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BIM IN CONSTRUCTION PRODUCTION: GAINS AND HINDERS FOR FIRMS, PROJECTS AND INDUSTRY

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The construction industry strives to implement digitalization and Building Information Modelling (BIM). Studies of BIM in construction claim that a pronounced BIM strategy, knowledge of the subject and a willingness to change are important factors to succeed, but even when such conditions are in place, BIM implementation in construction production is scant and has limited impact. So how should the construction industry go from grand digital visions to practical application in reality? By identifying gains, obstacles and success factors on company, project and sector levels the paper aims to set out a road map for successful BIM implementation in construction production. Data sets, both qualitative and quantitative from eleven studies of using BIM in construction production, show that although the industry is making progresses in implementing BIM and digitalization, the full potential is far from realised. Specifically, the research presents an analysis of factors in relation to (1) strategy and innovation, (2) technology, (3) organizing, and (4) ecosystem. Conclusively, all these levels are strongly interdependent and need to be considered by adopting a holistic approach to reach an enhanced implementation.

Keywords: BIM, ecosystem, implementation, production, strategy

INTRODUCTION

The visionary idea of Industry 4.0 has been introduced to describe the trend towards digitisation, automation and the use of ICT in manufacturing. Despite the many promises and initiatives for improvements, the construction industry is far behind other industries, such as the automotive and mechanical engineering sector, in terms of integrating innovative technologies (Hampson *et al.,* 2014). Within the construction environment, Building Information Modelling (BIM) has been identified as the central technology in digitisation in the process of converting information from a physical format into a digital one (Oesterreich and Teuteberg 2016; Azhar 2011) and in efforts to increase digitalisation as to leveraging this process to improve business competitiveness. BIM can be defined as: “set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in a digital format throughout the building’s life cycle” (Succar 2009).

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Thus, BIM is both a technology and a process for project and asset management (Bryde *et al.,* 2013).

BIM can be applied from design to facility management, in processes of tendering, design, planning, construct, and use and maintain (Hartmann *et al.,* 2012), thus, involving different actors, including contractors, clients, architects, designers, subcontractors, suppliers, and facility managers. Hence, BIM encourage the integration of the various stakeholders (Azhar 2011), but in an industry characterised by a temporary project nature (Winch 2003), high fragmentation with numerous relationships among the many actors (Dainty *et al.,* 2001) and increasing complexity of projects (Chan *et al.,* 2004), integration appears to be the holy grail in the industry. In line with that, grand visions in relation to BIM implementation define a future state of enhanced collaboration and improved integration that in turn leads to improved performance and reduction of project costs, achieved over time.

Previous research point to benefits and challenges in the implementation of BIM. Improved profitability, reduced costs, improved time management and client-contractor relationships are brought forward, but also the legal pitfalls with proprietary and risk sharing that have to be regulated in the contracts, otherwise hindering successful implementation (Azhar 2011). The IFC interoperability is another barrier for BIM implementation in relation to collaboration between firms (Delgado *et al.,* 2017; Farghaly *et al.,* 2018). Furthermore, the absence of qualified staff delays the spreading of BIM in construction (Ho and Rajabifard 2016). Although exact numbers are difficult to calculate, comparing non-BIM and BIM projects shows tangible economic gains for the latter. In general, the total design costs increase, but at the same RFI reduction, reduced rework, schedule compliance, and decreased change orders lead to increased productivity and net costs savings (Chelson 2010; Barlish and Sullivan 2012). Other studies recognize the role of government policies as central for facilitating BIM adoption in the industry (Davies *et al.,* 2015).

However, besides a few exceptions (e.g. Oesterreich and Teuteberg 2016; Bryde *et al.,* 2013), research on BIM implementation beyond specific construction projects is scant (Davies *et al.,* 2015). Therefore, the paper aims to contribute to previous research by utilizing a data set of various actors, for example, contractors, consultants, and architects, from different firms in the Swedish construction industry in the exploration of BIM implementation. In line with this, the aim of the paper is to scrutinize obstacles, gains and success factors on company, project, and sector levels for understanding the co-evolution of BIM implementation.

Theoretical Considerations

BIM entails both technical aspects and processual working methods (e.g. Mondrup *et al.,* 2012), including how to cope with information content and exchange as well as business model features. BIM is thus able to manage the complex setting of different actors and their surrounding environments, but with challenging conditions of different hardware and devices as well as various needs and incentives for different actors to adhere to adoption, the road for increased implementation is not straightforward. In line with this, as to cover for the many aspects, several studies apply a socio-technical perspective in the scrutinization of BIM as to acknowledge a technological core (3D CAD, intelligent models and information management) with social layer components (synchronous collaboration, coordinated work practices as well as institutional and cultural frameworks). In order to asses and evaluate organizations' BIM implementation, various maturity models have been proposed

(Sacks *et al.,* 2018). The BIM Maturity Matrix (Succar 2009), for instance, offers a framework based on technology, process, policy, collaboration, and organization, with emphasis on differences between the organization's BIM capability and maturity.

Taking into consideration that BIM entails interdependencies between technological, process and organizational/cultural features, a theoretical lens is required that acknowledge BIM as an ecosystem where products, processes, organizations and people form a complex network (Gu *et al.,* 2015). BIM as a collaborative approach is thus contingent on how these various pieces fit together as to provide a comprehensive understanding of the systemic challenges. The ecosystem perspective acknowledges both the micro level of projects and organizations and the macro levels of industry and society, as well as the interplay between those levels, as a basis for understanding the patterns and co-evolution of BIM (Singh 2016).

Inspired by the socio-technical lens and the call for a holistic assessment of BIM as an eco-system, the research model from Bosch-Sijtsema *et al. (*2016) is utilized for exploration of facilitators and hinders for BIM implementation on micro and macro levels. This holistic research model is the result of a joint effort between industry and academia within the Centre for Management of the Built Environment in Sweden (CMB) as to guide research efforts and implementation strategies within the Swedish construction sector. Within the scope of the paper, the research model (see Figure 1) has two purposes: (i) to sort the factors of gains and obstacles in the data sets, and (ii) to analyse the interdependencies of products, processes, organizations and people in BIM implementation addressing company, project and sector levels.

Figure 1: Holistic research model to BIM implementation

METHOD

The data consists of qualitative interviews (n=114), observations and quantitative questionnaire data (n=183, mean response rate 31,3 %) gathered from 14 bachelor- and master theses supervised by the authors. The theses were carried out between 2011 to 2020, and cover a number of companies in Sweden, from medium sized to the largest contractors and consultants. All theses aimed to explore the implementation/lack of implementation of BIM in construction production. The data cover issues relating to project-, company- and in some instances sector level. Furthermore, in terms of actors the data cover the whole range from construction workers, engineers and different BIM- and management roles.

RESULTS

The result table below presents the analysed results of 14 bachelor- and master theses summarized in Tables 1 and 2. The analysis of the result has been done by using the holistic research model (see Figure 1) including four factors; ecosystem, strategy and innovation, technology and organizing, sorted into gains and obstacles connected to

BIM implementation related to company, project and sector levels. See Tables 1 and 2 for compilations of theses' results.

Table 1: Data from Theses. Gains/opportunities at company (C), project (P) or sector (S) levels

		Gains/opportunities * = potential gain, not derived from implementation	C	P	S	Ref.
Ecosystem	Standards	Turnkey contract gives opportunities for information flow *		X	X	2
	Laws, regulations, requirements	IFC requirements gives software interoperability *	X	X	X	2, 12
Strategy & innovation	Costs	BIM reduces paper drawings, saves money and environment	X	X	X	2, 11, 12
		BIM reduces time for understanding construction projects	X	X	X	2
	Productivity, performance	Earlier start of the building construction,	X	X	X	2
		Increased efficiency (less errors), e.g. it avoids reworks, BIM helps to stay within the budget of the project *		X	X	1,2,3 5,9, 10,12
		Accurate quantities can be taken directly from the BIM		X		5,10, 11,13 ,14
		Digital information and checklists in one place (efficiency)		X		10,11
		Up to 50% reduction of change orders	X	X		5
		Send information to produce rebar at the factory	X	X		5
		Construction cost control during design	X	X	X	5, 13
Organizing	Methods and processes	Better and common understanding, communication and collaboration between professionals and workers	X	X		1,2,5 9, 10, 14
		Knowledge transfer to the next projects	X			2
		Amount of information attainable is higher		X		1
		Specific BIM professions to support digitalisation in construction process	X	X		4, 6,7
		More accurate planning*	X	X		3
		Improved insight gives better plan and liability for workers		X		1
	Cooperation with BIM between firms	BIM for construction logistics: improved coordination*	X	X		3
		More flexible extraction of info (compared to drawings)		X	X	5
		Better understanding/interest among the different disciplines		X	X	5, 12, 14
		Model and design-review coordination	X	X		6, 12
Technology	Technological components	Tablets gives mobility and quality control possibilities		X		2
		BIM reduces visual conflicts and errors (clash detection)		X	X	2, 12
		ID numbers of BIM objects can be connected to timetables *		X		1
	Interoperability	Synchronized codes through the entire production chain *		X	X	2
		BIM software allows the integration of stakeholders'models		X		9, 12

Table 2: Data from Theses. Obstacles/hinders at company (C), project (P) or sector (S) levels

		Obstacles/hinders	C	P	S	Ref.
Ecosystem	Standards	Lack of standardization for codes/names	X	X	X	1, 2, 12, 13
		Turnkey contract needs to be updated to include BIM			X	2
	Laws, regulations, requirements	Need for industry standards on legal binding models		X	X	2, 8,9, 12
		Design-Bid-Build contracts complicated for BIM application			X	1
Strategy	Costs	BIM costs more money compared to traditional design	X	X	X	2, 11
		Consultants want a new payment model for BIM design	X	X		9
	Productivity, performance	Lack of case studies regarding efficiency/quality	X			1,2,5,8, 11, 12
Organizing	Methods and processes	Limited use of BIM for visualisation on construction site		X		2
		Quality of BIM is not good enough (lack of information for the construction site)		X	X	1,2,11,
		Use 2D-drawings and BIM lead to diverging information	X	X	X	11
		Lack of education, knowledge transfer and support on BIM for employees on construction site	X	X	X	1,2,4,5, 7-9,11, 12, 14
		No template system in work to organize the data contained within the BIM-model	X	X		2, 12
		Lack of dedicated time for employees to drive and practice BIM related issues and learning software use		X		1,4,11, 12, 13
	Cooperation with BIM between firms	Unfamiliarity with BIM professional roles	X	X	X	6,7,9
		BIM for logistics: different work methods cause loss/overload of information	X	X		3
		Clients lack in knowledge and in setting demands on BIM		X	X	5, 12
		Designers lack in skill on BIM requirements and design		X	X	5, 12
		Difficult to agree on a suitable level of detail in the model		X	X	5, 12
Technology	Technological components	Lack of supporting BIM in tablets and smartphones	X			2
		Difficult to take measurements in the model	X	X	X	5, 13
	Interoperability	Software/tools are un-user-friendly and complex	X	X	X	1,2,5, 11-14
		BIM is not automatically synchronized in software	X	X		1
		A lot of different programs for different disciplines		X	X	1,3,11
		Lack of filtering information for BIM objects		X		11

References for Tables 1 and 2: [1] Blomberg, 2019; [2] Norberg and Brantitsa, 2018; [3] Carlson and Kraemer, 2019; [4] Eklund and Galliher, 2018; [5] Götborg and Olsson, 2016; [6] Gunnemark and Heinke, 2014; [7] Hansson and Johnsson, 2016; [8] Landgren and Lys, 2019; [9] Motiejunas, 2016; [10] Sandahl and Sernemyr, 2018; [11] Westerlund, 2019; [12]Alassadi and Khallouf, 2020; [13] Josefsson and Lindhe, 2020; [14] Siahkalrudy, 2011.

ANALYSIS AND DISCUSSION

By sorting the factors of gains and hinders in BIM implementation in accordance to the first issue pointed to in the research model, some interesting patterns are revealed (see Table 2). Focusing on the identified obstacles in the theses' studies, consistency is observed regarding model quality, lack of education and on-site technical support, lack of user-friendly software, as well as interoperability problems (both at the software level and standardization level). Also, aspects of unclear professional roles and the common problem of falling back to traditional, non-BIM ways of working, during times of high pressure are identified. In addition, a substantial number of obstacles can be connected to the cost of implementing BIM together with the lack of sheer numbers regarding improved efficiency and reduced project cost. A recurring theme is that BIM is known to provide better communication and understanding within a project, but tangible, quantifiable gains its terms of actual costs are less easy to find (see Table 1).

The latter is especially interesting, as several examples contain concrete numbers/values for increased quality and reduced costs as outcomes of implementing BIM. Clearly, these benefits have not gained traction or obtained any notable visibility throughout the industry. The decision to and also the cost for implementing BIM commonly refer to the project level, wherefore it appears crucial to present these benefits at all levels in the organizations, and not only at strategic and top management levels. In addition to reduced cost, increased quality, production efficiency, as well as improved communication and understanding, several identified gains are connected to efficient re-use of data and automation, such as, automatic quantity take-offs and generation of reinforcement specifications. Furthermore, the theses highlight many additional gains that BIM can provide - but are currently not utilized - such as 4D planning, 3D site layout plans, and integration with logistics systems.

In general, discussions regarding digitalization within the construction industry are often synonymous with BIM implementation, which is not necessarily the case. For instance, digital checklists and issue management systems are reported as being very efficient digital tools, yet they are not dependent on BIM. Often these functions are part of different BIM-tools, such as Dalux, but they do not actually require the use of BIM but can be used together with traditional (digital) 2D drawings. As such, a clear distinction between digitalization and BIM has to be made. Mixing 2D and BIM in the same project is further recognized as a successful approach to ease the transition to BIM. However, at the same time, the availability of traditional construction documents enhances the risk of falling back to traditional working methods, which makes it somewhat a double-edged sword.

Furthermore, as seen in Götborg and Olsson (2016) there is the possibility to take BIM implementation to the fullest (i.e. no traditional 2D-drawings at all) with a successful outcome. As evident, obstacles still exist, however, without the possibility to fall back to traditional non-BIM ways of working, the projects are essentially forced to find new ways around these obstacles - ultimately leading to new and improved working methods. Taken together, analysis of the theses shows that several of the gains and/or obstacles have been identified by different organizations and different roles, wherefore taken together, the data set provides a representation of the state of the sector.

The second issue in relation to the research model concerns analysis of interdependencies of products, processes, organizations and people in BIM implementation addressing company, project and sector levels. No sequential or linear process is discovered in terms of that certain hinders must be overcome, before certain other steps can proceed. However, several interdependencies exist among the factors. Technology and organizing are strongly interdependent as technological components and interoperability must be in place as to reap the benefits of methods, processes and the different ways of working with BIM. In the same way, a high quality of technology cannot be exploited without the support and training of the people that are supposed to use the technology for their working methods. These two factors go hand in hand so to speak.

Furthermore, advanced and accurate technology in itself is not going to solve the many obstacles and hinders observed in BIM implementation, if not being adjusted to the specific needs of various organizations and the people within these organizations. This includes adjustments in relation to the purpose of using the technology, and the products that are used. For example, there is a better understanding among the different disciplines (e.g. carpenters, HVAC) by using BIM compared to 2D Model coordination, but still different work methods may cause information loss or overload. Furthermore, software and tools are still un-user-friendly with different programs lacking appropriate filtering information for BIM objects, thus, this is another example of the lack of alignment between people, products and technology in relation to the processes.

Many of the identified gains in terms of cost reduction and improved productivity and performance are also contingent on the alignment between technology and organizing, thus, the strategic potential for BIM also adheres to strong interdependencies among processes, people and technology. Thus, the fact that BIM costs more than traditional design, which is an obstacle observed on both micro- and macro levels, cannot turn into a gain by making BIM cheaper, but by providing more value when addressing with the interdependencies among technology, organizing and strategy and innovation. Thus, adjustments among these factors are more crucial, and shows greater potential than to direct all efforts into just one of the factors.

On the sector level, the lack of standardization, regulations and laws as to form an ecosystem where several organizations can connect, delays the adoption of BIM methods severely, especially in terms of no clear legal responsibility for the model as BIM is not a legal contract document. Instead, organizations invest their efforts in 2D drawing as they are the legal requirements. As such, the lack of consistency as to cope with the interdependencies among the macro level in the form of an ecosystem and strategy and innovation for organizations and projects on the micro level hampers BIM implementation.

CONCLUSION

Previous research identifies that in general, larger firms, particularly major contractors and/or public clients, operating on design-and-build basis are the ones that have led BIM adoption (Davies *et al.,* 2015). In practice, that may still hold true, however, successful BIM implementation is in fact contingent on numerous factors. Firstly, technology advancements - and thus the software vendors - is still a very important factor as both gains and obstacles can be traced back to the need of powerful and user-friendly BIM software, which has been lacking in the industry. Secondly, without implementing BIM to the fullest (i.e. no traditional 2D-drawings), projects always have a 'back-up' which allow them to retreat on traditional organizing in times of pressure or when obstacles emerge. Thus, taken together, utilization of advanced technology products and methods is interdependent with management processes that provide for and support implementation to its fullest. In order to reap the benefits of these technologies and processes, education, training and support of people as users of the technology are of outmost importance. As such, there is an interplay between the quality of technology and products, and the quality of the support for people.

Thirdly, also the various needs of different organizations when using BIM and accordingly, that technological components and interoperability are designed to diversify operability, appear crucial. Thus, the technology must be adapted to the purposes of using it, including how various organizations can align BIM to their working methods. However, coping with the interdependencies among product features, processes, people and technology, and achievements of alignment among them, is not enough per se in individual projects as to enhance implementation. BIM in the form of strategy and innovation processes for individual organizations is contingent on development of project methods to be applied in several projects. This is the only way the necessary investments of time, money and other resources can be justified.

Thus, how the interdependencies on the micro-level of companies and projects are dealt with appears most central for the perceived gains of increased BIM implementation, but also on how various companies and/projects exploit these opportunities. Finally, if laws and regulations hinder implementation or a lack of standards apply, hence, the macro level of the ecosystem is not in place, the spread of achievements on the micro level of organizations and projects will be hampered. Accordingly, alignment between the interdependencies among macro- and micro levels, and the technical and the social layers, is key in the strive for an increase in BIM implementation and enhanced use of BIM technology for project management processes. More specifically, by using a holistic approach, and connecting the ecosystem, strategy and innovation, organizing and technology factors, connected to BIM implementation related to company, project and sector levels, this study has shown that all these factors and levels are interconnected. It is therefore important to approach BIM implementation in construction production from a systemic perspective, including the potential in revising existent management processes, as to release the ability of Industry 4.0 visions.

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