



## Article

# Barriers, Strategies, and Best Practices for BIM Adoption in Quebec Prefabrication Small and Medium-Sized Enterprises (SMEs)

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**Abstract:** Prefabricated construction has long faced problems due to the industry's fragmentation. Building Information Modeling (BIM) has thus appeared as an efficient solution to provide a favorable environment for efficient completion of projects. Despite its benefits, implementing BIM successfully in small and medium-sized enterprises (SMEs), which represent the vast majority of manufacturers in Quebec, requires deep risk analysis and rigorous strategies. Hence, this work aims to study BIM implementation barriers, strategies, and best practices in wood prefabrication for SMEs through a literature review, semi-structured interviews, and an online survey. After qualitative content analysis, 30 critical barriers, 7 strategic milestones, and 31 best practices to maximize BIM benefits were revealed. One of the critical barriers concerns the effort required to develop BIM software libraries and programs to translate information from the BIM model to production equipment. Among the best strategies, it is essential to start by analyzing the current business model of the SMEs and to appoint a small BIM committee whose main responsibilities are management, coordination, and modeling. The prevalent best practices were to support the implementation team and encourage communication and collaboration. Previous studies show that BIM is not fully exploited in prefabrication for various reasons. This study highlights the critical barriers, strategies, and best practices for BIM adoption and proposes a framework for BIM implementation in prefabrication SMEs in Quebec, Canada. It also provides a summary of current knowledge and guidelines to promote BIM adoption in this sector.

**Keywords:** building information modeling; implementation; adoption; barriers; best practices; SMEs; prefabrication



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## 1. Introduction

From the outset, prefabrication seems to be an asset to upgrade the construction industry due to its productivity and quality improvement, environmental protection, and fast construction speed [1]. Despite its numerous strengths, this sector faces major problems due to the construction industry's fragmentation [2]. In fact, a large number of stakeholders and various disciplines complicate communication and coordination efforts, which usually leads to errors in the design and construction phases [3]. Thus, researchers are actively looking for new processes and technologies to overcome these issues. An approach like Building Information Modeling (BIM) seems to be an efficient solution to facilitate the connection between the main stakeholders and the smooth running of a project, thanks to its different applications from 3D modeling to 4D and 5D dimensions related to time and cost estimation [4]. In fact, BIM facilitates collaboration throughout the life cycle of the construction project due to the 3D model that must be updated and shared between the project participants along the different phases of the project from planning to

commissioning [5]. It also improves communication and information management due to more efficient exchange and updates of project data [6].

Meanwhile, the environmental footprint of buildings has gained the interest of both the private and public bodies in Canada, specifically in the province of Quebec. Along the same line, the North American construction industry faces a well-documented crisis in labor availability, so productivity improvement has been targeted as an avenue with great potential [7]. As a result, the prefabrication of buildings has gained significant interest in practice and in the literature. In this context, the *Société d'Habitation du Québec* (SHQ), the public entity managing social housing in the Quebec province, launched the VISION 2030 project in 2015 and has since supported numerous projects aimed at dispelling prejudices about the use of prefabricated solutions [7]. Quebec manufacturers have also rallied behind the Quebec Wood Export Bureau (QWEB), responsible for developing the market for Quebec's wood products, to set up a Design for Manufacturing and Assembly (DFMA) platform and to complete a digital diagnosis to improve their competitiveness [7]. FPInnovations, a Canadian non-profit research and development organization, carried out industrialized construction with a strategic orientation based on its "Building with Wood" program [7].

Currently, the combination of prefabrication and BIM is seen as an efficient solution to effectively achieve emission reduction, green environmental protection, and cost reduction, which plays a positive role in promoting the development of this sector [8]. However, many studies conclude that BIM is not exploited in prefabrication for various reasons [1,5]. First, the vast majority of Quebec manufacturers are SMEs—99.98% in 2018—which has slowed BIM adoption in this field [9]. In Canada, SMEs are defined as companies with less than 500 employees [10]. Moreover, Quebec SMEs are mainly involved in small construction projects but aim to increase productivity and their exports to the United States, their nearest market, to become world leaders in the prefabricated building sector [11,12]. Particularly, they aim to export processed products with high added value instead of commodities [11]. Hence, Quebec SMEs are looking for new processes and technologies to increase their productivity, their market share, and to become more competitive. BIM seems to be an efficient solution to achieve these objectives [13,14]. In this sense, the *Groupe BIM du Québec* (Quebec BIM Group), a non-profit organization created in 2011 to support and promote the digital transition in construction in Quebec, was mandated by the Government of Quebec to conduct a study on the state of deployment of BIM tools and practices in the province [15]. Based on semi-structured interviews conducted with experts in the field, GBP revealed that BIM helps improve the efficiency of the project execution by 37%; it reduces risks on site by 34% as it allows for detecting any conflicts between the different models (architectural, mechanical electrical and plumbing (MEP), and structural models); it promotes prefabrication and the manufacturers' integration by 26%; it reduces waste by 24%; it improves transparency in communication by 21%; and it offers an automation potential to industrialize construction [13].

This work aims to study three main topics: barriers to BIM implementation in the prefabrication industry in the province of Quebec, Canada; strategies for its proper deployment; and best practices for its efficient use. Few articles have studied BIM adoption in prefabrication, especially in the SMEs, and its potential benefits in multi-housing projects. For example, Olbina and Elliott [16] analyzed BIM benefits for both small and large projects to demonstrate that BIM could be used in any project and could therefore benefit SMEs. However, they did not study the barriers that could be faced when using BIM in small projects [16]. Similarly, Wong et al. [17] investigated BIM benefits for the SMEs in order to highlight the importance of this digital shift and convince them to adopt it. They presented recommendations to implement BIM successfully, but they did not cover the entire implementation process nor the internal and external factors affecting this process [17]. Li et al. [18] presented a general BIM implementation framework without specifying BIM adoption levels. Garcia et al. [19] focused on BIM committee creation and the human factor. Kouch et al. [20] proposed an initial BIM implementation framework without setting

the best practices to better conduct this process. Therefore, this study intends to offer guidelines to properly implement and adopt BIM in construction, specifically for SMEs in prefabrication, and show how to apply it in a multi-housing project. In brief, it will provide a summary of what has been achieved until now and a roadmap to help the SMEs move toward digitization.

First, a literature review on the subject was conducted to analyze what has been studied so far. Then, semi-structured interviews with BIM experts revealed barriers and best practices for BIM implementation and adoption, specifically in the province of Quebec, Canada. Afterward, a comparison between the theoretical and practical findings was conducted to create a global framework for BIM implementation. Finally, using outcomes from an online survey, this framework was adapted to Quebec prefabrication SMEs and to the specific case of multi-housing projects.

Some of the significant findings highlighted by this research are the importance of BIM's pre-implementation phase and the crucial role of human resources in attaining BIM benefits as well as the critical barrier related to BIM technological tools in the prefabrication process. Moreover, the BIM implementation process seems highly related to the company's size, goals, and maturity levels. Distinguishing between different levels of BIM implementation (governmental, industrial, and team project level), potential barriers, and best practices to face them also appeared essential. Finally, the riskiest phases in multi-housing projects—design and production—should exploit the wide array of BIM dimensions, such as 4D and 5D applications [1,21]. The frameworks proposed in this research therefore contribute to advancing current knowledge by focusing on both the construction SMEs and the prefabrication industry while investigating the industry at the government, organization, and team project levels.

## 2. Literature Review

As a recent approach, BIM has raised interest throughout the world. Some parties support this trend; others still have some doubts about its real potential. This review defines BIM and its application in the prefabrication sector and presents the SMEs in the province of Quebec.

Many studies stated that one of the major problems faced with BIM is a misunderstanding of this new approach [20]. However, to better benefit from a new invention or process, it is important to define it and better understand it [8]. Many relevant articles, dating from 2007 to 2021, offered various definitions. Some definitions are based on the BIM process, others cover BIM tools, and some focus on BIM goals [22–24]. These different views lead some to see BIM as a process [25], a new way of working [26], a 3D model or modeling software [27], a management tool [28], a technology [29], a database to share files and communicate [30], and even an innovation [31]. Hence, BIM can be defined as a set of technologies, processes, and strategies, based on a 3D model that must be shared between stakeholders, to better conduct a construction project and to facilitate information sharing about a building along its lifecycle. When properly implemented, BIM leads to many benefits such as better communication and coordination, time and cost savings, and an improvement in productivity and quality [13].

However, prefabrication is still facing technical problems due to the lack of communication and coordination between stakeholders, which reveals many issues such as project delays and customer dissatisfaction [32]. Luo and Chen [1] demonstrated that using BIM can improve the efficiency of prefabricated building design as well as the production and management of prefabricated components, along with simulating the construction process and improving maintenance management. Similarly, He [33] explained that using BIM in this field leads to many advantages linked to quality management and the whole prefabrication process. In fact, visualization through 3D models ensures a better understanding of the whole project using accurate information for each component and facilitates the change updates among the project team [34]. In the design phase, BIM can increase design quality by displaying the degree of integration between the components, detecting collisions, and

checking connection precast lines [1]. During the production stage, this approach provides detailed information about component characteristics, allowing for better coordination between the designer and the manufacturer, especially when component requirements are modified. Thus, it leads to an efficient scheduling of the production process and reduces the construction delay.

Regarding SMEs in Canada, particularly in Quebec, they are defined as companies with less than 500 employees: the small enterprises have at most 99 employees and the medium ones have 100 to 499 employees [35]. These companies have a great impact on economy growth as they represent 99.8% of the companies in Canada (97.9% small and 1.9% medium-sized enterprises) [36]. In 2014, the contribution of SMEs to the gross domestic product (GDP) generated by the private sector was 52.5% [36]. However, this report also claimed that, from 2010 to 2015, the average annual number of SMEs created in Canada was 95,000, while 85,000 of them closed, which indicates the emerging need to study the challenges and issues faced by these firms. In the construction industry, 99.9% of the Canadian and Quebec enterprises are SMEs, which is why this study intends to propose solutions that help them progress and enhance their current processes, particularly by implementing BIM [37].

The next section will expand on the research methodology used in the study.

### 3. Materials and Methods

A mixed method approach based on both qualitative (interviews) and quantitative (survey) methods was considered, as this was an explorative study. It was therefore divided into two main parts: developing a global BIM implementation framework for construction, and specifically prefabrication, based on both the literature and interviews and then adapting it specifically for Quebec prefabrication SMEs. Figure 1 presents a summary of the main steps.

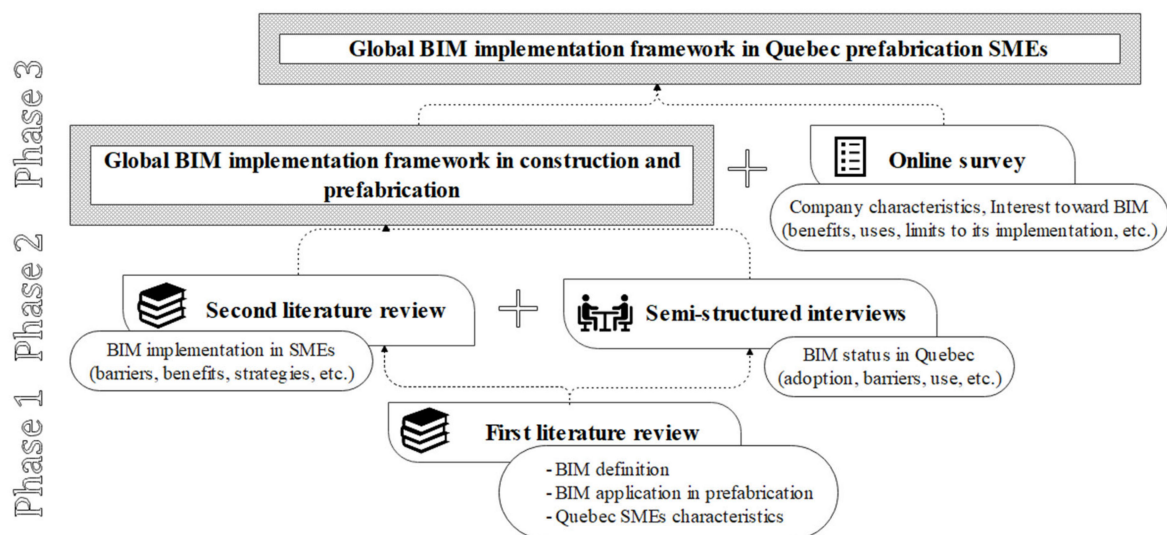


Figure 1. Research methodology.

The literature review was conducted in two phases: the first was to define BIM, its application in prefabrication, and Quebec SMEs characteristics while the second was to focus on BIM implementation in construction and prefabrication SMEs. Engineering Village, Web of Science, and ProQuest were the databases used to span across the related studies up to 2021. These databases were selected due to their compatibility with a rigorous literature review (consistent results, transparent filters, structured research, and reliable source) and their significance in engineering research [38]. Google Scholar was also used when no relevant results were obtained for some research queries. The first review used several keywords related to the definition of BIM as well as its applications in prefabrication and Quebec SMEs (i.e., BIM, definition, application, use, prefabrication, industrialization, offsite



construction, Quebec SMEs, Quebec, small and medium-sized enterprises). The second review focused on BIM implementation in the SMEs using another set of keywords (i.e., BIM, implementation, adoption, deployment, barriers, strategies, best practices, SMEs, small and medium-sized enterprises, prefabrication, offsite construction, modular construction, and industrialization). The inclusion criteria consist of the papers that contain words from the following three sets in either the title, the abstract, or the keywords:

- (1) BIM;
- (2) Deployment or implementation or adoption or strategies or “best practices” or barriers;
- (3) SMEs or “small and medium-sized enterprises” or prefabrication or “offsite construction” or “modular construction” or industrialization.

As we did not find many studies about BIM implementation in SMEs, we expanded our research to all company sizes and then compared it to our case. We excluded the articles that studied specific topics related to technical details about how to use BIM tools such as Revit and Navisworks, BIM applications in the renovation process, BIM’s role in reducing greenhouse gas emissions, BIM for building energy assessment, BIM use in a sustainable supply chain, and information management in the BIM process. In all, 66 articles were selected for further analysis.

Semi-structured interviews were selected as the suitable method to collect data from BIM experts in Quebec. Indeed, Georgiadou [39] indicated that the interactive nature of the interviews allows the participants to freely express their points of view, and Benoît [40] stated that it provides data rich in details and descriptions. Thus, in phase 2, BIM experts in Quebec were interviewed for a period of 60 to 90 min. Each one was asked a set of 16 open-ended questions (Appendix A.1) in order to identify BIM benefits and barriers, implementation strategies, best practices to encourage communication and coordination between stakeholders, and responsibilities among the BIM group. We moved from general to specific questions. In the beginning, we asked for information about the participant’s background, position and experience with BIM. Then, we asked specific questions about BIM’s implementation process, its benefits, the barriers faced by the interviewee when implementing BIM in different companies, the best practices to better manage the risks and avoid these barriers, and the main stakeholders affecting the BIM implementation process. As BIM adoption is emerging in Quebec, there were only nine well-known experts to contact in this field. These experts were chosen based on their experience with BIM, had an average of eight years of experience with the approach, and held various positions (BIM manager, architect, engineer, etc.) in different organizations (e.g., government, private consulting companies, nonprofit organizations). As some were already working in public and private consulting companies, they already had extensive experience in the implementation process. Other experts were working in public construction companies and had started the BIM implementation process. Some participants also contributed to conference programs to better introduce BIM in Quebec and provided training for both companies and students. We then conducted a qualitative content analysis of these interviews to identify the critical barriers, best strategies, and best practices for the BIM implementation process. This method helps convert the collected information into a concise and well-organized structure of key results [41,42]. Moreover, Bengtsson [42] indicated that the purpose of this method is to organize and elicit meaning from the data collected and to draw realistic conclusions from it. QDA Miner, a qualitative data analysis software developed by Provalis research in Montreal, Canada, was used to analyze the collected data. The first step consisted of inserting the nine interview files. Then, data were divided into smaller sections to create the right codes. The codes helped achieve the right categorization. It is important to note that many revisions and analyses were conducted to achieve the final categorization set.

The main results of the second literature review and interview analysis were compared to identify differences and similarities, to provide a comprehensive review of current views, and to set a global BIM implementation framework.

To adapt the general framework specifically for prefabrication multi-housing projects, thirty well-known Quebec manufacturers were sent a web survey asking for their insights on the status of prefabrication, the process to carry out a multi-housing project (milestones, main actors, tools, challenges), and their knowledge of BIM benefits and barriers. These companies were selected as they were active in the sector, had heard about the BIM approach even though they had not implemented it yet, and had already collaborated with researchers and/or were especially interested in new approaches and technologies to increase their productivity and improve their business models. These companies manufacture different products, some producing non-volumetric elements such as frames, beams and columns, wall panels, and roof trusses, while others manufacture volumetric elements referring to 3D modules. They are usually involved in many phases of a construction project, not only in the fabrication and transportation phases but also in the design phase. Surveys have been used by many studies in order to collect relevant data from the industry [43,44]. Though the sample size may seem small, it specifically targeted wood prefabrication companies in Quebec, which totaled 56 in 2015 [37], since this field plays an important role in the growth of the province's economy and Canada's as well [12].

Thirty-one questions were used with either a 5-point Likert scale, yes/no, and multiple-choice format. From the thirty companies, fifteen answered the survey and nine (30%) were fully completed and could be used in this analysis. According to many studies, 30% is an acceptable response rate for surveys [43,45]. The data collected helped establish the main phases of multi-housing projects. Finally, the proposed BIM implementation framework was adapted for this specific case.

Further details about the respondents of the interviews and the survey are presented in Table 1.

**Table 1.** Summary of the interviews and the survey conducted for the research.

Characteristics	Interviews	Survey
Goal	Analyze BIM implementation status in Quebec as well as the issues faced and strategies used by BIM experts	Analyze the status of prefabrication SMEs and their opinion about BIM implementation
Number of respondents	9	15, 9 completed the entire survey
Respondents' expertise	BIM implementation and applications	Prefabrication of 2D and 3D elements
Average years of experience with BIM adoption and use	8 years	3 have started BIM application in their projects and have respectively 1 year, 2 years, and more than 5 years of experience
Respondents' position	1 BIM manager 6 BIM directors 2 academic researchers	5 project managers 4 other positions (sales manager, CEO, etc.)

#### 4. BIM Implementation in Construction and Prefabrication

As shown in Figure 1, the global BIM implementation framework proposed in this article is based on a comparison of a current global view compiled through a literature review with a more specific view obtained through interviews with BIM experts in Quebec.

##### 4.1. BIM Implementation Barriers

In the literature, most of the authors started by explaining the main barriers for a better understanding of the current challenges when adopting BIM. For example, Ghaffari-hoseini et al. [5] and Tan et al. [46] determined five key issues: technical, management, environmental, financial, and legal barriers. Several studies worldwide agree that technological, financial, and legal barriers are common issues [47], but the main difference arises in the other two, which are highly related to the human factor. Some called have called them environmental and management barriers, others call them cultural barriers, and others

refer to them as organizational issues [39]. Regarding this critical topic, Sardroud et al. [48] stated that these barriers are highly linked to other factors such as the country's maturity level toward BIM and its adoption, the company's size, the technological tools available, the government actions [5], etc. In the United States, management and legal issues seem to be the most critical, while in the United Kingdom, the most common seems to be cultural barriers [18,48]. Financial issues associated with the initial investment required, technological issues related to BIM tools, and cultural and management barriers linked to human resources may probably be faced if the company does not make a rigorous plan before BIM implementation [49,50]. Regarding the resistance to change that significantly limits BIM adoption, one of the studies stated that it is highly linked to the fear of leaving one's comfort zone [8]. The following studies focused specifically on the challenges that may be faced within SMEs. Saka and Chan [2] stated that BIM implementation within SMEs is highly related to the internal and external environment in which they operate. This study synthesized the barriers using three theoretical lenses (TOE: technology, environment, and organization, IDT: innovation diffusion theory, and INT: institutional theory) and highlighted the most critical ones, which are the resistance to change and the high risk involved when implementing BIM. According to Garcia et al. [19], barriers tend more toward technological aspects, such as the interoperability and scalability criteria, lack of design items, or the time required to develop the software library. For Vidalakis et al. [51] and Hong et al. [52], implementing BIM in SMEs raises more financial and human issues related to lack of in-house skills, resistance to change, and high implementation expenses. Finally, a few studies have identified BIM barriers in the prefabrication industry. Mostafa et al. [32] indicated that this industry suffers from the lack of change in business practices to support BIM, the high investment to implement it, the legal concerns with fabrication and multiple designs, and collaboration and information sharing challenges.

Regarding the interview outputs, analysis of the collected data revealed that BIM barriers in Quebec could be grouped into five main classes: legal, technological, financial, human, and organizational. According to manufacturers who have not yet implemented BIM, technological, financial, and legal barriers are the most prominent while BIM experts, who have mastered the BIM implementation process in different companies, claimed that human and organizational issues were the most critical ones. Legal barriers refer to any contractual or regulation issue such as the intellectual property of the 3D model that is co-created by several parties and must be shared among all participants to achieve BIM goals. In the same category, the typical contract form usually raises some issues, as it does not include clauses about sharing responsibilities, risks, and information. Technological barriers are mainly linked to interoperability problems that prevent file exchanges between stakeholders and complicate their collaboration. In fact, many interviewees indicated that undefined goals, weak planning, and lack of information before implementing a new software lead to inappropriate use or incompatible tools. Furthermore, some actors complained about the effort required for creating their own library of objects in the new software. For financial barriers, respondents mentioned the high investment required to cover license-purchasing fees, the cost of hardware and software upgrading, and staff training expenses. About human barriers, the most prominent one appeared as resistance to change and the effort required for training, practicing, and connecting with others. Likewise, most of the companies suffer from skill shortages, maturity gaps, and lack of communication between stakeholders that often lead to several problems even if BIM tools are well implemented. In addition, the BIM process requires liability and collaboration among the actors, which is not the case with the conventional method. Another critical issue consists of misunderstanding the BIM concept and its baselines, which often creates a gap between the actors. Regarding organizational issues, lack of coordination, management, standardization, and alignment between BIM and current processes, as well as a dearth of control and updates of the information flow, cause serious problems when using BIM. Table 2 summarizes BIM implementation barriers from both the literature and interviews.

Based on the interviews, the barriers were grouped into five main classes: human (HB), technological (TB), financial (FB), organizational (OB), and legal (LB) barriers.

**Table 2.** BIM barriers in conventional construction and prefabrication sectors.

Class	Barriers	Interviews		Literature	
		Const.	Prefab.	Const.	Prefab.
HB	B1: Resistance to change	✓	✓	✓	✓
	B2: Misunderstanding of BIM process	✓	✓	✓	✓
	B3: Confusion between BIM dimensions	✓	✓	∅	∅
	B4: Communication and collaboration shortage	✓	✓	✓	✓
	B5: More effort and time for planning	✓	✓	✓	✓
	B6: Waive professional liability	✓	✓	✓	✓
	B7: Use of 2D plan instead of 3D model	✓	∅	∅	∅
	B8: BIM is riskier than beneficial	✓	✓	✓	✓
	B9: Employee control and monitoring	✓	✓	∅	∅
TB	B10: Need for learning new tools	✓	∅	✓	✓
	B11: Wide variety of tools	✓	✓	✓	✓
	B12: Interoperability problems	✓	✓	✓	✓
	B13: Need for technological updating	✓	✓	✓	✓
	B14: Gap between the actors' maturity level	✓	✓	✓	✓
	B15: Need to specify the prefabricated objects and MEP details in the software database	✓	✓	✓	✓
	B16: Need for computer translation from the BIM model to production machines	∅	✓	∅	∅
FB	B17: High investment cost	✓	✓	✓	✓
	B18: Information overload	✓	✓	∅	∅
	B19: Lack of an action plan	✓	✓	✓	✓
OB	B20: Wrong diagnosis of the company's needs	✓	✓	∅	∅
	B21: Wrong assessment of the maturity level	✓	✓	∅	∅
	B22: Using BIM tools without culture change	✓	✓	∅	∅
	B23: Training without practice	✓	✓	∅	∅
	B24: Lack of BIM alignment with existing business processes	✓	✓	✓	✓
	B25: Improper risk assessment	✓	✓	✓	✓
LB	B26: Lack of process standardization	✓	✓	✓	✓
	B27: The classic form of contracts	✓	✓	✓	✓
	B28: Intellectual property of the 3D model	✓	✓	✓	✓
	B29: Poor definition of BIM protocol	✓	✓	✓	✓
	B30: Confidential data security	✓	✓	✓	✓

This table reveals the widespread awareness about BIM barriers. In fact, the experts that we interviewed agreed on the great impact of technological, financial, and legal barriers, but emphasized the significant role of human and organizational factors in this process. The difference between the literature and interview findings concerns these two factors and details about the prefabrication industry. This could be because the interviewed experts are closer to actual construction projects as well as the fact that prefabrication in Quebec is new



to this digital shift. Thus, the manufacturers have not fully mastered the BIM approach, its tools, its requirements, and the implementation milestones. Moreover, an important issue in this field concerns current BIM tools that do not offer detailed specifications about the prefabricated elements.

#### 4.2. Strategies for BIM Implementation

Many studies in the literature sought to reveal a suitable strategy for BIM implementation. Some papers only examined the BIM implementation process within the project [1], others focused on the whole industry in different countries [51,53], and others outlined several implementation levels spanning from large to small scales [46]. The different frameworks found present several similarities such as outlining the importance of implementing the right software and providing continuous training to the BIM team as well as checking if the new process is well integrated into the current one. However, the main difference between these frameworks concerns the first step in the process. In fact, some highlighted the need to analyze and examine the current business processes first [20,30,49] while others directly introduced the tools and competencies required to make this shift [22]. For example, Arayici et al. [30] presented four major steps to implement BIM in a company: diagnosis, action planning, taking action, and evaluation. On the other hand, Kouch et al. [20] presented this process with three main steps: understanding, planning, and piloting. Similarly, Ahmad et al. [49] also used three phases, while Garyaev [22] considered only the two latter phases. The first phase in Kouch et al. [20] is about understanding BIM and how it should be used. However, for Arayici et al. [30] and Ahmad et al. [49], diagnosis and pre-implementation, as a review and analysis of current business practices, is a mandatory step to identify the potential BIM efficiency.

Despite considerable interest in BIM deployment, there is little focus on the prefabrication sector, specifically in SMEs. Tan et al. [46] introduced three levels to facilitate BIM adoption in this sector: 1-socio-level, 2-organization level, and 3-project level. In level 1, they identified the need to strengthen research on BIM applied to prefabricated construction; to prepare and publish BIM standards and guidelines by government actors; for software vendors to develop BIM tools specifically for this industry; and to present best prefabrication practices by industry practitioners. For level 2, they pointed out the need for manufacturers to establish efficient workflow and cooperation mechanisms as well as the necessity for its members to acquire BIM knowledge and skills. In level 3, the main actors have to optimize technical and managerial solutions to achieve cost and time savings and other BIM benefits.

The interviews with BIM experts also addressed the milestones of the BIM implementation process in prefabrication, which could be used in construction as well. Interview analysis led to three main steps: pre-implementation, implementation, and post-implementation phases.

All respondents underlined the need for a pre-implementation phase for the success of the whole process. During this phase, it is important to analyze the status and the current business processes using different methods and tools to assess the company's means (e.g., human resources, software, standards). The company manager can then identify the eventual improvements to these processes. In fact, large companies often use consulting services and external support to accomplish this phase, which is not always possible for SMEs. Then, underlining the importance of this step encourages SMEs to appoint an internal group to analyze their situation.

Afterward, the implementation phase is dedicated to planning and conducting the implementation process. Hence, the company manager should prepare a strategic roadmap for this shift using three main documents: the BIM implementation plan (BIP), BIM execution plan (BEP), and BIM management plan (BMP). One of the precious tips provided through the interviews is proceeding step-by-step with a clear BIP. The best strategy is to start by practicing 3D modeling, then upgrading to BIM 4D, and so on. The BIP should include the main information about this shift, such as the reasons and goals, main actors, tools, steps,

schedule, investment, trainings, BIM committee and their missions, and benefits to reach. Once prepared, the next step will be to install software; to create the BIM committee that will manage, coordinate, and lead the whole process; and to align BIM with the current business processes. It is also pertinent to highlight the need to properly choose the right tools for the prefabrication needs and to focus on the required applications. Regarding the BIM committee, the SMEs can appoint a small, motivated group from their staff to make this shift and be the company's internal experts. Then, specific training should be planned for them. These well-trained experts should impart knowledge to the rest of the staff and support them throughout this shift. Successfully integrating the BIM process and tools is about taking advantage of both the company's strengths and BIM benefits. A kick-off meeting is crucial at this stage to present the main goals, clarify the new concept, introduce the new actors, explain the rules, identify the risks, and identify the potential benefits of this process.

The last phase, which is post-implementation, includes applying BIM in a pilot project to integrate it with the firm's practices. It is better to choose a standard project usually carried out by the company as it will serve for future reference. The most efficient documents to handle this step are the BEP and BMP, as mentioned before. The BEP will be used when applying BIM in a project [54]. It should then include the goals of this project, the benefits to reach through BIM use, the stakeholders and their roles, the deliverables, and the risks. For benchmarking purposes, at the end of the project, the company manager should quantify the benefits, evaluate the experience, and monitor the progress in using BIM. This step is based on the key performance indicators (KPIs) that must be defined by BIM experts using cost, time, and quality indexes. Using this process, SMEs will be able to make this shift without needing consulting services, as they will be able to manage their own resources.

When comparing the literature and interviews on BIM implementation strategies, it seems relevant to indicate that the interviews specifically targeted BIM implementation within the company and the team project, while the literature covers different levels (e.g., governmental and industrial) [55]. In fact, BIM leads to concurrent revolutionary changes across several scales within the organizational hierarchy, ranging from individuals and groups to industries and the whole market [56]. Among the 66 references used in this study, ten articles focused essentially on the BIM implementation process at the company level [19,20,22,30,49,54,55,57–59]. The other studies looked at its deployment within the project or in the whole industry for a specific country. Figure 2 lists the milestones for this process and its frequency in the interviews and literature.

## Milestones of BIM implementation within the SMEs

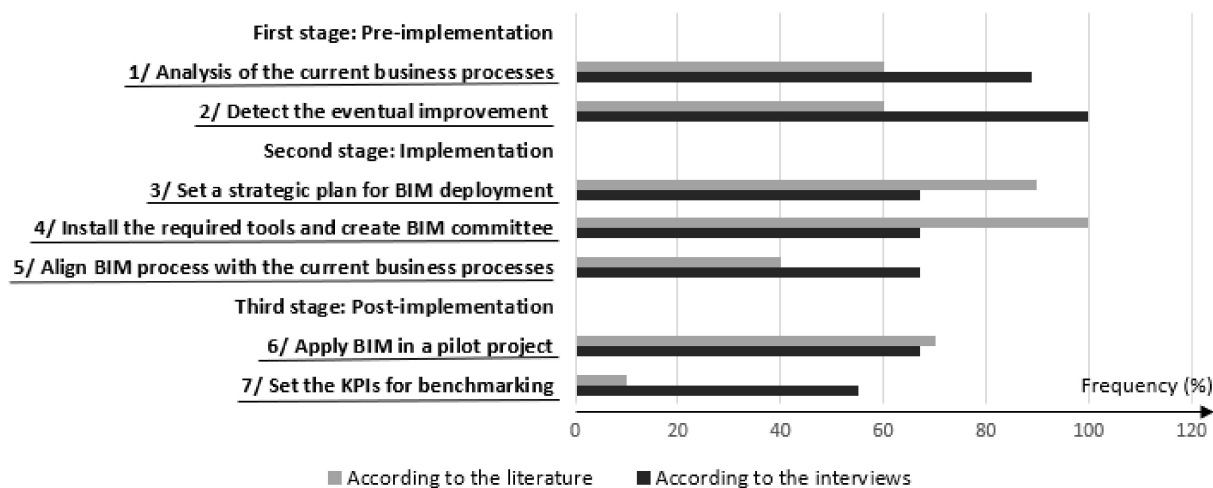


Figure 2. BIM implementation process at the organization level.

The literature therefore seems to give more interest to setting the strategic plan, as well as the required tools and staff, so as to ease BIM implementation. However, most of the BIM experts interviewed emphasized the need to start by analyzing the current business processes of the company and to integrate BIM within the company's processes. Moreover, although assessing the company's progress using BIM is deemed important, there was little mention of the KPIs that should be used to evaluate the firm's progress in the literature. These discrepancies are linked to the specific case of this study, which concerns prefabrication SMEs. Being in the first stage, they need to analyze their existing means before deciding to invest in BIM adoption.

#### *4.3. Best Practices for BIM Adoption*

It is also significant to compare the different methods used by the authors to study the best practices for BIM adoption. Some identified them according to each barrier category (e.g., financial and legal) [46]. Others presented them according to each actor involved in the process [54]. Other articles introduced them using three levels of BIM adoption (government, organization, and project) [60,61]. According to different studies, the government and industries have an important role to play in promoting BIM adoption to different organizations (e.g., [46,62]). They should provide a suitable environment for this digital shift, mandate the use of BIM for their public projects, strive for full collaborative BIM based on open standards for information exchange, and support the major industry players. In fact, according to international experience, when governments have required BIM for their procurements, other public bodies and the private industry were motivated to follow suit [32]. Moreover, Smith [54] confirmed that one of the best practices is to provide universal free and easy access to online BIM building product data and libraries with international consistency. For the second level, relating to deployment in companies and organizations, most of the studies highlighted the critical role of each company, organizational subdivision, and group to facilitate this phase as they must encourage the different members to learn about this approach through BIM education, training, and research [51,54]. According to Georgiadou [39], one of the best practices is to develop an international evidence base of lessons learned in BIM to be used in training and educational courses. Another tip lies in promoting the client's involvement during the design phase. Furthermore, there is an emerging need for a new form of contract that fits with BIM requirements and concepts as well as regulation and standardization to create a common language between the stakeholders [48]. Regarding organizational and project levels, Hong et al. [52] revealed that BIM adoption in SMEs requires a rigorous analysis of the eventual risks that may occur during BIM applications and a better management of these risks according to a strategic plan. At this stage, knowledge support is highly recommended to ensure a good understanding of the new process [44]. Similarly, Garyaev [22] outlined the real need to apply a proactive approach to risk management when using BIM in any project. Another study indicated the importance of promoting internal feedback practices and trust within the company to provide better communication and coordination among the staff. Likewise, one of the best pieces of advice for SMEs is to ensure high-performance work practices for retaining and motivating BIM experts by endowing them with adequate autonomy and task flexibility, imposing goal sharing among them, and publicly recognizing noteworthy performance whenever applicable [19]. About the third level, when implementing BIM in a project, external coaching or consulting services may be an efficient way to initiate the BIM adoption process, especially if there is a lack of internal BIM expertise. In addition, it is important to start by fixing short-term goals that are quickly and easily evaluated rather than deal with long-term goals. For BIM projects, Barlish and Sullivan [23] were the only ones to study the KPIs that must be used to better quantify BIM profits and convince the stakeholders about the potential benefits of BIM.

When looking at the information gathered from the interviews, a list of key actions was deducted and summarized in five main practices within the company, the 5C. Clarify consists of highlighting the BIM approach, its requirements, the main actors, their respon-

sibilities, the risks, and the main goals to achieve. Communicate consists of sharing the right information, skills, positive experience, and updates. Collaborate refers to sharing models, responsibilities, and risks so as to achieve mutual benefits and progress. Create is about creating new files and parameters required for BIM adoption, including the BEP, the BMP, the library of objects based on the manufacturer's production, standard files, and codes to make the right updates based on the BIM model's information. Compute refers to calculating different indexes based on KPIs to assess the company's progress and to learn from the experience.

Thus, a comparison between the literature and the interviews highlighted the best practices proposed and synthesized the most efficient ones. Again, among the 66 references analyzed, fifteen papers specifically addressed the best practices to overcome BIM implementation barriers, to favor its adoption, and to maximize the benefits [19,22,23,29,31,32,39,44,46,48,51,54,59,63,64]. Table 3 presents the 31 best practices deduced from the interview analysis according to each barrier class and their occurrence during the interviews and in the 16 related articles.

**Table 3.** Best practices for BIM adoption using the interviews and literature outcomes.

Barrier Class	Best Practices	Interviews (%)	Lit. (%)
HB	BP1: Clarify BIM concepts and baselines to the entire group	67	67
	BP2: Hire/appoint a small team of experts for the mission	55	13
	BP3: Appoint a special group to check the updates and to review the models after each step	55	33
	BP4: Provide more effort at an early stage of the project	67	40
	BP5: Get informed about the market and technology news	22	0
	BP6: Support the team during this shift	100	87
	BP7: Make sure each actor is well informed after each step	67	27
	BP8: Provide continuous effort	89	7
	BP9: Encourage communication and collaboration	100	87
	BP10: Share positive experiences and knowledge	55	67
	BP11: Ensure the internal experts' motivation	55	7
	BP12: Start BIM experience with most motivated members	22	27
TB	BP13: Analyze company technical needs before purchasing software	89	53
	BP14: Check the interoperability factor	67	73
	BP15: Create a product database and a library	67	47
FB	BP16: Regular analysis of the financial status	22	73
	BP17: Perform an ROI study and respect it	22	53
	BP18: Compute profit (cost, time, quality)	55	87
OB	BP19: Efficiently use 3D models instead of 2D plans	67	53
	BP20: Review the reliability of the model information	100	67
	BP21: Integrate BIM into current processes	67	53
	BP22: Simplify and facilitate the process (go step-by-step)	22	33
	BP23: Standardize BIM processes	55	80
	BP24: Pay more attention to the planning and design phases	67	20

Table 3. Cont.

Barrier Class	Best Practices	Interviews (%)	Lit. (%)
	BP25: Apply BIM even if not required by the client	22	27
	BP26: Update and review the process after each step	100	27
	BP27: Provide manuals as references	33	47
	BP28: Make logistics simulations when needed	22	33
	BP29: Use KPIs for BIM assessment	55	60
	BP30: Document each step	33	40
LB	BP31: Adapt contract to highlight BIM requirements	55	60

For human barriers, a certain convergence was noticed between the literature and the experts' statements. The major difference concerns human resources management. The interviewees gave more details about this aspect to ensure the continuous effort and motivation required for BIM adoption. Regarding technological barriers, BIM experts in Quebec insisted on the crucial need to analyze the company's technical needs before purchasing software specifically for prefabrication SMEs to avoid a waste of funds, effort, and time in the following steps. Despite awareness of financial barriers, only a few studies mentioned the importance of regular analysis of the financial status of SMEs. For organizational barriers, the difference between the literature and the interviews concerns paying more attention to the planning and design phases and updating the process and information after each step. Lastly, for legal barriers, both the literature and the interviews pointed out the need for a new form of contract that fits with BIM requirements.

The differences cited previously could be due to the specific context of the current study and the interviews, while the cited articles studied diverse cases and aspects (e.g., national/industrial scale, prefabricated/traditional construction). The literature aims to make general conclusions and guidance that could be adopted by any type of company in any project as well as the whole community. However, the interviews focused more on the BIM adoption status in Quebec, especially in prefabrication, targeting these SMEs' specific issues in managing this digital shift.

#### 4.4. Global BIM Implementation Framework in Prefabrication

Using the literature and interview results, a global implementation framework was created based on the three main levels of BIM adoption, as shown in Figure 3: government level, industry level, and project level. In Canada as well as in Quebec, the use of BIM for public projects is not mandatory. However, it is important to note that many public organizations in Quebec are promoting BIM applications and are already using them in their projects. For example, Poirier et al. [15] stated that the *Société Québécoise des infrastructures* (SQI), responsible for managing real estate and public infrastructure, has been requiring the use of BIM in their major projects since May 2016. They also added that different universities and colleges in Quebec are now offering specialized courses in BIM. Three axes were thus considered to explain the government's role and how it could promote BIM implementation in Quebec. These axes are mainly the educational, legal, and financial axes. The educational axis concerns the integration of BIM concepts in educational programs as well as open training to support young professionals and students and provide a favorable environment for this digital shift. For the legal axis, there is an emerging need for new forms of contracts and standards to promote a common language within the stakeholders and to clarify the 3D model's intellectual property and benefit/risk-sharing. The financial axis mostly concerns the SMEs as they represent a large part of the prefabrication industry in Quebec, Canada. Governments could help these enterprises move toward digitization by supporting them financially and promoting the use of BIM in public projects.



As presented previously, implementing BIM at the company level is based on three main steps. The first one is the pre-implementation phase, which is to analyze the company's current business process and to make decisions about BIM deployment. The second step concerns the implementation process, from planning to acting. Finally, the post-implementation phase is about piloting and monitoring BIM applications in a specific project. Levels 1 and 2 could be applied in both prefabricated and conventional construction. However, level 3, regarding the team project level, is based on the main phases of prefabrication projects: planning, design, fabrication, transportation–storage, and assembly–finishing. During the planning phase, it seems relevant to establish a rigorous description of the project, the actors and their roles, and the schedule, and to prepare the BEP in order to clarify the goals to achieve while using BIM in this project. At this stage, it is highly important to prepare appropriate contractual documents. Communication and coordination between stakeholders at the early stage remains the key to success in this process. At the design phase, detailed plans of the models to create should be made so as to easily check and review them. Once revised, these models could be integrated in the final 3D model that will be shared between the stakeholders and called the federated model. Throughout fabrication, the team project should efficiently use the federated model to control component quality and conformity with the design. Before transportation and storage, BIM simulation tools are highly recommended to predict the different scenarios that may occur and to complete this phase successfully. Finally, the 3D model and other technologies such as RFID (Radio Frequency Identification) should be used on-site to control and monitor the assembly process [65].

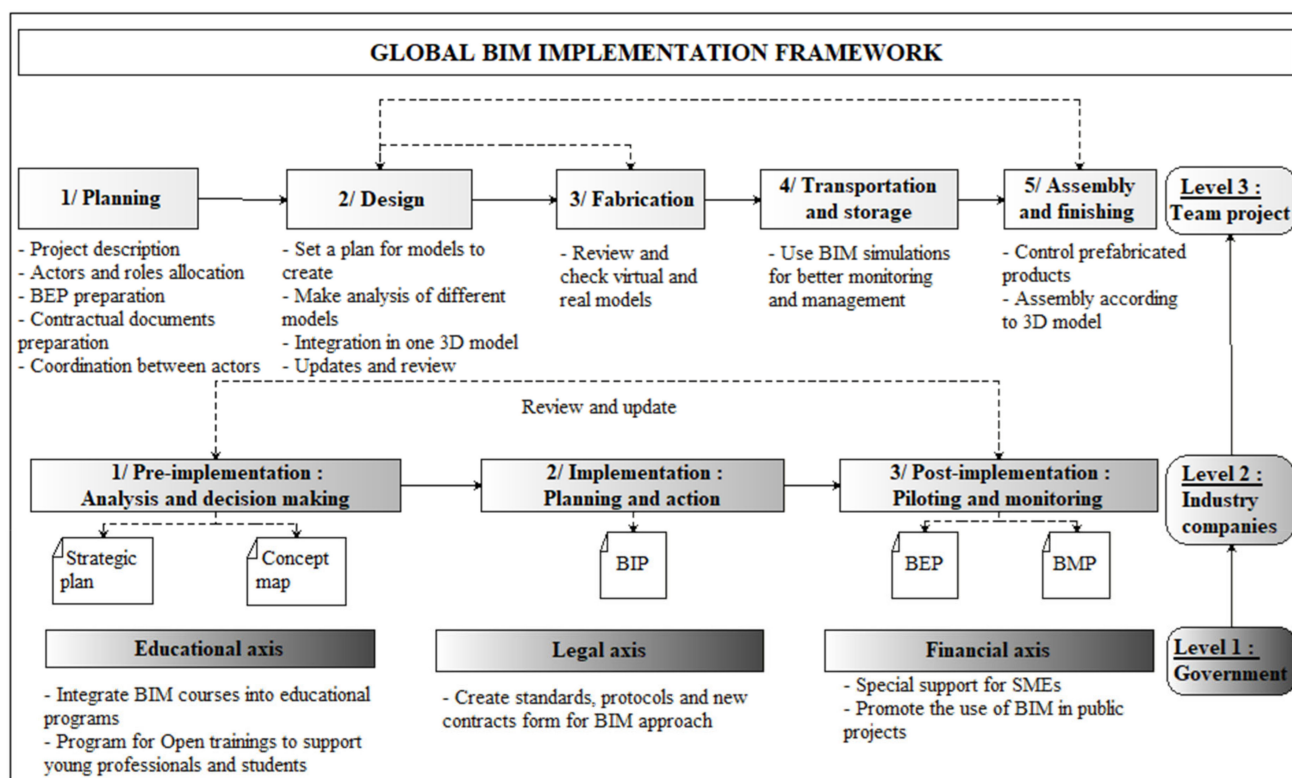


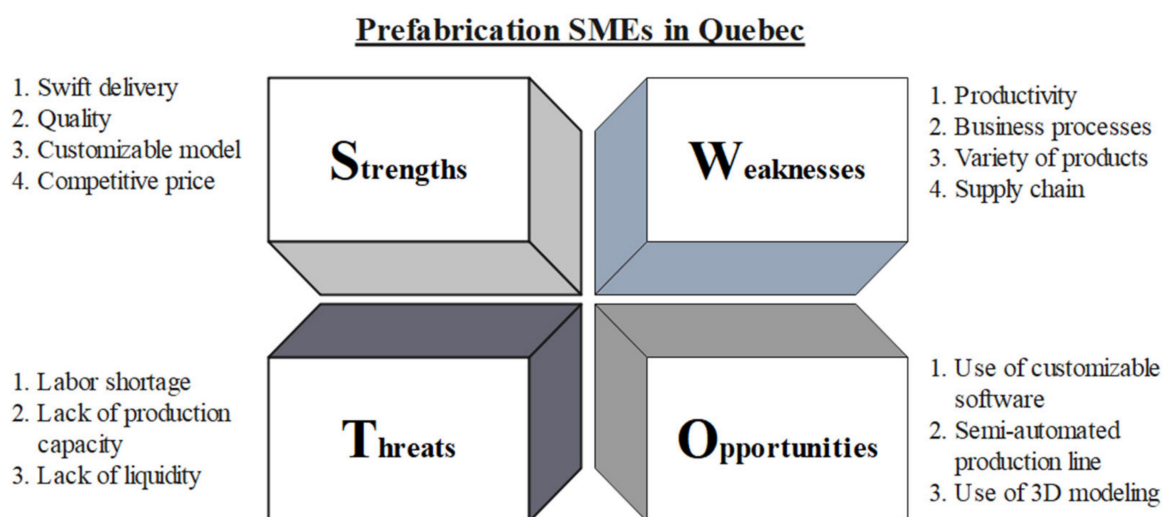
Figure 3. Global BIM implementation framework.

## 5. BIM Implementation within the Prefabrication SMEs in the Province of Quebec

The general framework presented in Figure 3 was adapted specifically to prefabricated multi-housing projects in Quebec. In fact, multi-housing projects are in high demand due to modernization and increased urbanization worldwide, as claimed by 66.7% of the participants in the survey launched, and often require collaboration between the SMEs.

The survey was sent to 30 Quebec SMEs specialized in this sector to obtain insights on the state of prefabrication and the process of carrying out multi-housing projects. Fully completed surveys were received from 9 of these companies. More details about these enterprises are presented in Figures A1 and A2 in Appendix A. Most of the participants work as company managers (55.6%) while the rest hold various positions such as sales manager and headmaster. Moreover, 77.8% of the respondents have more than 10 years of experience in this sector. When asked about the types of projects carried out by their SME, five participants chose single-family housing and multi-housing projects.

The survey responses were used to develop a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of the wood prefabrication industry's current state (Figure 4). Each factor was ranked according to its frequency in the answers. For instance, these companies' main strengths are swift delivery (31.8%), products' quality (27.3%), the ability to offer customizable models (22.7%), and their competitive pricing (18.2%). Their major weaknesses are highly related to the productivity rate (40.0%), their business processes (25.0%), a limited product variety (20.0%), and their supply chain (15.0%). These weaknesses are mainly due to labor shortage (66.7%), lack of production capacity, and lack of liquidity (22.2%). Other critical threats mentioned (11.1%) were seasonality, coordination with architects, competition with other sectors, and technical software. On the other hand, many opportunities such as 3D modeling, customizable software, and automated production were stated.



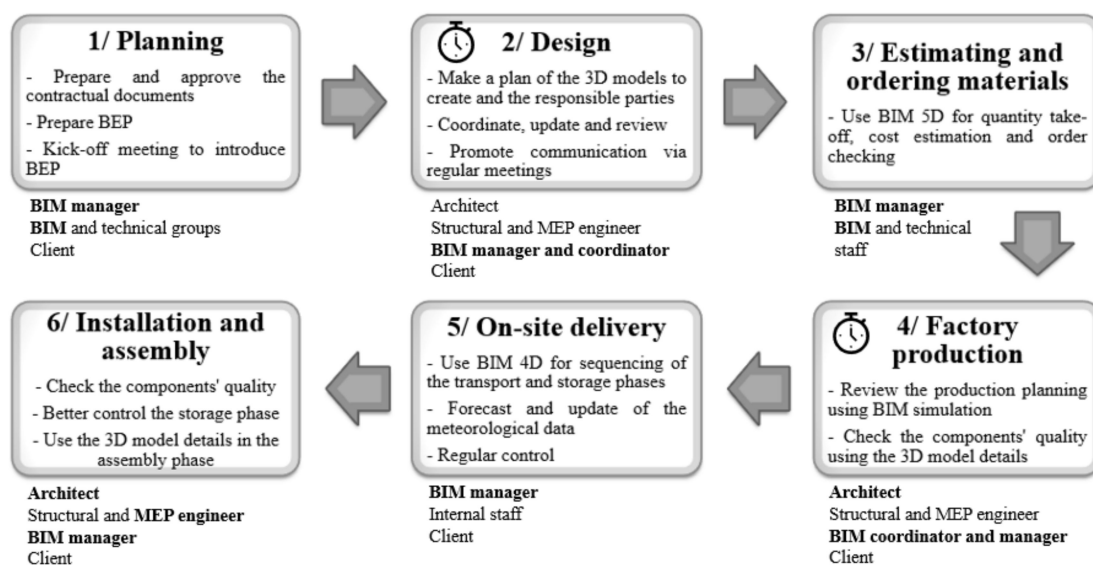
**Figure 4.** Survey-based SWOT analysis of prefabricated SMEs.

The survey asked about the main phases of a multi-housing project, the riskiest ones, and the ones that require more time as well as the actors involved. A multi-housing project usually has six phases: planning, design, estimating and ordering materials, factory production, on-site delivery, and installation and assembly. The results analysis revealed that design and production phases are both the most time-consuming and the riskiest, causing most of the issues occurring during the project. This could be because several actors are involved in these phases, which require regular communication, review, and updates.

Regarding the major problems faced by the professionals in a multi-housing project, technical problems related to the software used (43.7%), logistics problems (31.3%), changes and short delays, as well as business processes (25.0%) and lack of follow-up by the subcontractor were the main problems mentioned by the respondents. Such issues may be caused by a lack of communication and coordination between the different parties, seasonality, and lack of follow-up by some parties. Thus, BIM seems to be a suitable solution for this situation. The survey also revealed that of all respondents familiar with BIM, 33.3% have already started its implementation (Figure A3 in Appendix A), 66.7% are planning to implement it, and 55.6% are already using Revit software for the design

phase. According to the participants, the potential benefits of BIM are reducing errors and clash detection (18.8%), enhancing quality (17.5%), and promoting communication and coordination (16.2%).

Regarding the critical barriers, in contrast to the interviews and the literature, technological barriers seemed the most critical (32.0%), but they were followed by human issues (26.0%). The financial, legal, and organizational barriers obtained the lowest ranking (14.0%) (Figure A4 in Appendix A). This could be because BIM software requires training, effort, and time to be mastered, leading then to human reluctance. It also requires effort and time to develop its libraries of objects according to the manufacturer's needs. Based on the previous results, a list of actions was prepared to maximize BIM benefits in these projects. Hence, there is an emerging need to revise the prefabrication SMEs' current business models before BIM adoption. When using BIM, SMEs will need to set and respect a deadline for the multi-housing projects, choose the right tools, and develop them according to their needs as well as determine productivity, cost, and time KPIs to assess the eventual benefits of this process. Figure 5 introduces a specific framework for the BIM implementation process at the project and team level (third level of Figure 3) for multi-housing projects conducted by an SME. The actors involved now align with BIM requirements and include the BIM committee. BIM 4D (scheduling) and 5D (quantity take-offs, cost estimation, order checking) seem to be very important to upgrade and facilitate project execution [66]. Thus, used properly, BIM could be very efficient to overcome the current barriers in this sector.



**Figure 5.** BIM implementation process at the project and team level for multi-housing projects conducted by an SME.

In sum, prefabrication companies in Quebec are facing important competition, leading them to collaborate in order to widen their internal and external markets. BIM could facilitate this collaboration, but several barriers should be well clarified and managed before moving toward digitization. The best practices identified in this article should help them overcome these barriers, and the BIM implementation process specifically addressing their needs, shown in Figure 5, will guide them to a BIM implementation that meets their goals.

## 6. Conclusions

This study aimed to reveal the need to adopt BIM in prefabrication to help upgrade this industry, as there was a lack of research in this area. Since most of the companies in this field are SMEs, making this shift raises many challenges. The main goals of this study were to identify these barriers and the strategies and best practices to overcome them. To reach these objectives, a literature review, semi-structured interviews with experienced

BIM users, and a web-survey targeting prefabrication were conducted and analyzed. The study highlighted 30 barriers to BIM implementation. One of the significant findings is the interviewees' awareness of human and organizational factors, unlike previous ideologies considering only financial and technological issues. It also revealed that technological barriers were the most prominent for the prefabrication SMEs in Quebec as there was a crucial need to develop the current software libraries and to provide a continuous effort to master these tools and to better use them. As for the BIM implementation strategies, they were grouped into three distinct phases: pre-implementation, implantation, and post-implementation. The analysis also led to the identification of 31 best practices to overcome the barriers and maximize BIM adoption within the company. All of these elements were synthesized into a global BIM implementation framework clarifying the different levels that must be considered when studying the BIM implementation process (governmental, industrial, and team project levels) as well as the milestones of each level. Finally, information from a web-survey targeting prefabrication companies allowed for adapting the framework to prefabricated multi-housing projects held by Quebec SMEs of this sector.

In the future, it would be interesting to apply the BIM implementation framework in a real case within an SME that has not yet implemented the BIM, to evaluate the limits and benefits resulting from BIM adoption and to use the KPI for the BIM benefits evaluation.

More studies and research could be conducted to promote collaboration and communication between the actors as the proper functioning of BIM is based on a good and healthy communication and coordination between the stakeholders of a construction project. A fault at the level of information transfer flows can disrupt the smooth running of the project and the exploitation of the potential of the BIM.

Further research could moreover address the efficiency of the tools and processes that may guarantee a better connection between the actors. It would also be relevant to study the technical and economic impacts of BIM implementation as well as the changes that will affect the 3D model along the project phases and how it will be shared. Analyzing real case studies of BIM adoption for different types of projects could as well be relevant for both the scientific community and the industry.

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**Data Availability Statement:** Restrictions apply to the availability of the data. Data were obtained from many companies and may be provided by the authors if these companies agree.

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## Appendix A

### *Appendix A.1. Semi-Structured Interview Questions*

- Can you tell us about yourself and your professional background?
- How long have you been using BIM, and for which types of projects?
- What are the benefits and applications of BIM in both a small and a large project?

- According to your expertise, what are the barriers to BIM implementation and the risks to consider before making this digital shift?
- Can you tell us about your role in this process? (If BIM manager, what are the skills that a BIM manager should have?)
- Can you describe the strategies followed to move from the traditional way of working to BIM in your organization? (before, during, and after implementation)
- What are the problems often encountered when implementing BIM?
- Once implemented, can you tell us about the best practices for adapting to this new process?
- What is the role of each actor in this process and at what stage of the project should they act (architect/engineer/contractor/client/BIM manager)?
- Can you explain the coordination and communication procedure between all stakeholders to take advantage of BIM? (meeting, phone, email)
- What BIM software do you use and recommend to your clients, and on what basis do you make such a choice?
- In the BIM method, can you tell us about the new information to be specified in the regulation and contractual documents?
- Once implemented, what is the process the company should follow to evaluate its progress via BIM?
- What do you think of BIM in prefabrication (its usefulness, its particularities during implementation, etc.)?
- Which actors are the most reluctant to implement BIM, and how do you manage this situation to motivate them toward this approach?
- Can you tell us about the current state of the Quebec prefabrication industry with respect to BIM and how well the industry has mastered it?

#### Appendix A.2. Survey Results

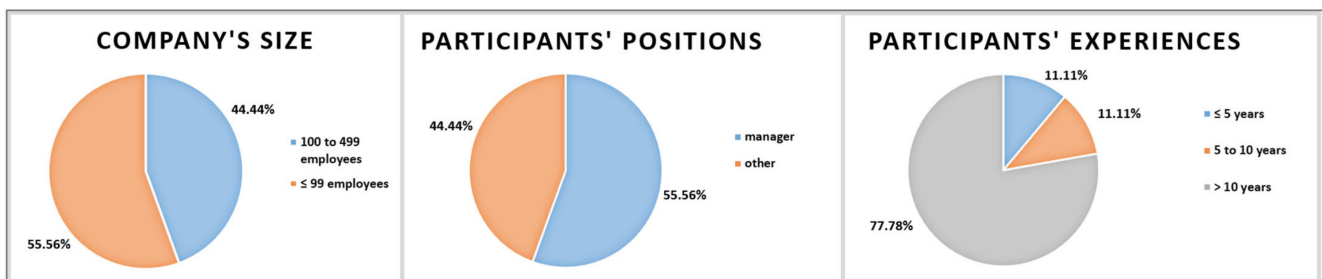


Figure A1. Information about the companies.

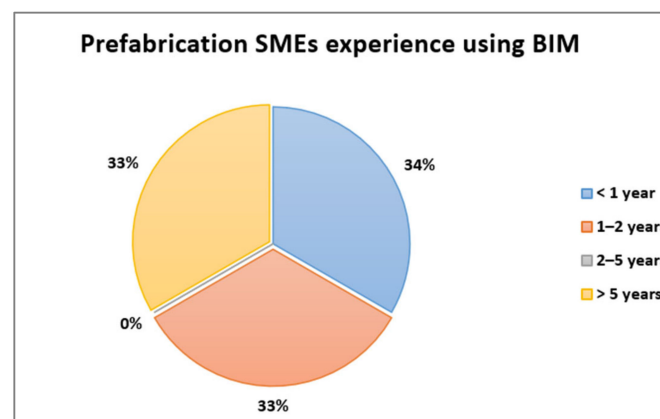


Figure A2. Information about the companies' experiences with BIM.



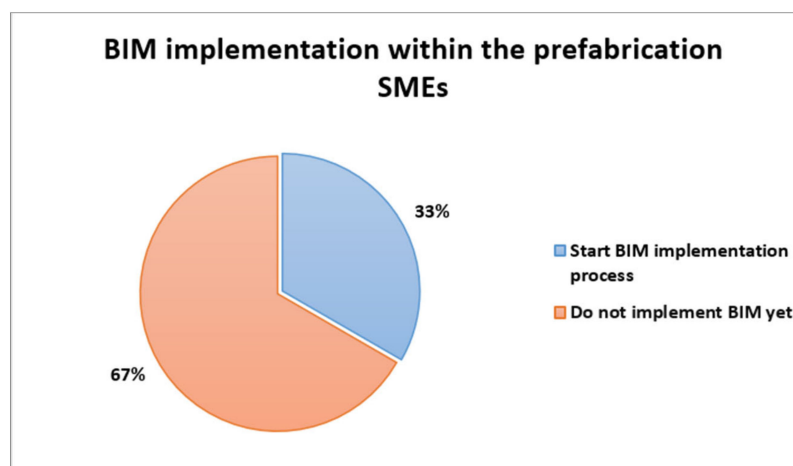


Figure A3. BIM implementation within prefabrication SMEs.

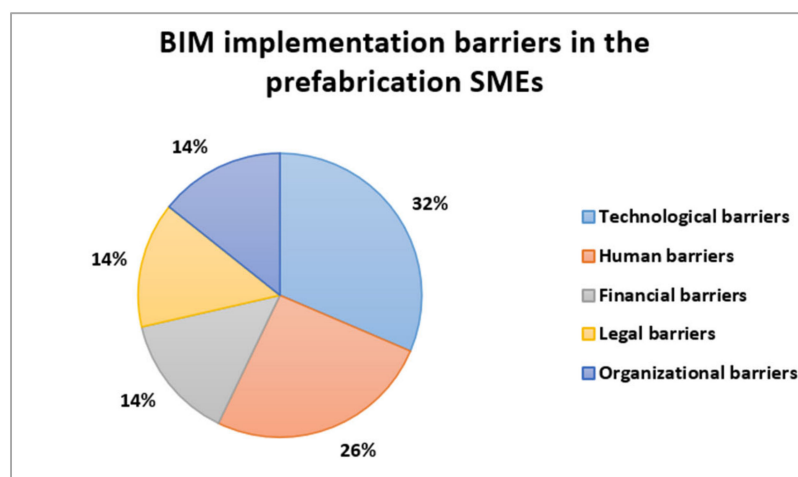


Figure A4. Barriers to BIM implementation according to prefabrication SMEs.

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