand, the implementation is to be carried out in parallel with traditional techniques (so as not to jeopardize the current project). Parallel work can become part of the real chain once mastery of that phase or objective has been successfully achieved; that is, in subsequent projects, work previously done in parallel (but now validated) can be incorporated into real process lines. Thus processes dominated by professionals are continuously incorporated.

3.5.3. Definition of a Pilot Project. The implementation process is to be carried out with a pilot project, which may be a current company project or one already completed. If a current project is used, its implementation on BIM platforms should be carried out in parallel with the work carried out under the traditional methodology; in this way, the changes in work methodology and the ease of use provided by the BIM platforms can be demonstrated with evidence. On the other hand, when working with a previously completed project, there are benefits in contrasting implementations under BIM vs traditional methodology (e.g., how previous problems are now simplified with BIM), as well as comparisons of results once the pilot has finished (results from material take off for the previous project, for example).

3.5.4. Definition of Percentage of Professionals Involved. The professionals to be trained in BIM should be established. For small and even mid-sized companies, BIM training and implementation should be done by all professionals in the company. However, in medium-sized or large companies, a group of professionals should be assigned. In small companies, it is much easier to manage and instruct a small group of people (strengthened by the likely closeness and trust among the work team) and to take their different professional roles into consideration. This is especially true given that there are not a sufficient number of professionals to assign specific tasks to each. On the other hand, large companies generally establish working groups and areas of expansion, and it would be unmanageable to work with all professionals in the first instance.

Rather, the aim is to generate a “BIM nexus” within the organization, which will generally be in charge of future expansion of BIM knowledge in the rest of the organization and with any new professionals who can be strengthened by formal training.

3.5.5. Strategic Adaptation to BIM Workflow. The requirements of BIM propose an ideal workflow; however, initially, a gradual incorporation of BIM into the office should encourage compliance with this flow, from partially to wholly. In view of this, the adaptation of the workflow should start with what the company has declared, reformulated, and oriented towards partial, gradual replacements and, eventually, ideal BIM workflow. The speed of these changes will be in accordance with the traceability of objectives achieved.

3.5.6. Assigning Roles. The selection of professionals that best meet the profiles required of new BIM roles is possible by identifying current competencies found in the roles of the work team, and the characteristics of each of the professionals that the office currently has. This selection should first be made with reference to personal and collaborative work skills, followed by technical knowledge; it is easier to train technical skills than soft skills.

3.5.7. Technology Implementation Plan. To define the technological gap of a company to work in BIM, it must have the following information: current capabilities of technologies and technological characteristics. Here, it is also important to know the plan for the acquisition and renewal of equipment and licenses in order to take advantage of any already planned resources in purchasing platforms and equipment necessary for the operation of the BIM methodology. This procurement schedule should also be planned according to the traceability of defined objectives.

The implementing company should be responsible for installing licenses and configuring the organizational intranet network. In this way, it will be possible to offer the service of sale of licenses (through a strategic partner distributor of programs) or to leave the choice open to the organization. In addition, there must be a technical team to install the necessary equipment and networks.

3.5.8. Physical Space Remodeling Plan. A remodeling plan should be proposed regarding resources of the physical space required by the BIM workflow and the company's current physical state in order to adapt to the size of the office. A gradual plan for site changes and/or a change to another branch, as planned with the owners, should be proposed. Here, it is attractive to know the acquisition and expansion plan of the organization, in order to channel it with the required changes.

In sequential terms, it will be imperative to first reorganize the teams, as shown in Figure 4, and then (based on the gradual progress of implementation and available resources) incorporate the office layout shown in Figure 5 and/or generate the necessary physical changes.

3.5.9. Training Strategy. Training strategies are organized into three focuses: initial general dissemination of the plan, methodological training, and technological training.

Once the action plan for the office is defined, it will be relevant to inform all professionals about what will be developed. This "empowerment" and "conviction" should begin with senior company management to ensure firm commitment to the project. It is important to achieve these high levels of commitment with the work team as well, since they will have to make the greatest effort in terms of training and time dedication. Specifically, there should be explanatory sessions and consultations about the plan to give the entire team written support for the actions to be taken.

Training in BIM methodology should be a priority. The methodology, its scope, and general challenges should be taught theoretically. Afterwards, there should be specific explanations of how the company will adapt in functional and strategic terms, how roles will be assigned to each member, and what implications the process will have. Failure to correctly understand this will have a strong impact on the success of the implementation. Group training sessions are to be established, along with provision of background explanatory material.

Technological trainings should be oriented around BIM role requirements and selected technologies. Program trainings should consider previous professional knowledge in order to optimize curricula of employees. If professionals do not have an official certificate for the knowledge they declare (from e.g., professional internships or academic courses), evaluations to measure their content mastery are convenient: an instrument may be developed independently or jointly with a university to provide proof of academic certification for professionals. In turn, training should be conducted by level and based on implementation progress so as to distribute resources invested in training over time.

It is preferable that the company provides training service through its own resources, subcontractors, or agreements generated with universities or private institutes. Ideally, trainings are carried out at the office. Content delivery should be closely related to the practical work in the defined pilot project.

3.5.10. BIM Office Protocol. The BIM Protocol, and the extent to which it has been reformulated from the Traditional Design and Drafting Practices Manual, should have the same guidance and order as the latter in order to facilitate and accelerate understanding of new requirements, details, and necessary reconsiderations. The implementing company is to be in charge of generating the document, requesting all the required background information from the company, and providing examples and recommendations for its use. The different updates the protocol undergoes as it evolves in the use of BIM should be monitored.

The company will not be able to start its work in BIM if it does not have this document or if it has not been disseminated and socialized by all the members of the team.

3.5.11. Standardization and Creation of Elements for Working in BIM. Vignettes, templates, parametric elements (families, for example), information requirements sheets, and interference detection sheets, among others, must be created and/or adapted so that, at the beginning of the pilot project, the office has all the necessary elements available in BIM platforms for the successful development of the project. The objective is that deliverables are plotted and visualized in the BIM platform (Revit, for example) with same details and characteristics as in 2D CAD (referring to the final product in plans). The indications for this will be set out in the office BIM Protocol.

3.5.12. Indicators of Compliance and Quality. Compliance and quality indicators are related to the achievement of BIM objectives and purpose within the organization. In this sense, the evolution of the implementation will be measured with respect to its degree of capacity, understood as company aptitude in developing BIM features and services; and maturity, understood as the degree, depth, quality, and repetition of BIM features and services [41]. The above measurements provide generic indicators of BIM methodology progress (and implications) in global terms; that is to say, they serve to compare and classify the company within a certain range that, for example, is useful in identifying compliance with a maturity profile requested by a contractor (for e.g., bidding bases). That said, in order to measure progress and fulfillment of proposed objectives, the topics necessary for the fulfillment of each objective (theoretical and technological learning and/or acquisitions) should be identified and evaluated into three possible categories (1 = not achieved, 2 = somewhat achieved, and 3 = achieved). With this, efforts can be redirected to reinforcing unsuccessfully learned content or to reviewing moderately acquired content. Evaluations should be conducted on a topic-by-topic basis, so as not to leave knowledge or implementation gaps in the course of the process.

3.6. Assessment and Monitoring

3.6.1. Monitoring of Compliance with Objectives and Plan. The process must exhaustively document all company actions carried out and decisions taken within the platform that the implementing company deems appropriate. This record should note progress and compliance vis-à-vis indicators. This will allow for the generation of plans and actions to reformulate and restructure scheduled actions not yet completed.

3.6.2. Knowledge Monitoring. The knowledge acquired by professionals should be constantly monitored. To this end, knowledge tests are to be conducted on the use of programs and methodology as aligned with the progressive advancement of knowledge professionals acquire. Such evaluations generated by the implementing company and/or by university or technical entities (house certification programs) certify professionals and thus increase the competitiveness of the work team (with respect to personnel training in bidding, for example). The type of certification is subject to the resources available in the organization [42].

3.6.3. Resolving Doubts. Active communication channels are to be established between the organization and the implementing company in order to establish means, times, and dates of assessments regarding procedures and technical aspects of the use of programs. Professionals are encouraged to self-teach and learn collaboratively with team members in order to gradually allow the organization to be self-sufficient.

3.6.4. Development of Parametric Elements. To facilitate modeling on BIM platforms, a family building service is to be provided. This service allows the company to optimize modeling times and access requirements of the projects they carry out. The family building service is not considered part of the initial costs of implementation, but is rather intended to be a contribution in the course of the development of BIM in the office.

4. Conclusions

A methodology was developed for BIM implementation within structural engineering companies (SEC). This methodology clearly and objectively shows how to carry out implementation and includes processes for analysis and diagnosis, rethinking of objectives, identification of requirements, planning, and monitoring of the proposal.

The methodology made explicit the instruments to perform the in-depth company analyses and include steps for gathering information on current expectations, processes, and resources in order to clearly identify the potential of the company with a view to BIM restructuring.

The requirements for the adoption of BIM have been detailed and consider roles of the work team, technologies and space distribution, BIM-focused workflow, protocols, and other specific elements necessary for the success of the implementation. This allows companies to identify implementation gaps and, subsequently, real requirements for optimizing current resources.

Points which must be considered while planning a BIM implementation were raised in regards to general strategy, parallel and incremental forms of implementation, work with pilot projects, adaptations to BIM workflow, efficient assignment of roles, technological and physical remodeling plans, training strategies, standardization and creation of elements in BIM platforms, and the generation of a BIM Protocol for the company with follow-up and assessment actions.

The proposed methodology, although considers computational tools and technology that should be used, does not specify how they connect directly with each other and does not detail the technical aspects for it to work. It has been prioritized in this paper to show how BIM should be implemented in methodological terms, given that it is considered essential in the success of the incorporation of BIM. The technical will be relative to the computational tools used and will vary in each case.

In general, emphasis is placed on how to address each of these situations that should consider a structural engineering company, with a view to solving its productive inefficiencies, associated with collaborative work and interconnection, and clear actions were delivered that lead to a successful implementation.

Finally, the implementation of the described methodology should be carried out in pilot companies, for its practical validation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was developed in the Civil Engineering School of the Pontificia Universidad Católica de Valparaíso (Chile), with the regular investigations. R. F. Herrera acknowledges CONICYT, PCHA/National Doctorate/2018, 21180884, for funding the graduate research.

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