Key Factors of an Initial BIM Implementation Framework for Small and Medium-sized Enterprises (SMEs)

Arman M. Kouch[a*], Kimmo Illikainen[a] and Seppo Perälä[a]

[a]Department of Civil Engineering, Oulu University of Applied Sciences, Finland
E-mail: arman.kouch@outlook.com, kimmo.illikainen@oamk.fi, seppo.perala@oamk.fi

Abstract –

Building Information Modeling is the process and the technology transition from a traditional single sequential form to a modern multiple parallel form of data integration. BIM is the process of data sharing and distribution with the ability to employ the data via numerous applications for managing several multidimensional tasks and activities of AEC/OM (Architecture, Engineering, Construction/ Operation and Maintenance) throughout the building lifecycle. Indeed, employing BIM technology not only seems vital for small and medium-sized enterprises (SMEs) who are active in the construction sector of the building industry but also it is unavoidable for the firms who are seeking to increase their competitiveness and even their existence in the future era of the industry. The era of automation, robotics and 3D printing is coming faster due to the extraordinary developments and innovations in the digitalization and automation sectors, absence of desire productivity and efficiency in the building industry where BIM can efficiently provide the required information and accurate data to be used for model simulation and machine control in robotic construction.

However, most of the active SME contractors are not aware of building information modeling, nor are they familiar with the BIM implementation framework and its key factors. Therefore, the main aim of this article is to provide realistic key factors for an initial BIM implementation framework that can help the SMEs, who are working in the construction sector of the building industry such as contractors, to understand BIM as modeling and employ it with less costs and more efficiency.

Keywords –

Building Information Modeling (BIM); Building lifecycle; SMEs; Competitiveness; Building industry; BIM implementation framework; Automation and robotics;

1 Introduction

This research study encompasses a background on building information modeling (BIM), its importance for the building industry, the construction and particularly SME contractors. The importance of BIM in automation and robotics will be discussed too. Next, the problem and the research focus will be explained. Followed by, the research methodology covers the most relevant studies about BIM implementation, published in the last decade. Finally, key factors and an initial BIM implementation framework will be presented.

1.1 Background of BIM

What is BIM? A common question with numerous answers and definitions! BIM as a context is not a new phenomenon. In 1975 a building description system (BDS) was introduced by Eastman [1]. However, after popularity of the term “BIM”, several definitions and explanations for building information modeling have been introduced. For instance, Laiserin indicated BIM as a process and not a software [2], while, Woo described BIM as a new methodology for building design and documentation that provides faster and easier construction process for all involved parties [3]. Similarly, Penttilä defined BIM as a methodology but for managing the digital format of design and project data during the building lifecycle [4]. Furthermore, Eastman et al defined BIM as a technology that allows the building digital and virtual models to support design process phases by the accurate geometry and data. This not only will support the fabrication, procurement and construction phases but also will be used for other phases and activities of the building lifecycle. Thus, BIM can facilitate a form of integrated design and process that marks higher quality and reduces costs and time of the project [5]. Furthermore, in 2007 the US National Building Information Modeling Standard (NBIMS) defined BIM as “BIM is a digital representation of physical and functional characteristics of a facility” [6]. Azhar [7] expressed BIM as a pattern within AEC industry that can boost integration of all stakeholders on a project.

Although there is not a common consensus among researchers, software developers and practitioners, it is possible to distinguish an immediate difference between BIM as "modeling" and BIM as "a model". Nevertheless, BIM as a model can be derived a product of building information modeling. BIM as modeling is the process and the technology transition from a traditional single sequential form to a modern multiple parallel form of communication and data integration. In addition, building information modeling is the process of data distribution and data sharing with the ability to employ the data via numerous applications and tools for managing several multidimensional tasks and activities throughout the building lifecycle. A related point to consider is that in practice, current building information modeling and BIM software as well as BIM tools have their own limitations and challenges particularly for existing buildings and renovation that requires more research and development activities [8] [9].

1.2 Importance of BIM

There are familiar questions that the industry practitioners, specially contractors, ask such as "Why should we employ BIM?" or " What are the benefits of BIM?". In this section and through the next paragraphs, the BIM importance and its impacts on the building industry as well as its future use for the automation and robotics will be discussed.

1.2.1 BIM and the Building Industry

It is well known that the building industry is a late majority adopter or even the laggard adopter of new technologies, processes and methods in comparison with, for instance, the aviation industry. This lack of willingness to change, throughout the past decades, have created significant levels of time waste, quality decrease and profit loss as well as duplicating activities and repeating mistakes for the industry [7]. In addition, the construction industry has not been fully employing new innovative opportunities [10]. A very good example of the industry's hesitation to use the latest technologies, which is significant to be addressed, is BIM implementation, particularly, in the SMEs.

However, the building industry in general and the SMEs in particular demand for an effective and more integrated management during the initiation phase to the closing phase of a project. In addition, construction industry should seek for productive time, higher quality and fewer costs as well as try to avoid the parallel and unnecessary activities. Furthermore, eventually, the industry will ask for automation as unique solution to the lack of sufficient efficiency, mass production, labors and professional workers. Finally, the industry should intensely consider reducing waste materials and using recycled products and materials.

Although BIM has been introduced for years, for many the SMEs in the building and construction sectors BIM is yet to be recognized as a modern 3D software. On the other hand, BIM has several direct and indirect impacts on the building industry. Same as any other new technology, BIM brings advantages and disadvantages for its users. However, it has been confirmed that employing BIM will increase a firm's ROI (Return of Investment) which means more profit for the company in a long term [11]. Additionally, Barlish and Sullivan (2012) [12] developed a method for analyzing and quantifying BIM benefits, value, impacts and outcomes. The metrics, investment and cost, were tested against multiple cases on BIM based projects and traditional based projects. The results reveal that actual ROI varies depended on each project but for BIM based projects, there is a high potential of benefits. In addition, according to the NISB report, only in the national level, an estimated cost of inadequate data interoperability in the US capital facilities industry is approximately $15.8 billion dollars annually [13].

Furthermore, in a project level, the lack of interoperability increases costs of projects up to 3,1% of total project costs in the building industry [5] which is shown in Figure 1. Nonetheless, this is likely to be a small portion of the cost showing only the top of the industry's cost "iceberg". Consequently, it is not far from reality that the costs of inadequate and poor data management and interoperability consist billions of dollars of many countries' GDPs per year, globally. Furthermore, the study of using BIM in different stages of a building lifecycle shows that BIM is mostly used just in early stages and the use of BIM decreases while a project is progressing to the next stages. It is also found that BIM collaboration and process create positive impacts on projects. Also, clients as well as facility managers can benefit from BIM [14, 15].

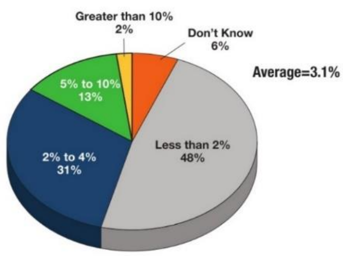

Figure 1. Total AEC/OM cost of non-interoperability, adopted from [5]

Thus, BIM is an essential technology for the future construction processes and the SMEs who have started to employ BIM will experience a higher level of competitiveness and technical improvements. Besides, BIM users will experience faster delivery, enhanced quality and efficiency in the projects [16] [17]. On the other hand, employing BIM requires new investments and some changes of the firms' organizational structure and culture [12, 18]. Possibly, in the long term BIM may change the industry's lifecycle management too. However, the indirect impact of BIM can benefit and help a wide range of other fields such as saving energy, waste materials, CO_2 emission and natural recourses and it can increase sustainability [17] [19].

1.2.2 BIM and Automation

The building industry is seeking potential solutions to the current problems. Problems such as high costs, traditional time consuming tools and methods, low quality, high waste, labor difficulties, high risk, inefficiency, low sustainability and low productivity [20]. Alternatively, the developments and innovations in the ICT, digitalization and automation sectors of the building industry are visible such as automated equipment and methods [21]. Thus, based on that, it is not out of imagination that inevitably the industry will employ more automated processes and automatic machines in the near future for mass production too. However, while BIM and digitalization are booming among the industry practitioners, automation and employing robotic technology as well as 3D printing are scaling. This will gradually motivate and seize attention of more contractors and innovation organizations who are active in the construction section.

On the other hand, dimensional control and identification are required for exploiting automation [22] and BIM can efficiently provide the required information and accurate data to be used for model simulation and machine control in construction automation and robotic construction. Therefore, BIM's importance and effects on the future usage of automation and robotics in the industry not only appear strong but also, in the long run, they are inevitable for the firms who are seeking to increase their competitiveness [20], productivity [23] and even their existence in the future era of the building industry.

1.3 Problem Statement and Aims

Regardless of considerable development of BIM based tools, still AEC/OM firms, particularly the SMEs, hesitate to employ BIM so its technical and financial benefits are not fully employed [16] [24]. On the other hand, according to the EU user guide to the SME definition, about 90% of enterprises and over 67% of jobs are generated by the SMEs. The SMEs include a broad category of companies from micro to small and medium-sized enterprises comprising less than 250 employees and a turnover of less than 50 million Euros annually [25]. Thus, due to the significant number, role and effect of the SMEs on the building industry in general and the construction market in particular, it is essential to address the issues, the BIM technology and its implementation framework to the SMEs.

The problem is that most of the active SME contractors are not aware of building information modeling, nor are they familiar with the BIM implementation framework and its key factors to increase their competitiveness. Thus, the main aim of this article is to provide the realistic key factors for an initial BIM implementation framework that can help the SMEs, who are working in the construction sector of the building industry such as contractors and sub-contractors, to understand BIM as modeling and employ it with less costs and more efficiency.

2 Methodology of the Study

This study is mainly based on a literature review on BIM implementation in the AEC sectors of the building industry with more emphasis on BIM adoption for contractors in the construction sector of the AEC/OM industry. In order to achieve the goal successfully, first the most related factors of a successful BIM implementation will be explored through the literature review from the past decade publications. Then a proposed solution as an implementation framework will be provided in order to increase the practitioners' general knowledge of BIM and the factors related to BIM implementation. This must be mentioned that likewise any other research, the framework is limited to and will focus on SME contractors in the construction section. Figure 2 illustrates the general view of the study structure including the problem statement, the aims, methodology and anticipated output.

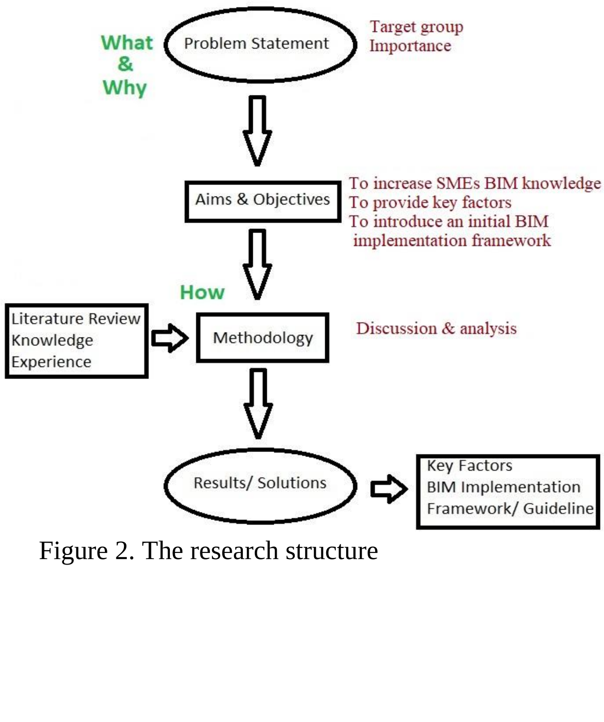

Figure 2. The research structure

2.1 Literature Review

To establish a related context of this study on BIM implementation, a selected literature review of the most relevant publications of the last decade of BIM implementation and adoption studies is provided. Table 1 illustrates a summary of the literature review.

In 2006, Brucker et al [18] offered a strategic BIM implementation plan for USACE (the U.S. Army Corps of Engineers) in order to improve the processes of design, planning and construction. The proposed BIM implementation plan, for the designing phase, is as follows:

- Gather up the current design team including the managers and the designers to define the current process and the responsibilities for the transition
- Assign a BIM team, including the design team and the lead technicians, to create and organize a BIM action plan including tasks, processes, metrics, expectations, BIM vision and team's needs
- Technical and organizational training by workshops based on the staff's role and responsibilities are required

Arayici et al (2009) [26] identified the BIM implementation challenges and factors by surveys in the UK and interviews in Finland with the construction stakeholders and academics. The study indicates that BIM implementation requests considerable changes of organizations and processes. However, in order to decrease resistance to change and build the process of implementation, training of BIM technology and BIM based tools are essential. This also, includes the change of redefining HR (Human Resource) system of the organizations, their responsibilities and the working processes. According to the study, the main challenges and barriers for BIM implementation are as follows:

- Lack of sufficient knowledge of BIM technology and BIM definition
- Unwillingness to employ the new technology and train/ lack of trained staff
- Lack of demand
- High costs of implementing that cannot cover the costs and make benefit
- Low rate of return of investment (ROI) which requires longer time to make BIM beneficial

Nonetheless, a paper published by Succar (2009) [27] describes an ontology of the BIM domain concepts and identifies the conceptual parts of BIM and main BIM activity fields. The main BIM activity fields are introduced as process, technology and policy that partially share deliverables (e.g. regulations, standards, construction products and services, software, hardware and equipment) and players (e.g. designers, engineers, contractors, manufacturers, technology developers, owners, operators, legal bodies, researchers).

In addition, Gu and London (2010) [28] conducted a FGIs (Focus Group Interviews) research study on the focused group of architects, engineers, contractors, BIM consultants, academics and software vendors for BIM adoption in the building industry. They found that besides various implementation levels, based on practical knowledge of BIM, there are mainly two types of issues as technical and non-technical that can affect BIM adoption and technology diffusion among the building industry. The technical issues comprise technical tools and software whereas the non-technical issues are related to work practices, strategies and processes.

Jung and Joo (2011) [29] addressed the variables for a BIM framework consisting of three main dimensions as BIM technology (dividing into four categories including standards, data properties, relation and utilization), BIM perspective (of industry, organization and project) and construction business function (design, contracts, estimation, scheduling, planning, materials, safety, quality, administration, finance, HR, cost control, sales and R&D).

Besides, Khosrowshahi and Arayici (2012) [30] provided a roadmap for BIM implementation in the UK to be used at operational and managerial levels. According to their suggestions, in BIM implementation, firms should consider three factors, including organizational culture, information management and training.

Following, Eadie et al (2013) [14] established an analysis of BIM implementation showing that BIM can be used throughout all stages of a building lifecycle. They found that the stakeholder collaboration aspect is the most effective factor following the process, as it is more important than software besides training. The two barriers are the lack of training and the industry experience of BIM. Takim et al (2013) [31] studied factors of BIM implementation in the AEC industry at two levels, the national level and organizational level in Malaysia. The study revealed several factors can create gaps for the implementation such as product limitation and interoperability, technical support and process change, economic demand and people acceptance, perceived usefulness and ease of use.

An analytical study by Miettinen and Paavola (2014) [32] presented that local experimentation, continued learning, standards and guidelines have a main role in BIM implementation. In addition, for BIM implementation, Morlhon et al (2014) [33] established an interaction model based on some critical factors such as reengineering business process, standardization, external stakeholders involvement, education whether technical and or information management as well as system selection process. Meanwhile, Peter Smith (2014) [34] examined the issues of BIM implementation in the construction industry. The results of the study show that leadership and government support, national and global standards, liability and legal issues, research, education and training as well as business impacts and opportunities have critical role on BIM implementation.

In 2015, Lindblad and Vass [35] investigated the changes, in three areas of product (model), organization (resources) and process (work practices), required for BIM implementation initiating in a large public infrastructure organization in Sweden. Furthermore, Son et al (2015) [36] studied the drivers of BIM adoption in design organizations of AEC industry aiming to examine the factors enabling the adoption process by the architects. What they found show that computer self-efficiency, top management support and subjective norms are the critical factors to make the adoption useful and ease for the architects. Risto Tulenheimo (2015) [37] introduced several key challenges and obstacles of BIM implementation generated by customers/ clients (demand, procurement skills and contracts), companies/managers (vision and strategy, management's will and competence, and ROI), organizational behavior (change resistance, education and training, project organization) and technologies (such as hardware, software) in Finnish construction industry.

Table 1. A summary from the literature review

Fields	Technology	Process	People		Organization		Policy
Factors/ equivalnt parameters	Tools (software & hardware)	Work process & team collaboration	Training & need (HR, organizatioan)	Resistance to changee	Investment (costs, ROI)	Risks & Challenges	Standards, Regulations, legal issues
Brucker et al, 2006 [18]	○	○	○			○	
Arayici et al, 2009 [26]		○	○	○	○	○	
Succar, 2009 [27]	○	○	○				○
Gu and London, 2010 [28]	○	○				○	
Azhar, 2011 [7]	○	○	○	○	○	○	○
Jung and Joo (2011) [29]	○	○	○		○	○	○
Eastman et al, 2011 [8]	○	○	○	○	○	○	○
Khosrowshahi and Arayici (2012) [30]	○	○	○	○	○	○	○
Eadie et al (2013) [14]	○	○	○				
Takim et al (2013) [31]	○	○		○	○		
Miettinen and Paavola (2014) [32]			○				○
Morlhon et al (2014) [33]		○	○			○	○
Peter Smith (2014) [34]			○		○	○	○
Lindblad and Vass (2015) [35]		○					
Son et al (2015) [36]	○					○	
Tulenheimo (2015) [37]	○	○	○	○	○	○	
Bui et al (2016) [38]			○		○		○
Cao et al (2016) [39]			○		○	○	
Hosseini et al (2016) [40]					○	○	
Ghaffarianhosein et al (2017) [16]	○	○	○		○	○	

Bui et al (2016) [38] studied the issues preventing BIM implementation in developing countries. The factors of current BIM adoption are mentioned as technical, perspective (including lack of standards and professionals, legal issues and governmental support) and construction business function (including unclear benefits of BIM). Cao et al (2016) [39] conducted a research on social and economic motivations for BIM adoption in construction industry projects in mainland China. They suggested that BIM users will experience more economic motivation while BIM is maturing. Also, there is relation between organizational ownership and BIM implementation motivations. Additionally, Hosseini et al (2016) [40] studied that the main obstacles to BIM implementation is the lack of clients' and subcontractors' interests and that the SMEs' key stakeholders recognize higher risk of investment and uncertain ROI. However, it is indicated that in Australia the main barrier is not lack of resources and knowledge.

Finally, in 2017, Ghaffarianhoseini et al [16] studied current BIM adoption, its benefits, risks and challenges. The study revealed that lack of adoption is due to factors such as cost, ROI, demand and interoperability issues (software, skills and experience). They suggest that in order to have a successful BIM implementation, firms need to invest in training, software, hardware, an internal process development and business development based on BIM technology. Table 1 shows a summary of the BIM implementation key factors adopted and or are equivalent from the literature review.

3 Discussion on the Key Factors

In order to understand the challenges and issues, we define fields and factors or equivalent parameters. Each field points a group of factors addressing challenges and essential needs that can affect BIM implementation. Although the BIM implementation studies show various approaches and viewpoints of challenges and factors by the researchers, the most cited factors can be divided into five main fields as people, technology, process, organization and policy. The first four fields are showing inner layer factors of firms and the policy field shows an outer layer field that indicates the influences that other organizations and enterprises can make on firms, such as policy makers and governments covering e.g. legal issues, national standards and guidelines.

Figure 3 shows the BIM implementation key factors distribution cited in the literature review and their frequent citations in percentage. The most cited factors are belonged to the organization field, the people field, the process field, and the technology field followed by policy field including standards, regulations and legal issues with 32%, 25%, 17%, 15% and 9% respectively.

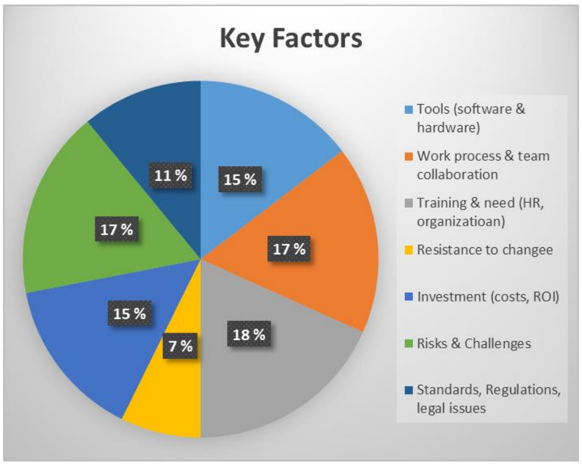

Figure 3. BIM implementation Key factors distribution

The people field includes training human resources (HR), organizational culture and change management issues. The factors of people are challenging parameters that can affect a successful adoption too. The process field is the roadmap of how the technology and people execute the activities and tasks. The technology field indicates the factors including tools, software and hardware. Without appropriate hardware and required software BIM implementation cannot be practically executed. Nonetheless, people, technology and process fields are parts of organizations that decision makers are involved with financial factors such as investments, costs and ROI as well as organizational risks, challenges of business changes and processes.

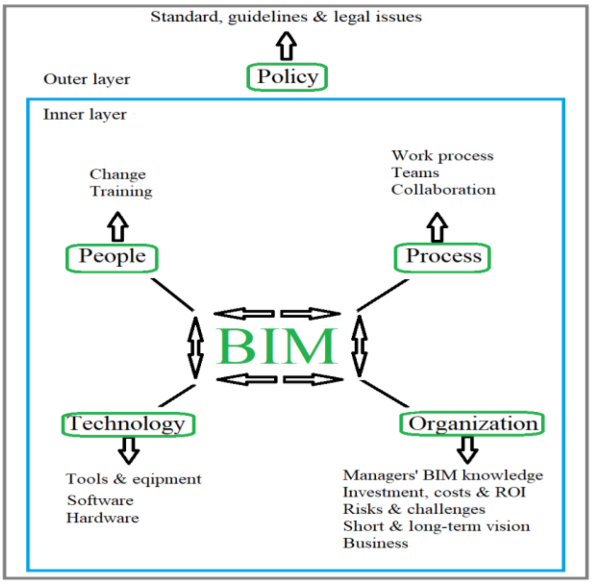

Figure 4. The key factors and BIM fields

Figure 4 illustrates how BIM is centered in the inner layer creating a common source and the outer layer as policy. However, the four internal fields are interconnected and can affect each other.

4 BIM Implementation Framework

BIM implementation is a complex process, due to the mentioned various factors being involved in the implementation process. This article attempts to point out the common aspects applicable to SME contractors. Regarding the similarities and differences between design, construction and service firms, the other firms, with some modifications, can also benefit the presented system to design their own frameworks.

Figure 5 shows an initial BIM implementation framework presented by this study for the SMEs. The framework consists of three main steps and each main step includes some sub-steps addressing challenges, activities, planning, communication, integration and collaboration under the fields of organization, people, process and technology. The first step consist two parts. The first part is targeting that managing directors, boards and shareholders of the SMEs fully understand BIM challenges and impacts. They are ready to change the firms' long-term strategy from the current form to an integrated form, invest in the BIM based business, and work model. The second part is related to the middle level mangers such as directors and managers of technical sectors, ICT sectors, business sectors and financial sectors. They are responsible for change management in their sections, addressing challenges, legal issues, security issues and discovering new business opportunities as well as short-term targets for the firms and assigning BIM teams.

The second step is planning step and the BIM team including current team members should analyze current processes of activities, human resources and tools in order to design new processes based on BIM technology and tools. This is crucial to communicate the progress of this step and send the feedbacks to the organizations for adopting and supporting new decisions aligned with the short and long-term strategies. This step also can benefit current available standards and guidelines for BIM implementation, depends on their availability.

The third step is piloting what has been planned in the second step. The output of second step supports people, process and technology to be employed in real work places. For instance, during bidding phase the teams can prepare quantity takeoff list (QTL) and cost estimation by the 3D parametric models and BIM based software instead of using traditional means. However, constructability and clash detection are feasible and an accurate construction plan can be obtained. In the execution phase, work activities, timetable and scheduling as well as site and risk management are considered more accurate by using BIM based project managing software and other tools like virtual reality (VR) and augmented reality (AR). For the monitoring phase tracking activities, verification and guidance are covered. In order to review and reorganize the involved processes, people and technology for each piloting step the feedback and results as well as challenges should be reported to the BIM team. The circulation of information, feedbacks and knowledge between the three steps supports the system to improve the framework and acquires more advantages from it.

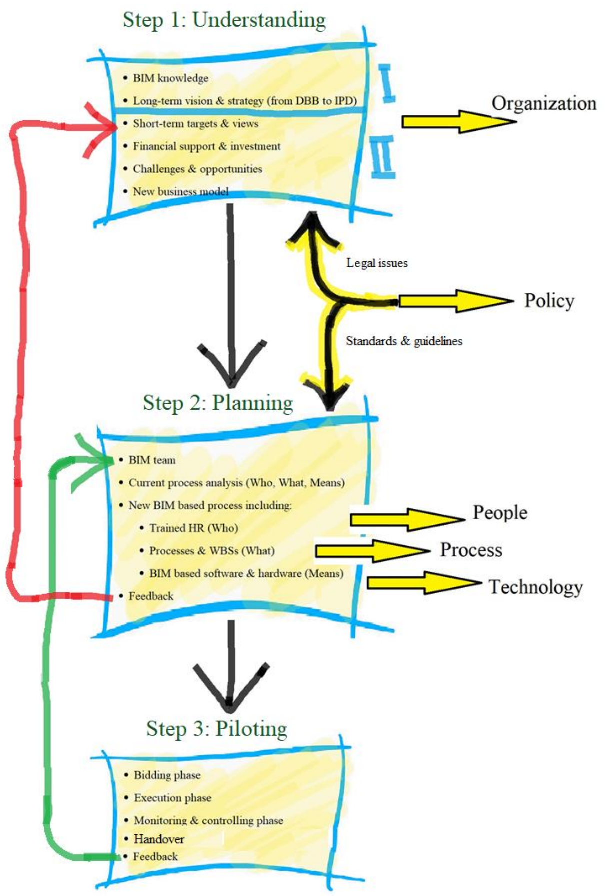

Figure 5. Initial BIM implementation framework

5 Conclusion

In this article, the authors have tried to define and introduce BIM as a modeling system, which can increase ROI and competitiveness of the SMEs and in the near future will be an essential approach and tool in the building industry. Additionally, BIM in the building industry and the current necessity of BIM implementation as well as the future role of BIM in automation and robotic construction were discussed. However, as the main aim of this article, a simplified initial implementation framework for SME contractors was introduced. The authors expect that this article to help the SMEs to understand BIM as modeling and employ BIM with less costs and more efficiency by knowing the key factors of the implementation framework and strengthening their competitiveness.

Finally, this study is limited to an initial BIM implementation framework for SME contractors and has not categorized the SME firms so as a future research proposal a more detailed investigation on the BIM implementation framework for different types of construction firms via real cases can be conducted.

Acknowledgment

The authors would like to express their gratitude to the director of civil engineering school of Oulu University of Applied Sciences (OAMK) Jyrki Röpelinen, the project manager Antti Haapalahti and all other members of the EU funded Interrg Nord project, ICNB (Increasing Competence in Northern Building), from Finland, Sweden and Norway for their general contribution during the meetings and workshops.

References

[1] Eastman, C.M., The Use of Computers Instead of Drawings in Building Design. *AIA Journal*, 1(1):46-50, 1975

[2] Penttilä, H., Describing the changes in architectural information technology to understand design complexity and free-form architectural expression. *Journal of Information Technology in Construction (ITcon)*, 11:395-408, 2006

[3] Woo, J.H. BIM (Building Information Modeling) and Pedagogical Challenges. In *Proceedings of the 43rd ASC National Annual Conference*, 2006.

[4] Laiserin, J. To BIMfinity and Beyond! (AEC Insight Column), Building information modeling for today and tomorrow. On-line: http://www.cadalyst.com/aec/to-bimfinity-and-beyond-aec-insight-column-3686, Accessed: 01/09/2017.

[5] McGraw-Hill, Interoperability in the Construction Industry, in SmartMarket Report. *McGraw Hill Construction*, 2007.

[6] NIBS, The National Building Information Model Standard (NBIMS). *American National Institute of Building Sciences*, 2007.

[7] Azhar, S., Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering*, 11(3):241-252, 2011.

[8] Eastman, C., Teicholz P., Sacks R. and Liston K., BIM Handbook - A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, 2nd Ed. *John Wiley &*

Sons, Inc., 2011

[9] Volk R., Stengel J., and Schultmann F., Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in Construction*, 38:109-127, 2014.

[10] Buehler M., 10 ways aerospace can shape the future of construction. On-line: https://www.weforum.org/agenda/2016/11/future-of-construction-lessons-from-aerospace/, Accessed: 15/01/2017

[11] Azhar S., Hein M., and Sketo B., Building Information Modeling (BIM): Benefits, Risks and Challenges. *The 44th Associated Schools of Construction National Conference, Auburn, AL*, 2011.

[12] 16. Barlish K. and Sullivan K., How to measure the benefits of BIM — A case study approach. *Automation in Construction*, 24:149-159, 2012.

[13] Gallaher M.P., O'Connor A.C., Dettbarn J. John L. and Gilday L. T., Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. *The USA National Institute of Standards and Technology (NIST)*, 2004.

[14] Eadie R., Browne M., Odeyinka H., McKeown C. and McNiff S., BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, 36:145-151, 2013.

[15] Motawa, I. and Almarshad A., A knowledge-based BIM system for building maintenance. *Automation in Construction*, 29:173-182, 2013.

[16] Ghaffarianhoseini, A., Tookey J., Ghaffarianhoseini A., Naismith N., Azhar S., Efimova O. and Raahemifar K., Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, 75: 1046-1053, 2017.

[17] Chong H.-Y., Lee C.-Y., and Wang X., A mixed review of the adoption of Building Information Modelling (BIM) for sustainability. *Journal of Cleaner Production*, 142:4114-4126, 2016.

[18] Brucker B.A., Case M. P., East E. W., Huston B. K., Nachtigall S. D., Shockley J. C., Spangler S. C. and Wilson J. T., Building Information Modeling (BIM): A Road Map for Implementation To Support MILCON Transformation and Civil Works Projects within the U.S. Army Corps of Engineers. *Engineer Research and Development Center, U.S. Army Corps of Engineers*, 2006.

[19] Eleftheriadis S., Mumovic D., and Greening P., Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities. *Renewable and Sustainable Energy Reviews*, 67: 811-825, 2017.

[20] Bock, T., Construction Automation and Robotics, in Robotics and Automation in Construction, C. Balaguer and M. Abderrahim, Editors. *InTech*. p. 21-42, 2008.

[21] Vaha, P., Heikkila T., Kilpelainen P., Järviluoma M., Heikkila R., Survey on automation of the building construction and building products industry. *VTT Report*, *Finland*, 2013.

[22] Vaha, P., Kansala K., Heikkila R., Kaisto I., Use of 3-D product models in construction process automation. *Automation in Construction*. 6: 69-76, 1997.

[23] Kamaruddin, S.S., M.F. Mohammad, and R. Mahbub, Barriers and Impact of Mechanisation and Automation in Construction to Achieve Better Quality Products. *Procedia - Social and Behavioral Sciences*, 222:111-120, 2016.

[24] Hosseini M. R., Banihashemi S., Chileshe N., Namzadi M. O., Udaeja C., Rameezdeen R. and McCuen T., BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model. *Construction Economics and Building*, 16(3):71, 2016.

[25] Europian Commission. User guide to the SME Definition. *Luxembourg: Publications Office of the European Union*, 2015.

[26] Arayici , Y., et al., Towards implementation of Building Information Modelling in the construction industry, in Fifth International Conference on Construction in the 21st Century (CITC-V). *Collaboration and Integration in Engineering, Management and Technology*, May 20-22, 2009, Istanbul, Turkey, 2009.

[27] Succar, B., Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3):357-375, 2009.

[28] Gu, N. and K. London, Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, 19(8):988-999, 2010.

[29] Jung, Y. and Joo M., Building information modelling (BIM) framework for practical implementation. *Automation in Construction*, 20(2):126-133, 2011.

[30] Khosrowshahi, F. and Y. Arayici, Roadmap for implementation of BIM in the UK construction industry. *Engineering, Construction and Architectural Management*, 19(6):610-635, 2012.

[31] Takim, R., Harris M., and Nawawi A.H., Building Information Modeling (BIM): A New Paradigm for Quality of Life Within Architectural, Engineering and Construction (AEC) Industry. *Procedia - Social and Behavioral Sciences*, 101: 23-32, 2013.

[32] Miettinen R. and Paavola S., Beyond the BIM utopia: Approaches to the development and implementation of building information modeling.

Automation in Construction, 43: 84-91, 2014.

[33] Morlhon R., Pellerin R., and Bourgault M., Building Information Modeling Implementation through Maturity Evaluation and Critical Success Factors Management. *Procedia Technology*, 16: 1126-1134, 2014.

[34] Smith, P., BIM Implementation – Global Strategies. *Procedia Engineering*, 85:482-492, 2014.

[35] Lindblad H. and Vass S., BIM Implementation and Organisational Change: A Case Study of a Large Swedish Public Client. *Procedia Economics and Finance*, 21: 178-184, 2015.

[36] Son, H., S. Lee, and C. Kim, What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions. *Automation in Construction*, 49:92-99, 2015.

[37] Tulenheimo, R., Challenges of Implementing New Technologies in the World of BIM – Case Study from Construction Engineering Industry in Finland. *Procedia Economics and Finance*, 21:469-477, 2015.

[38] Bui, N., C. Merschbrock, and B.E. Munkvold, A Review of Building Information Modelling for Construction in Developing Countries. *Procedia Engineering*, 164:487-494, 2016.

[39] Cao, D., Li H., Wang G., Huang T., Identifying and contextualising the motivations for BIM implementation in construction projects: An empirical study in China. *International Journal of Project Management*, 35: 658-669, 2017.

[40] Hosseini M. R., Namzadi M. O., Rameezdeen R., Banihashemi S. and Chileshe N., Barriers to BIM adoption: Perceptions from Australian Small and Medium-sized Enterprises (SMES). In *40th AUBEA 2016 conference, Radical Innovation for Built Environment*, 271-280, 2016.

[41] McGraw-Hill, The Business Value of BIM in North America Multi-Year Trend Analysis and User Ratings (2007–2012) in SmartMarket Report. *McGraw Hill Construction*, 2012.

[42] Deutsch, R., BIM and Integrated Design: STRATEGIES FOR ARCHITECTURAL PRACTICE. *John Wiley & Sons, Inc*, 2011