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Measuring the effects of using ICT/BIM in construction projects

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Abstract

This paper focuses on presenting part of the findings from a research project completed in the period of 2009-2013.The research project was funded by the Danish Building & Property Agency with the primary aim to identify and measure the economic effects of using ICT/BIM in construction projects.

Firstly, this paper presents a conceptual evaluation method developed in order to define and describe how case studies focusing on use of ICT/BIM in construction projects could be completed in order to measure (both quantitatively and qualitatively) the effects achieved from using ICT/BIM in construction projects. In this context effects are defined both as tangible and intangible effects (both economically and non-economically) directly and/or indirectly as a consequence of using ICT/BIM in a construction project.

Secondly, the paper presents and analyses findings achieved from completing four case studies in Denmark, with focus on the method and how it effectively can be used to complete case studies documenting the effects of using ICT/BIM in construction projects. The case studies completed involved construction projects in which the participating companies were client consultants, architects, consulting engineers or contractors. Participating companies were of different sizes and construction projects were at different stages, including the design, construction and operation stage.

T*he findings presented in the paper are firstly that using the developed evaluation method to document the effects of using ICT/BIM in construction projects requires extensive efforts in documenting and tracing the contextual conditions for achieving the effects in order to fully understand the value of using ICT/BIM in construction projects. Secondly, the findings indicate that using ICT/BIM in construction projects has a significant impact on the processes completed in both design and construction and that an advanced field-study approach is necessary in order to be able to measure the effects.*

Keywords: Case Studies, BIM, Costs, Benefits

1 Introduction

As the use of ICT/BIM tools has become routine in the construction industry, it is increasingly evident that knowledge about how to document the effects achieved by using ICT/BIM in construction projects is necessary in order to effectively manage companies' and the construction industry's development and use of ICT/BIM. The Danish construction industry accounts for about 6% of the Danish GNP (2012 figures) equalling around DKK 75 billion (IDA, 2014). As there is always substantial pressure on the national government to improve productivity in the construction industry, it is crucial to fine tune in any way possible and the use of ICT/BIM in construction projects has been identified as one of the key tools to achieving this.

In this paper, ICT/BIM is defined as anything related to computing and communication technologies, such as hardware, software, the Internet, networks, wireless networks, cell phones or the people that work with these technologies. ICT/BIM also includes technology and working methods related to the concept of Building Information Modelling/Model.

This paper contains a presentation of a method to measure the effects of ICT/BIM in construction projects. Several such methods already exist, both generic methods and methods specifically designed for use in a construction context (Andresen 2002). Despite the existence of many methods, none of the identified methods fulfils all the identified criteria in the research project, of which the most important criteria are that the method (a) fits into the context of construction, (b) can be used on multiple levels of organisational structures, (c) focuses on a broad variety of costs, risks and benefits relevant to the construction context and lastly (d) uses an ex-post point of view.

For many reasons, measuring the effects of using ICT/BIM in construction projects is not easy, as a construction project is a relatively complex organisational structure with a relatively complex task. Furthermore, ICT/BIM affects a wide range of aspects within both construction projects and within the participating companies. Several dilemmas when measuring the effects of ICT/BIM in construction projects have been identified. These include (a) effects might accrue at several different levels of organisational structures at the same time, (b) effects achieved might not necessarily be directed at the initiating actor, (c) effects are not always realised at the same time as ICT/BIM is initiated and (d) many different types of effects are realised (and not all of these effects are measureable in economic terms). Each of these dilemmas might effectively wreck the output of the measurement process, if they are not taken into consideration when the measurement activity is conducted.

The ambition for the method is to produce reliable and traceable measurement results that give a realistic and complete overview of the effects of using ICT/BIM in a construction project and to provide the understanding of how ICT/BIM effectively improves the performance of a construction project. The evaluation method requires training within central aspects of evaluation such as how to identify effects and how to complete actual measurements of an effect in order to provide accurate and reliable measurements.

This paper gives a brief introduction to the developed evaluation method and presents the key lessons from using the evaluation method in a number of case studies. Based on this, the paper discusses the experiences learned and suggests how future evaluation methods and actual measurements of effects from using ICT/BIM in construction projects can be developed.

2 Preface and background

As a consequence of several reports, both national and international, stating that productivity in the construction industry has at best stagnated over at least a few decades (Erhvervsfremme Styrelsen, 2000), the Danish Building & Property Agency decided that a large development project called ‘Det Digitale Byggeri’ (abbreviated DDB) (translated: ‘the digital construction’) should be completed. The DDB project was completed in the period 2004-2006 and resulted in some guidelines for how the construction industry should use ICT/BIM in construction projects and particularly for how the initiators of construction projects (e.g. building owners/real estate managers) should make requirements on the use of ICT/BIM to their suppliers (e.g. architects, consulting engineers, contractors etc.) in a construction project. Initially, the requirement was directed solely at Government buildings, but later all public buildings and social housing were included.

A part of the ambition behind DDB was to increase motivation for the Danish construction industry to using ICT/BIM in construction projects and therefore a research project named ‘Måling af økonomiske gevinster ved DDB’ (translated: ‘Measurement of the economic effects of implementing DDB’) was initiated. The ambition of the project was ideally to both enable and complete actual measurement of effects from using ICT/BIM in construction projects. The research project was completed in the period 2010-2013. The overall main research priorities in the research project were to:

- develop an evaluation method to measure the effects of using ICT/BIM in construction projects
- complete a number of case studies in which the developed evaluation method was used
- document the effects of using ICT/BIM in Danish construction projects

The research project was completed by a research team consisting of five experienced researchers from the construction industry, the university environment within both economic research and research into management of ICT/BIM in construction in Denmark.

3 Research objectives, methodology and organisation

Explicitly, the research objectives in the project were to:

- develop a framework for identifying and measuring the effects of ICT/BIM in a construction project
- develop an evaluation method that quantifies/qualifies all identified effects achieved directly or indirectly
- use both economic and non-economic measures in order to express the effects
- produce results for use by experts and non-experts in the ICT/BIM area in construction
- examine the relationship to the contextual parameters that have a significant impact on the achieved effects.

The research methodology used in the research project is a classical hypothetical deductive-inductive approach in which the case study methodology played a major role in gathering the empirical data used to derive, induce and validate the reliability and consistency of the evaluation method.

A methodology protocol was developed as a framework for conducting the case studies, describing in detail the most central activities to be completed in the case studies in order to define the criteria to be met, to define/describe the tools to be used, and to specify the key processes/activities to be completed. Figure 1 shows the process diagram in the case studies.

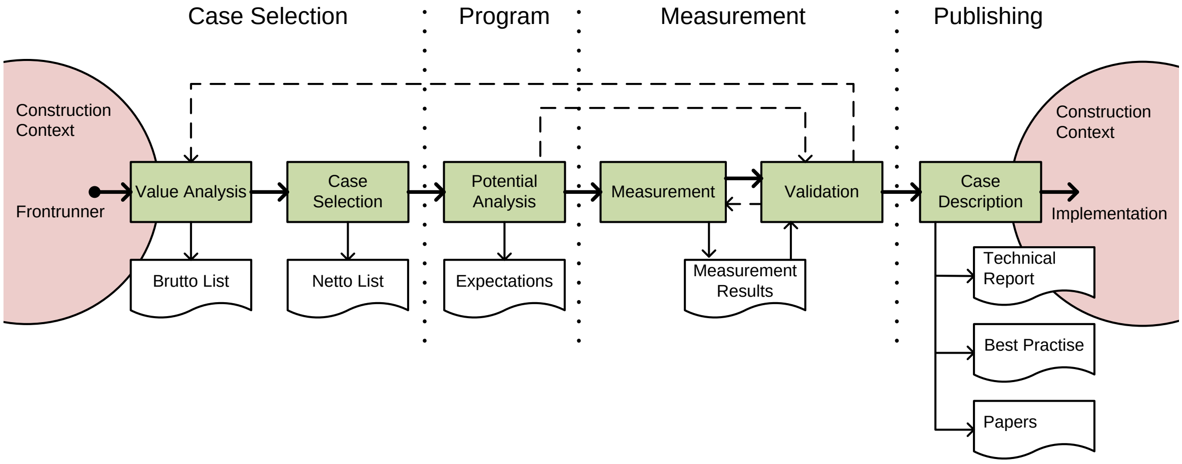

Figure 1 Process diagram showing the activities in a case study, from selecting a relevant case, analysing its potentials, measuring the effects, evaluating the results and communicating it.

The data gathering was primarily conducted by the same two researchers, whereas the case study analyses were conducted by a working group consisting of a group of experienced researchers. All data collected from the case studies has been verified and validated both by the information sources themselves and by an expert group consisting of a number of experienced external experts related to the construction industry.

4 Developing the post-implementation evaluation method

The research team started the project by identifying the 'state of the art' within the research field 'methods for evaluation of ICT', both in a generic context and in relation to construction. Many different approaches and methods for evaluation of ICT were found in this process (see also (Andresen, 2002)) and these were analysed in context to, among other things, identify the type of input required, the type of output from the method, the liability of data etc.

Thereafter, the research group started defining the most central characteristics and objectives which the evaluation method needed to fulfil in order to ensure that both the data collected and the outputs of the method had a high reliability and consistency. These characteristics and objectives were also to ensure useful outputs that can help companies in the construction industry to make objective and well-informed decisions regarding their investments in ICT/BIM.

The evaluation method was developed partly based on the knowledge and experience from the DDB development project and partly on reviews of existing literature on the topic, including the documentation of the methods 'Measuring the Benefits of IT Innovation' (Construct IT, 1998), 'Information Economics' (Parker and Benson, 1988) and 'Net Present Value' (a classical economic method among others described by (Brealey and Myers, 1988, Fox et al., 1990)).

The development of the evaluation method was completed in iterative steps. The initial step was to test the developed evaluation method on a single case study (involving a construction project), after which the lessons learnt and the experience achieved in the case study was used to fine-tune the framework and the evaluation method. Based on the updated evaluation method, a total of four full case studies were completed and documented in a following process. Minor adjustments to the evaluation method were implemented during the completion of the four case studies. As an output of the research work, both a documentation guide to the method and four case study reports were published (Vestergaard et al., 2011, Vestergaard et al., 2012d, Vestergaard et al., 2012c, Vestergaard et al., 2012b, Vestergaard et al., 2012a, Vestergaard et al., 2012e).

5 Central characteristics of using ICT/BIM in construction

A very important ambition in the development of the method was to be able to reflect the current context in a construction project in the evaluation. Eight different characteristics of a construction project's context are specifically addressed in the evaluation method. Each of these are briefly presented in the following (for more detailed descriptions of each of the characteristics see (Vestergaard et al., 2012e)).

A remarkable and unique characteristic of ICT is that it has the ability to affect multiple levels of organisational structures at the same time, as ICT often affects many aspects of the daily activities and operations performed in the context of a construction project. This includes both trends/paradigm shifts at construction industry level, the way the collaboration is conducted between the partners in a construction project, and the daily operations executed by the building-site worker on the site. For this characteristic, the method obviously needs to be able to cope with different levels of framing of effects achieved through the use of ICT/BIM. In order to define this characteristic, the research group defined five analytical levels of organisational structures (a) Society, (b) Construction Industry, (c) Construction Project, (d) Construction Company and finally (e) the various Construction Processes as depicted in Figure 2. These levels were also later represented as target groups for communication of results.

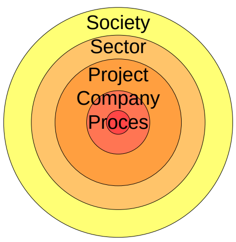

Figure 2 Level of framing. Diagram showing the different analysis and target levels. The effects are measured in processes in the individual company, but have implications at higher levels.

The level of framing in each evaluation has a significant impact on the type of data accessible to the case study and is to some degree essential for the choice of method useful for extracting the relevant data.

A fundamental characteristic of the evaluation method is to differentiate between different types of effects, as determining the generic type of effect also plays a major role when determining how to ideally measure the effect. The research group identified/defined four generic types of benefits and three generic types of costs (see also Table 1). Each type of effect is identified and measured by using an approach taking advantage of the special characteristics recognised as a part of the effect. The potential effect type differs from the other types by not necessarily being realized as the other types.

Table 1 Types of generic effects

Benefits	Costs
• Direct	• Direct
• Indirect	• Indirect
• Derived	• Risk
• Potential	

Although measuring the benefits is a very important part of measuring the effects of ICT/BIM in construction projects, it is also crucial to measure the costs, as there has generally been a tendency to underestimate the costs of ICT/BIM (Love and Irani, 2001). Measuring the costs is naturally equally as important as measuring the benefits.

Another central issue is that the generic types of effects are interrelated to the ICT/BIM context actually measured and that the measured effects cannot be interpreted outside their context.

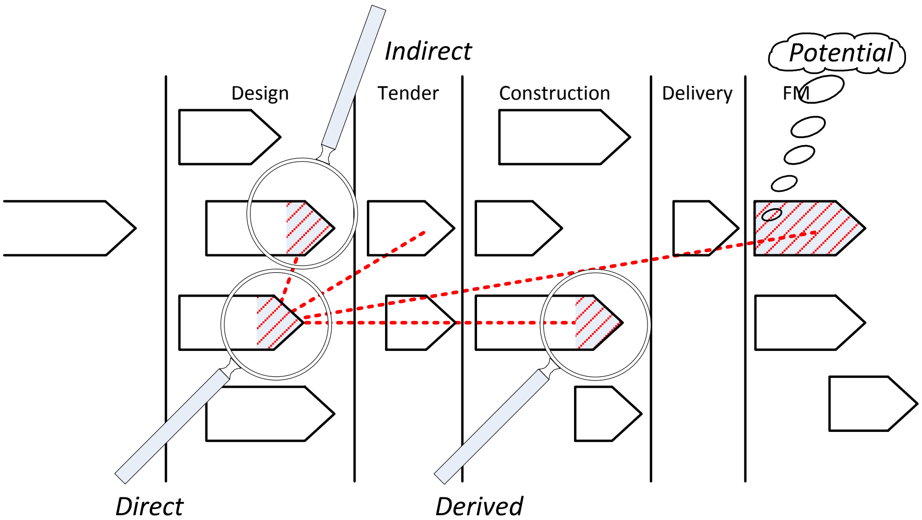

Figure 3 Types of effects. An ICT tool or a model-based approach can have a direct effect on a specific part of the process of the company. It may have an indirect effect in the second sub-process in the same company and have a derivative effect in a sub-process in another company.

A way of illustrating the different types of effects can be seen in Figure 3, where each type of effect is pictured in the context of both main business processes (vertical) and the stage of construction (horizontal). A central characteristic is that the different types of effects are defined by the stages of construction at which the effect is directed and by its occurrences in other business processes in the same company or in other companies in the project.

Another characteristic important to the construction context is the key activities conducted at each stage of a construction project. Using a framework to depict the BIM-oriented work approach used in the construction project, it is possible to identify which key activities are involved/affected by the use of ICT/BIM and to what extent.

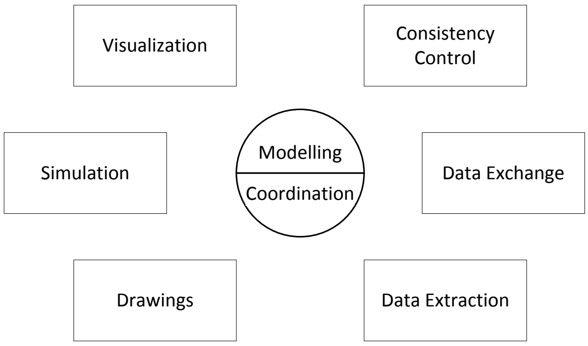

Figure 4 Key activities or main BIM uses

Through using Figure 4, it is possible to frame the central activities affected by ICT/BIM and to highlight which parameters need to be examined in detail in order to measure the effects achieved.

Measuring the effects of ICT/BIM in a construction project is much about examining the details of the cause/effect relationship of using ICT/BIM in the context of specific actions related to the construction project. Interpreting a measurement result in a meaningful way is impossible without knowing the details of the cause/effect relationship of the examined changes. During the data gathering in the case studies, the research group therefore spent much time on identifying, examining and discussing the logic models and the influential parameters of the cause/effect relationship of the different measured effects. Much learning has been extracted from completing this process, and this made it worthwhile to document the process.

An example of one of the outputs of these logic models/discussions was that the research group defined a concept called ‘information depth’, which is essentially a way of illustrating the point that information communicated by the sender may not necessarily be the same as the information perceived by the receiver of the information, as the contextual understanding might differ (see also Figure 5).

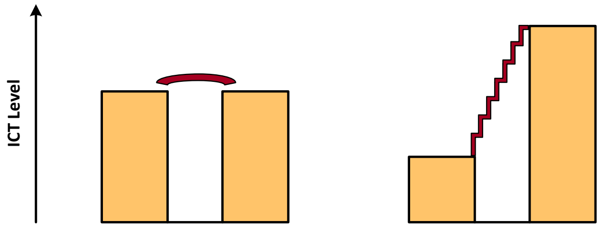

Figure 5 Illustrative example of consequences if the sender of information has respectively same or significantly different ICT level than the information receiver (Information depth)

A second example of a learning the research group derived from the examination of the cause/effect relationship from the case studies is that the magnitude of an effect seems to correlate with whether the use of ICT/BIM tools is integrated between the companies or whether they use their own ICT/BIM tools in the construction project. There is also correlation between the magnitude of an effect and whether the work processes are primarily internal activities or the work processes are completed as a result of a collaborative effort between two or more companies in the construction project.

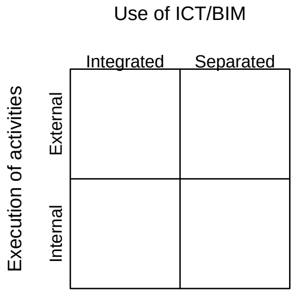

Figure 6 Conceptual relationship between the magnitude of an effect and the use of ICT/BIM as an internal or interorganisational tool and the execution of activities as an internal operation and as a collaborative effort between two or more companies in the construction project.

All four case studies positively confirmed the correlation as depicted in Figure 6.

An illustrative example on the cause/effect relationship of an ICT effect is seen in Figure 7. The key element in documenting the cause/effect relationship is based on identifying the core activity influenced by the usage of ICT/BIM – from this identification it is possible, respectively, to trace backwards by examining the necessity of prerequisites for completing the activity using ICT/BIM, and to trace forwards by identifying the actual accrued effects of using ICT/BIM.

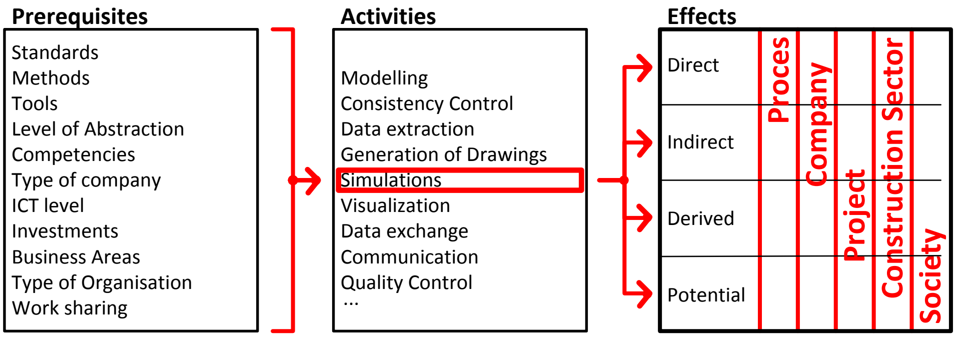

Figure 7 Example of a cause/effect relationship. A central issue is activities performed by new, model-based tools and methods, providing an effect. For this to be implemented, a number of prerequisites must be in place.

By mapping the context's influence on the measured effects, it is possible to interpret and hopefully understand the logic underlying the results achieved. Extracting learnings from this analysis will firstly enable conclusions on the generic relationship between effects of ICT/BIM in construction projects and the contextual conditions, and secondly it will improve understanding of the consequences of different actions and conditions on the effects achieved through using ICT/BIM in construction projects. Lastly, it will hopefully enable others to reproduce the effects of using ICT/BIM in a construction project in a more effective way.

Many contextual parameters have influence on the effects achieved from using ICT/BIM in a construction project. The importance of each of the contextual parameters will vary from case to case. However certain parameters are often referred to by other researchers (Farbey et al., 1993, Hochstrasser and Griffiths, 1991, Remenyi et al., 1995, Renkema and Berghout, 1997, Willcocks, 1994) – ICT level, BIM maturity level, ICT competencies, availability of tools, business area, types of organisational structure etc. Future research projects might reveal a clearer picture of the relative importance of each of the contextual parameters.

6 Framing the measurement of the use of ICT/BIM in a construction project

The key characteristic of the developed evaluation method is that it is based on a classical cost/benefit-method, which has been enhanced with a discounted cash flow analysis (like Net

Present Value) using some expanded definitions of what constitutes effects of the use of ICT/BIM in construction projects. This ensures that effects not easily measured in economic terms are also included as a central part of the measurement process.

An important part of the research project was to conduct a screening of potential construction projects to ensure that those with the highest potential were chosen as case studies. The screening process involved a couple of interviews with the key representative from each potential case study. The main objective of the screening process is to define the key contextual parameters such as type of ICT/BIM tool used, type of companies involved, construction stages involved and lastly and perhaps most importantly the likely access to useful data.

In total, four case studies were conducted as part of the development of the evaluation method. Each case study was individually selected with the aim that together the case studies should broadly be as representative of the construction industry as possible (see also Table 2).

Table 2 Main characteristics of the case studies

Case study	Main target group	Company size	Type of ICT/BIM	Type of construction project	Construction stages
Case 1	Architect	Small	ArchiCAD	Renovation of single family house	Design, Tender
Case 2	Consulting engineer	Large	Revit	New office building	Design, Tender, Construction
Case 3	Project management company/client consultant	Small	ArchiCAD and Vico Soft	Renovation of public schools	Tender, Construction, Delivery, FM
Case 4	Main contractor	Large	Revit	New office building	Design, Construction, Delivery, FM

The research group spent much time and attention on registering different contextual parameters that potentially had an influence on the measurement results. All registrations were made by the same two researchers and thereafter discussed and commented by the whole research group.

Special attention was focussed on examining the level of the ICT/BIM use by the involved companies, as the research group had a hypothesis that the level of a company's ICT/BIM use has a significant impact on the effects achieved (Willcocks et al, 1998). The construction sector is primarily project-driven, with many different roles/companies, meaning that registering ICT/BIM use in the construction project is very complex. This is partly defined by the ICT/BIM use in each of the participating companies and partly by how the construction project's management level fulfils its role with regards to ICT/BIM management. The research group therefore decided to define and use a concept that can represent this complex relation using two distinctive dimensions (a) model complexness and (b) model collaboration.

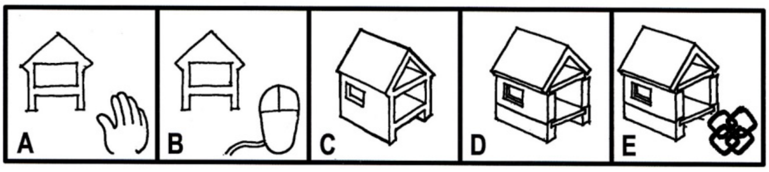

Figure 8 A 'BIM model complexness' scale going from A-E. A represents hand-drawn models, B represents a digitally drawn representation of the project. C represents a digital model consisting of flat objects. D represents a digital model consisting of objects with properties. E represents a digital model with objects and their properties using buildingSMART's standards

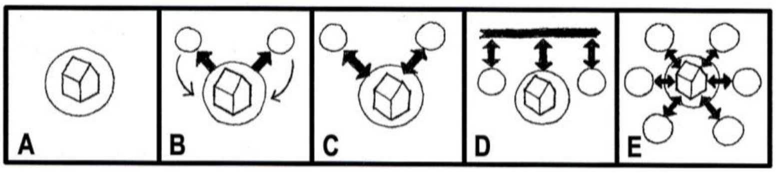

Figure 9 A ‘BIM model collaboration’ scale going from A-E. A represents a single model representing the project. B represents digital extraction of data from the single model – adjustments/requests for changes are communicated orally. C represents digital extractions and adjustments/requests for changes. D represents the use of several models, each representing a professional viewpoint of the project. E represents the use of a central model containing/combining the necessary models with each of the professional viewpoints in the project.

Figure 8 and Figure 9 display two significant characteristics (respectively BIM model complexness and BIM model collaboration), of which different levels (A to E) of the characteristics have been identified as central to describing the use of ICT/BIM in the construction project. The two characteristics in combination will define the overall level of ICT/BIM use in the construction project, but it might be necessary to differentiate and specify the level of ICT/BIM use within each participating company individually in the construction project, as differences between the participating companies’ level of ICT/BIM use have a significant influence on the total effects achieved.

An issue particularly difficult to get a firm grasp of is determining the scope of each identified effect. Most effects are relatively easily identified when related to the company and process level, whereas effects on both project, sector and society level are much more difficult to identify and measure for various reasons but predominantly because these levels represent higher abstractions by nature.

A significant and often difficult challenge to overcome in measuring effects from using ICT/BIM in a construction project is to define and use reference data with which to compare the measured effects. The measured effects are not essentially useful if they are not referenced to a defined base level of the measured activities. Two possible solutions to this problem were used in the case studies. The first solution was to ensure that all the data used in the measurement activities was, whenever possible, defined with respect to a well-known reference level. The second solution involved interviewing the key resource person responsible for the process about the consequences for the processes if the ICT/BIM was not used.

In order to conduct the actual measurement of the quantifiable effects, each identified effect was individually analysed in order to fragmentise its determining components into measureable parts. Thereafter, each measureable part was quantified using a multitude of reliable and verifiable sources such as project documentation in the form of models, drawings, extracts from project databases, spreadsheets, reports (both in digital and analogue forms) etc. In those cases where no reliable and objective sources were available for quantification of the measureable part, an (as precise as possible) estimate was extracted through interviews with key resource personnel related to the actual work processes in focus. Examples on measurement parameters are for instance (a) time savings on drawing production, (b) better production planning on building site and (c) fewer stops in building site production.

Even though the research group invested extensive effort on quantifying the effects, not all identified effects can be quantified, which resulted in that the remaining effects were simply rated by the selected representatives from the construction project using a scale from A to D (where A was the highest and D the lowest).

Lastly, the identified risks were quantified by the relevant representatives from the construction project through using a scale from A to D expressing the influence on the effect of using ICT/BIM in the construction project.

7 Discussion of the usefulness of the evaluation method

A significant learning from using the evaluation method on the four case studies was that most effects can be evaluated using relatively simple measurements. The difficult part is to divide each effect into measureable parts, which, in combination, constitute the effect. Few effects are directly measureable, partly because most companies do not collect this type of data directly, and partly because data that is collected as part of the companies' activities is not useable as it is collected with another purpose e.g. billing, marketing etc.

Construction activities are typically located or organised in construction projects, whereas economics and financial aspects are typically handled in the host companies. Many conflicts arise from this because of cultural differences between these two setups e.g. a temporary goal-orientated activity designed to produce a unique product or service versus continuous goal-oriented activity designed to produce products or services in an equal/specified manner. This challenge is partly related to the previous problem, as most data collected has a company perspective which results in the temporary project-orientated culture in a construction project rarely fitting into the premises on which the data is collected.

A major challenge experienced with respect to measuring the effects is that there is often a time difference between the actions enabling the effect and the realisation of the effect. The research group experienced on several occasions that the effects identified and measured were consequences of actions completed in another construction stage or by another stakeholder. This does not necessarily have to be a problem from an evaluation perspective, but it makes it rather difficult to measure the effects, as the logic relation between cause and effect may not always be evident. For example, actions completed by the architect (for instance construction of a BIM model) often generate effects for the contractors (who may be able to conduct a better production plan based on using the architect's BIM model) or that the building owner can reduce the cost of maintenance (through using the BIM model to extract more precise data on surfaces and square meters).

One important factor to be aware of when completing ICT/BIM evaluations is that, although one company in the construction project might realise a positive effect, it is also necessary to identify whether the effect actually results in a negative effect for one of the other companies in the construction project. In this situation, viewing the case within a construction project point of view will mean that the overall effect is zero as productivity has not changed. The same interrelated logic can potentially be found within the other levels of scope, and this is why the real positive and desirable effects effectively in most cases are achieved through either efficiency improvements or through developing new opportunities such as new services/products.

8 Conclusion

Conducting measurements of effects of using ICT/BIM in a construction project are not easily done as there are many potential pitfalls to be avoided. ICT/BIM is effectively influencing a vast number of activities and processes and stakeholders at many levels of construction, which among other things makes it difficult to focus the evaluation on the most influential activities and processes.

The presented evaluation method is developed through an extensive iterative development/testing process, in which four case studies were central. In each case study the focus was on a single and specific construction project where multiple activities/elements were examined involving e.g. building owners, architects, consulting engineers and contractors.

The complexity of measuring effects achieved using ICT/BIM in construction projects is difficult to tackle and requires evaluation skills (both practical, theoretical and analytical) and an advanced evaluation method, that is able to cope with evaluation on different levels of scope and with focus on different types of effects.

The research group spent much time on developing a useful evaluation method containing descriptions of necessary prerequisites for achieving effects that ultimately will generate knowledge in terms of a quantification of the effects and in terms of better knowledge/understanding the premises for the use of ICT/BIM in construction projects. This will in the longer perspective provide an opportunity to make better decisions on the use of ICT/BIM in construction projects that potentially will ensure a better productivity development in the construction industry although the use of ICT/BIM in construction projects is only a relatively small fraction of what constitutes the premises for a growth in productivity in the construction industry.

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