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Best Practices for Implementing Building Information Modeling in the Prefabrication Sector

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Abstract. Nowadays, Building information modeling (BIM) seems to be an asset to face the gap that may occur in the presence of several tools, various disciplines and different experience levels in the construction industry. In fact, this approach helps stakeholders to speak a common language by working on the same 3D model. Nevertheless, implementing BIM raises interesting challenges linked to many aspects, especially the human resource factor. Thus, this paper aims to reveal the best strategies to implement BIM in SMEs and to highlight the best practices that help face the main barriers during this phase. On the basis of a literature review and semi-structured interviews, the most notable findings are the impact of human barriers which requires more interest, the importance of starting the implementation phase by analyzing the company's current business processes so as to maximize BIM benefits, as well as, setting a strategic plan to outline the main steps and the different factors of this digital shift in order to better lead and support the whole staff.

Keywords: BIM, Prefabrication, Implementation, Best practices, Semi-structured interview, SMEs

1. Introduction

During the post First World War period, off-site construction appeared as the best technique to provide numerous temporary and emergency prefabricated buildings such as houses and schools [1]. Due to its potential benefits such as saving time, improving labor productivity and enhancing project quality [2], this industry has been widely spread all over the world, particularly in Canada. Likewise, Quebec remains the leading province in this field as it provides 29.7% of Canadian manufactories in 2015 [3]. Nonetheless, construction projects have been known for their fragmentation, complexity, and challenges [4] due to the involvement of different stakeholders from various fields (architectural, structural, electrical and mechanical, etc.) and other factors such as deadlines, budgets, human resources, etc. Thus, an approach such as Building Information Modeling (BIM) seems to be an efficient way to face these challenges and to better achieve prefabrication benefits. In fact, it aims to facilitate communication and coordination between stakeholders along different phases of a construction project using a shared 3D model full of relevant information about the building. However, transition from a traditional method to BIM requires investments in terms of budget, time and skills. These requirements may seem risky for small and medium enterprises (SMEs) that represent the largest proportion of the construction industry in Canada (99.8% in 2017 [5]). Even though BIM has captured academics and practitioners' attention over the years, finding a specific methodology to implement and manage the approach, especially in SMEs, remains an open question.
Hence, this study aims to reveal the best strategies for BIM deployment in SMEs as well as to highlight the best practices to support the firm's progress while avoiding issues. To do so, a series of semi-structured interviews were conducted with several BIM experts.
This paper will be divided into three main sections. The first one proceeds with a review of relevant literature that highlights the baselines of BIM. The second section outlines the methodology used to better conduct the interviews. The next one will be intended to present the results of this conducted study. Finally, a conclusion that represents a summary of the main achievements and perspectives will be presented.

2. Literature review

In order to outline the baselines of BIM and its potential in the prefabricated sector, the first part of this project was dedicated to a literature review. Thus, several key words, such as BIM, Building Information Modeling, implementation, deployment, prefabricated construction, prefabricated building, prefabrication, off-site construction, best practices, medium and small firms, etc., were used to formulate different equations in different databases, such as Compendex, Inspec, Proquest and Web of Science.

2.1. BIM definition and process

As a broad approach, many definitions have been associated to BIM (Building Information Modeling) over time. Some researchers and professionals see it as a 3D modeling software, some others consider it as a new technology, other ones define it as a new process that aims to facilitate communication and coordination between the stakeholders as well as management of a building project [3], [6]–[10]. Another relevant definition, cited in the BIM Handbook [11], introduces BIM as a modeling technology and associated set of processes to produce, communicate, and analyze building models. To avoid confusion, many authors use three key concepts to clarify the BIM process: Model, Modeling and Management [12], [13], [14]. To sum up, Building Information Modeling can be defined as a new way of working on a building project, based on a strong collaboration between stakeholders using a 3D model created via the advanced software. Used properly, it provides an efficient way to share information along the project lifecycle, leading to several benefits such as better project management and monitoring.
In order to describe the BIM process, we will first define the main levels of this process that are presented in figure 1: level of maturity, level of capability and level of development.

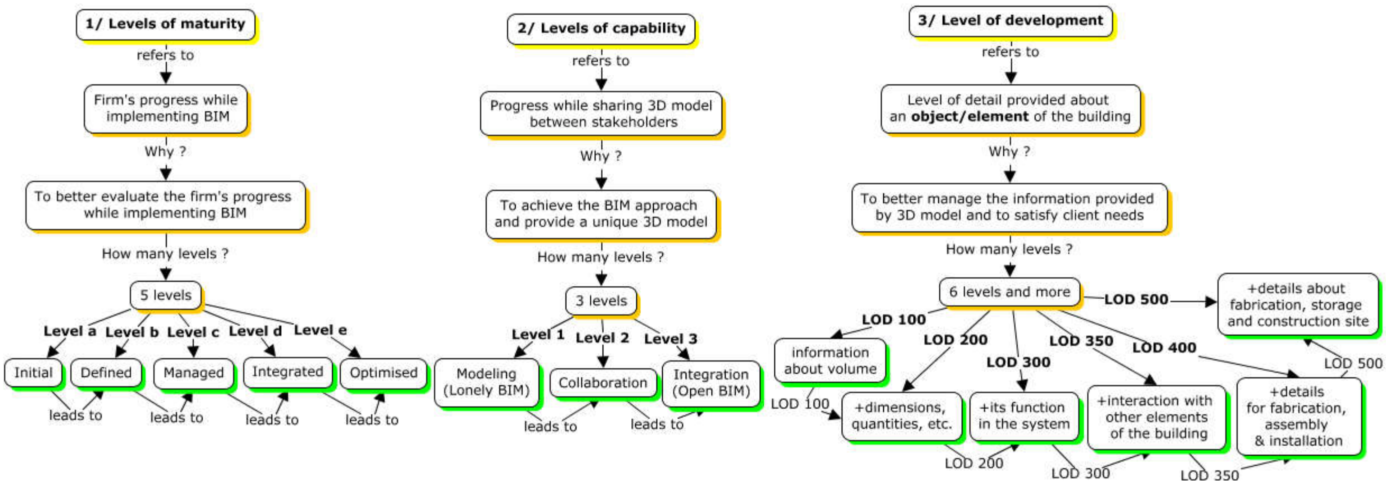

Figure 1: The relevant levels of BIM.

The maturity level refers to the performance improvement milestones that organizations, teams and the whole market aspire to achieve while implementing BIM. There are five levels according to Succar BIMMI (BIM Maturity Index)[15] [16]: the first level is called "Initial" as it is the first step of BIM deployment. BIM tools are installed but there is a shortage of defined processes, responsibilities, goals, etc. as when working with traditional method while using BIM software. The second one, called "Defined", is characterized by well-defined baselines of this approach. The third level "Managed level" refers to a better management of the whole process. This level is known for an efficient communication and a better understanding of the BIM process but productivity is not yet predictable. The fourth one, called "Integrated level", is characterized by better quality management and performance improvement through performance benchmarks. The productivity is consistent and predictable compared to the previous level. The last level "Optimized level" leads to review and updating of different factors related to the BIM approach (strategies, processes, tools, contractual models, etc.) in order to align it with the company's target. The capability level refers to the expertise of the company while using BIM and sharing the 3D model [17]. In fact, there are three levels of capability: the first level is called "modeling/Lonely BIM" as each actor will be interested in his/her own model, the second one is called "collaboration" so all stakeholders will exchange their models for a better communication. The third level known as "Integration/Open BIM" requires an

integration of different models (architectural, structural, MEP, etc.) in order to make one shared 3D model that will be used in the following phases of the construction project [18]. The level of development (LOD), refers to the information provided to introduce an element of the building in the 3D model. From one level to another, more details will be provided (dimensions, materials, connection details, etc.).
Based on the previous concepts, the BIM process starts with an intradisciplinary modeling, after a planning phase, in which every actor (architect, structural/MEP engineer) creates his/her own model. Once a quality control, a revision and an approval are made by a BIM expert of each department, models will be shared between those actors in order to ensure a better coordination and communication. The last step leads to the creation of a unique 3D model that will be shared and used by stakeholders to detect any conflict or error before the construction phase. This 3D model is called a federated model [19].

2.2. BIM benefits and limits

During the last decade, the construction industry faced a notable transition towards the BIM approach given the advantages offered by this new process. Many authors studied these benefits with interest in order to quantify their effect on a firm's progress [6], [20], [21]. The most commonly reported benefits are enhancing communication and coordination between the stakeholders through centralized information, reducing the total cost and duration of the project, enhancing the quality of the building and increasing the productivity and safety of the employees [13]. Moreover, many advantages could be deducted through the different BIM applications such as clash detection that allows to avoid a lot of errors and rework during the construction phase, a better visualization via the shared 3D model, better scheduling offered via BIM 4D, cost estimation through BIM 5D and so on [3], [18], as shown in Table 1.

Table 1 : BIM benefits based on BIM dimesions and applications.

BIM 3D Modeling	**BIM 4D scheduling**	**BIM 5D Cost estimation**	**BIM 6D Sustainability**	**BIM 7D Facility management**
Better visualization; More details; Better coordination/ communication; Clash detection.	Project phasing simulation; Sequencing of activities on site; Avoiding delays; Better monitoring of the project.	Quantity extraction to support cost estimate; Risk management; Order checks through fabrication models.	Energy analysis; Performance analysis; Sustainable tracking; Better quality.	Better facility management; Better operation of the building during its lifecycle; Maintenance plans and technical support.

Although it has numerous potential benefits, BIM raises interesting challenges and barriers that may be faced during the implementation phase. These barriers are related to resistance to change from the staff, several tools and software, the confidence level between stakeholders, lack of data integration and intellectual property of 3D model, etc.[22]. In fact, the deployment and efficient operation of BIM in a company require a systematic effort from various teams and multiple disciplines with problem solving interactions throughout the project lifecycle [23]. Moreover, many other issues may occur such as lack of sufficient knowledge of BIM, need of well-trained staff, lack of well-defined objectives, misunderstanding of the client's needs, interoperability problems and low rate of return in investment (ROI) that requires a longer time to profit from BIM, etc.[24][25].

2.3. BIM in prefabrication

Prefabrication is a vast concept that refers to any element of a building (truss, floor, module, etc.) that has been fabricated in a location other than its final location (workshop, factories, etc.) to be transported, installed and assembled on site [1]. Compared with traditional methods of construction, the global demand for prefabricated buildings is increasing due to its energy and time savings, environmental considerations, as well as quality and safety improvement. In fact, producing most of the elements in a factory improves working conditions and speeds up the project progress [26] [2]. According to a recent survey, the typical process used by most manufacturers in Quebec is based on three main axes: design, fabrication and installation [18]. The design phase includes project definition, task identification and preparation of relevant documents (plans, contract, etc.) that take place in the offices. The fabrication stage takes place in the

factory and consists of construction and assembly of prefabricated elements. The last step includes transportation, installation, on-site assembly and finishing of the modules to deliver the final building.
Despite its numerous advantages, prefabrication faces the same problems and issues that may affect any construction project such as lack of coordination and communication between stakeholders especially during the design phase, shortage of details and information sharing that leads to interference problems during the construction stage and on-site storage problems. Thus, BIM helps resolve these problems and achieve better prefabrication benefits due to its capacity to promote effective information exchange while also automating several steps in the design, estimation, and planning phases [27].
Applying BIM in the prefabrication sector will be detailed based on the three main axes of this process. At the planning and design stage, BIM brings several applications including: information sharing, visualization, modeling, code reviews, site planning and analysis, fabrication drawings, communication, cost estimating, construction sequences, and collision detection [28]. Moreover, accurate building information not only provides support to the estimation department but also enables an increased level of detail for production scheduling and for simulation that is frequently used in this field for production line performance assessment [27]. During manufacturing phase, several advantages could be noticed such as better quality control using accurate information of the 3D model and better management, monitoring and optimization of the production line using the efficient simulation offered by BIM tools [29]. Regarding the last phase which is the installation of prefabricated components on site, the use of BIM 4D allows to simulate different processes (transport, storage, lifting, etc.) which optimizes component inventory and site management. Thus, combining prefabrication with BIM can significantly lead to time/cost/energy savings, emission reduction and green environmental protection, which plays a great role in bolstering the transformation and upgrade of Canada’s construction industry.

3. Methodology: Main steps to conduct the interviews

The second part of this project consists of conducting a series of interviews with BIM experts in order to collect relevant information from the industry as to the state of BIM adoption in Canada. From these interviews, a set of best strategies and practices will be developed to help SMEs make this digital shift.
In particular, a list of open-ended questions was first developed so as to get a better picture of the BIM approach and its deployment process. Fifteen questions was prepared, covering various aspects such as: experience of each participant and her/his background in BIM, BIM benefits, challenges and barriers faced while implementing this approach, the most suitable projects for BIM, strategies and steps taken to implement BIM, the best practices to progress via BIM, tips to maintain better communication and coordination between stakeholders, the role of each actor, the group hierarchy to better conduct this approach, the best software for the prefabrication sector, the most reluctant actors and the reasons leading to this behavior, etc. After that, a list of nine interviewees was established based on experts’ experiences with BIM. The experts had different backgrounds and various positions (researchers, architects, engineers, BIM managers, BIM directors, etc.) and came from different organizations (government company, private consulting company, nonprofit organization, universities, etc.). They are known as the leaders of BIM in Quebec and their experience in this field ranges from two to twelve years with an average of eight years. Then, a series of meetings with the experts were planned. Different types of meetings (via Skype, phone or face-to-face) were proposed to facilitate this task. During the meetings, permission to record the interviews was obtained. The voice recordings were then transcribed into word files and imported into QDA Miner software for a qualitative analysis leading to a framework for the best strategies and practices to implement and conduct the BIM process. The main results are detailed in the next section.

4. Analysis and results

As explained previously, the use of QDA Miner allows a better analysis of the massive amount of information collected during the interviews. Only the most important findings will be discussed in this section such as barriers for BIM deployment and best strategies and practices to implement the approach.

4.1. Main barriers for BIM implementation

The interview analysis leads to five main barriers to BIM deployment: human, technological, financial, organizational and contractual, Figure 2 shows the importance of each barrier in term of percentage.

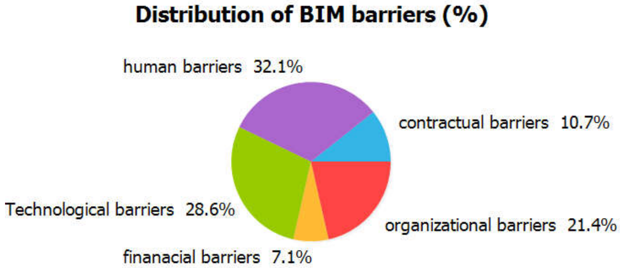

Figure 2: Distribution of BIM barriers according to the interview analysis.

Technological barriers arise in the form of various tools that may be used without planning or proficiency, as well as, information reliability and interoperability problems in case of undefined goals. Organizational issues refer to management problems such as the absence of a management plan, lack of coordination between technical and BIM staff and information overload that must be well managed and used. Regarding financial barriers, it is mainly based on the cost and time investment required for BIM implementation. Most of this investment is spent on purchasing software, personal training, and recruiting specialized staff so the main challenge is to justify and explain these costs to project stakeholders [30]. Contractual barriers are highly linked to classic contract forms and the intellectual property of the 3D model. According to the interview results, 77.8% of experts think that the 3D model is not yet a contractual document but should be shared while 22.2% think it is a contractual one, whereas all of them think that, sooner or later, it will be a contractual document. Hence, some conflicts may occur between stakeholders and prevent them from having a clear view of their responsibilities and rights. Furthermore, the BIM approach is based on information sharing, liability and collaboration between stakeholders that require a new form of contract to outline the role of each actor and emphasize sharing responsibilities and risks. As claimed by most of the interviewees, the new contract must be seen as a management plan that aims to highlight the goals of the project and of using BIM, to organize the relations between actors, to clarify responsibilities and risks, to put the light on information sharing and to set the standards that will be used along the project. Regarding human barriers, this category seems to be the riskiest one as mentioned previously, so it will be interesting to reveal its different forms as well as the best practices to manage them. The most prominent ones arise in the form of resistance to change, lack of communication, skills shortage, lack of information sharing, weak sense of responsibility, misunderstanding of the BIM approach, bad habit of working at the last minute unlike the BIM process that requires a great effort at the early stage, etc. In order to face these barriers, rigorous planning, continuous training and team support must be taken as serious actions, see Figure 3.

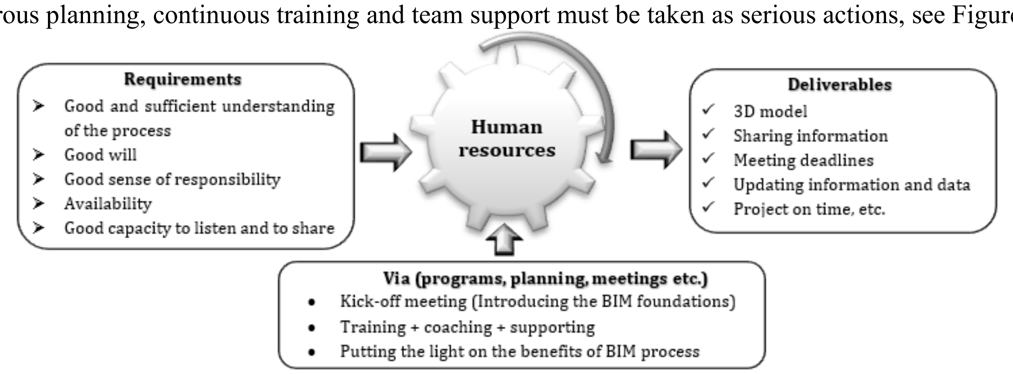

Figure 3: Human resources as a driver of the BIM process.

4.2. Best strategies to implement BIM in SMEs

Based on the interview outcomes, we were able to establish a BIM deployment framework in order to facilitate this phase, especially for SMEs, as shown in Figure 4. According to the experts, the BIM deployment process can be divided into three main axes: analysis, planning & conducting and piloting & monitoring [25][4]. The first axis is based on two main steps. In fact, all the experts claimed that deploying

BIM is innovating and improving the actual situation of the firm, so it must start by analyzing the actual situation. Thus, the first step will be dedicated to examining the current situation of the company using process mapping, surveys or SWOT (Strength, Weaknesses, Opportunities and Threatens) analysis. This step aims to reveal the current company means (actual processes, human resources, financial state, IT tools actually used, standards, etc.) Moreover, the company must pay more attention to the maturity and capability levels that have been introduced in the literature review, so that it will be able to better monitor its evolution while implementing BIM. After that and based on this analysis, it makes sense to detect the issues and areas of improvement in the current business model in order to reveal the first use of BIM that will bring more profit and enhance the actual situation. Once achieved, a roadmap or strategic plan must be set up to be used as a reference in BIM deployment. This plan includes answers and details about the main questions: Why implement BIM? (To increase productivity, to save time and cost, to be more competitive, to increase market share, etc.) Who are the main actors of this process? (BIM director, BIM manager, BIM coordinator, etc.) Their roles and responsibilities? Their benefits? BIM applications to use in the first stage, how to make this transition? Different steps and tools used to do so? How to share information? What are the deliverables, etc.? [31] Then, senior management has to establish the committee that will be responsible for this process deployment (assign members, their roles, required skills, availability, etc.). Once this plan is set, a kick off meeting must be planned in order to better introduce the BIM approach to all members. During this meeting, everyone will obtain a clear view of the responsibilities of each one, as well as, the deliverables that must be provided and the deadlines. So, this meeting aims to highlight the main steps, concepts and rules to better conduct BIM deployment. Then, required tools such as software and hardware must be set up and well used by the main committee. Furthermore, all respondents agreed about an important step that consists of aligning BIM with the current processes. Once tools are installed, staff is ready and all the concepts are clear, the next step will be dedicated to applying BIM in a pilot project in order to test it and to evaluate the firm's progress using this new approach. It is important to choose an appropriate pilot project as it is the first project realized using BIM. In this case, it is better to avoid critical projects limited by a short duration and/or an important budget. Finally, during the interviews, most of interviewees pointed out the need to set key success factors for BIM deployment assessment. These key factors may refer to time and cost saving, productivity increase, quality improvement, etc. Finally, meeting, reviewing and updating must be done after each step.

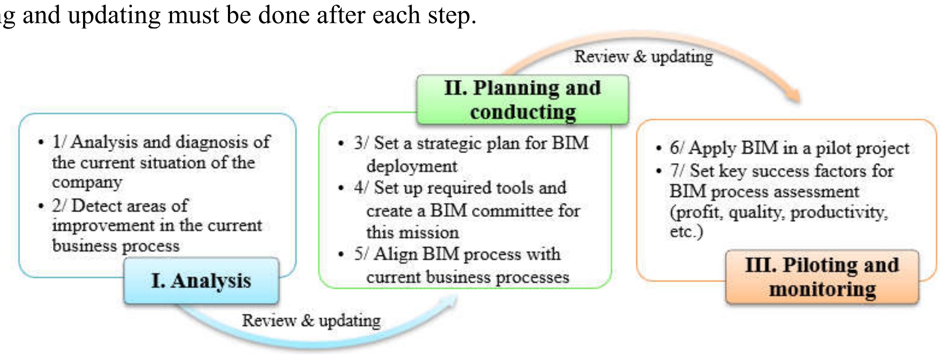

Figure 4: The main steps of BIM deployment.

4.3. Best practices for BIM adoption

Based on barrier classification, best practices will be related to each barrier class. Thus, there are five classes of best practices, linked to human resources, technologies, organization, financial and legal aspects. In the first class, one of the best practices is to better understand the different positions and responsibilities in order to ensure good functioning of the BIM process. According to most of the interviewees, the roles to occupy in a BIM approach are classified into three main functions, as shown in figure 5: management, coordination and modeling. The management function is based on a BIM manager/director who has the strategic vision and fulfils the organizational role to better conduct the deployment phase. According to most of the interviewees, the BIM process can function without a BIM manager or director, but needs someone who has this vision to establish training plans, standards at the office level, to set best practices, to coach and support the group and to gather resources on the project, whatever its status. The coordination function is covered by the BIM coordinator or creator who has to ensure that the models are committed to the requirements, that they are well integrated and functioning, and to monitor the model evolution and project progress. The modeling function is delegated to the BIM modeler who should create and manage the 3D model based on the client needs so he/she must be well-skilled in using the basic modeling software.

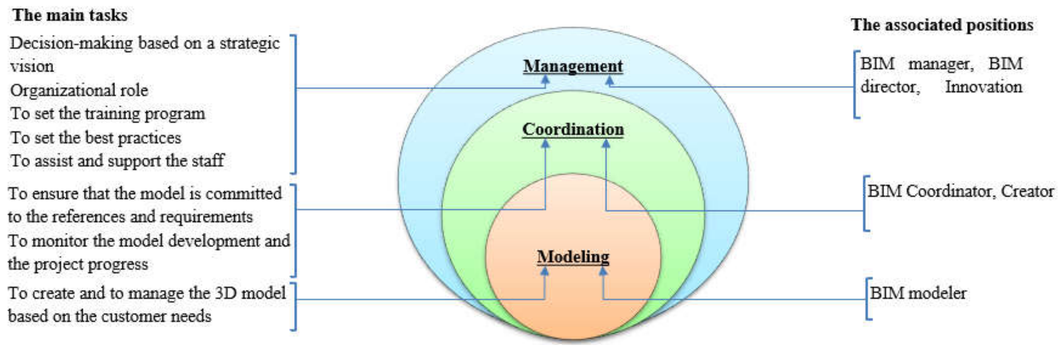

Figure 5: Three main functions in the BIM process.

The previous main classes of responsibilities must be present in each company in order to help stakeholders to better integrate the BIM approach and to achieve its benefits. Due to the importance of human resources in the BIM process, all respondents pointed out the need to support and coach BIM staff, to keep them motivated by sharing successful experiences and relevant knowledge, as well as, the main information about the company's progress. Furthermore, one of the main elements revealed in the interviews concerning this factor was to initially limit the number of members on the BIM committee and to ensure that they are given the time and resources to master this task. Then, they can become facilitators for the company. Another relevant practice is to invest considerable effort in the early stages of the project (planning and design phase) as it affects the following phases. It is also important to start the BIM transition with people who support this approach in order to create a favorable first BIM experience that will be shared among the group. Regarding the technological field, the committee must choose the right IT tools for the company's needs that will bring benefits and fit with group skills as well as the software that allows file exchange without interoperability problems. For the organizational factor, it seems better to start working with BIM 3D and to avoid working on all BIM dimensions at an early stage of the implementation. In fact, one of the most common mistakes made by some companies is aiming to reach all BIM applications from the first stage of BIM deployment without checking on the company maturity and capability levels. This mistake requires enormous effort and raises high risks. Another tip refers to simplify and to facilitate the BIM process by avoiding the use of various tools and software so that standardization of practices (conventions, file extensions, data forms, etc.) helps offer better team support and process operation. Finally, it is extremely important to provide reference manuals and handbooks and to keep detailed records documenting each step. As for the legal aspect, it seems relevant to look for a new kind of contract that encourages the collaborative process, information sharing and outlines professional responsibilities. In fact, one of the new forms, mentioned during the interview, that may fit with the BIM approach, is CCDC 30 which is a new form of contract called Integrated Project Delivery Contract specific to IPD projects including scope allocation, payments, changes, conflict management, termination, insurance and contract security, and liability allocation [32]. In addition, intellectual property of the 3D model must be clarified at the beginning of the project to avoid conflicts throughout the execution. Finally, regarding the financial aspect, it is important to estimate a return on investment (ROI) and to use it as a reference for BIM profit assessment. According to the experts, showing financial benefits to headmasters will be valuable to maintain their support.

5. Conclusion

This paper aimed to reveal, at first, fundamental concepts of BIM through a literature review to ensure a better understanding of this approach and then to analyze the findings of semi-structured interviews that were conducted in order to detect the state of BIM adoption in the province of Quebec, in Canada, and to highlight the strategies and tips that facilitate implementation and use of the BIM process by SMEs. One of the most relevant outcomes of this study was the classification of barriers to BIM deployment. Hence, the most critical barriers were highly linked to human resources: resistance to change, lack of communication and coordination, habit of working at last minute, weak sense of liability, etc. So that, more interest must be given to how to lead, support, motivate and manage human resources. Also, most of the respondents agreed on the crucial need for a new form of contract that fits with BIM as a collaborative approach. Regarding the best strategies to implement BIM in SMEs, analysis and diagnosis of the current business model and processes of the company seems to be a mandatory step to start this transition.

Furthermore, to ensure better communication and coordination between stakeholders, meetings, revisions and updates must be frequent in the committees that are involved in this process. As stated by one of the experts, a BIM model is not a gold mine! It brings benefits only if it holds accurate and relevant information which depends on the stakeholder's responsibilities. The next step of this project will be dedicated to investigate real case studies so as to update the current results and help SMEs make this digital shift.

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