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Looking at the big picture of IS investment appraisal through the lens of systems theory: A System Dynamics approach for understanding the economic impact of BIM

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ABSTRACT

Despite the fact that Building Information Modelling (BIM) is one of the most promising technological developments for the architecture, engineering and construction (AEC) industry, the body of literature addressing its financial implications on corporate level is still limited. Therefore, we propose a quantification model that is based on design science research and provides an enhanced understanding of cost and benefit implications arising from BIM investments from a systems theory perspective. The quantification model developed in System Dynamics (SD) is based on a literature review as well as a case study, whereby the socio-technical nature of BIM, its various tangible and intangible benefits as well as its multiple impact levels on the corporate system are taken into account. The results of our simulation experiments within the scope of the case study reveal that the interplay of costs and benefits of BIM with the subsystems of the organisation is manifold, which results in a long-term improvement of the company's economic performance. Through the lens of systems theory, the financial impacts of the BIM investment can be examined by integrating all costs and benefits into the subsystems of the organisation and by investigating their interplay on system level rather than treating them as isolated system elements.

1. Introduction

With the advent of digitisation initiatives like Industry 4.0 or Industrial Internet, companies from across all industries are increasingly confronted with the question whether or not to invest in new technologies. While the trend towards digitisation has shaped most industries over the past decade, the manufacturing environment of the construction industry is still characterised by a large amount of manual and repetitive tasks, paper-based processes and a high level of fragmentation [1]. Within the scope of Industry 4.0, digitisation technologies that optimise the processes within the entire construction value chain are being promoted. In this context, Building Information Modelling (BIM) is considered as one of the central technologies for the digitisation of the construction environment, as it efficiently enables collaboration and communication among project participants throughout the whole project lifecycle [2].

Notwithstanding the given maturity of BIM as well as the recognised benefits associated with its adoption, many construction companies still hesitate to invest in BIM [3,4]. The lack of clearly defined financial implications is mentioned as one of the main barriers to a widespread BIM adoption [5]. Hence, the provision of methods for estimating costs and benefits can help companies to overcome this barrier. Although there is meanwhile a large body of literature addressing the benefits of BIM [3,5–7], little guidance is provided on how these benefits can quantitatively be measured to evaluate the overall financial impact of BIM on corporate level prior to making the investment decision. Instead, literature in this area predominantly refers to the ex-post assessment of BIM on project level [3,8] where the real economic impact of BIM on the entire organisation cannot be captured as a whole. Apart from this gap, another important question that has to be answered is how intangible benefits of BIM can be made measurable. Regarding the complexity of real-world corporate system environments, it is further necessary to take into account the interrelations between the costs and benefits of BIM as well as their financial impacts instead of conducting simple linear calculations. Irrespective of the fact that BIM constitutes an interdisciplinary research area at the interface between various disciplines, such as information systems (IS), construction informatics (CI) and construction management (CM), it has attracted only little attention in mainstream IS research regarding the low number of publications in IS academic journals and conferences. The various research streams to date have mainly established BIM as a research area within engineering disciplines with a highly technological focus [9].

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Given the high relevance of BIM as one of the most promising technological developments for the AEC sector [9,10], the lack of interest in IS research is surprising. This mismatch prompted researchers to appeal to the IS community to strengthen its contribution to BIM research [9].

Over the last decades, several researchers from the IS domain have provided a comprehensive overview of common methods for the evaluation of IS investments [11–13]. The body of literature in this area describes the cost-benefit analysis (CBA) as a financial appraisal method with focus on the quantification of costs and benefits [11,13]. In this paper, we aim to apply CBA as a method for the financial appraisal of the BIM investment. More specifically, we propose a novel quantification approach that provides an enhanced understanding of costs and benefits of BIM from a systems theory perspective to take into consideration the dynamic and holistic impact of BIM on the corporate system environment. Based on the design science research approach according to Hevner et al. [14], the quantification model is developed by addressing these specific research questions:

1. *What are the costs and benefits associated with the adoption of Building Information Modelling (BIM) at corporate level?*
2. *How can the complex interrelations between benefits, costs and the elements of the corporate system be identified and visualised more effectively prior to quantifying the overall economic impact of BIM on corporate level within a cost-benefit analysis (CBA)?*

Adding to the body of knowledge, our paper is a first step for assessing and understanding the complex economic effects of BIM investments in the specific context of the construction domain. Therefore, the remainder of this paper is structured as follows. We begin by describing the applied research method in detail. Subsequently, we outline the theoretical foundation on which our research is built as well as previous works addressing the costs and benefits of BIM. A design analysis is then conducted in order to develop a cost-benefit analysis framework of BIM. Based on this cost-benefit analysis framework, a quantification model is developed and evaluated within a real case study. The quantitative analysis is conducted by means of System Dynamics Modelling including probabilistic sensitivity analyses. Finally, a discussion of the results as well as concluding remarks are provided.

2. Research methods

The ex-ante evaluation of IS investments by means of a CBA consists of a set of required steps. We aim to combine these steps with the principles of the design-science paradigm to create a solid methodological basis. By constructing and evaluating IT artefacts, design science focuses on providing innovative or more efficient solutions for organisational problems [14,15]. In this paper, we address the problem of quantifying costs and benefits for BIM investments by developing an assessment framework as well as a quantification model for the financial assessment of the BIM investment. According to Hevner et al. [14], our final IT artefact can be characterised as a model. As such, the artefact is not only focused on representing a real world situation, but rather on enhancing the understanding for the problem and the provided solution [14]. Given these considerations, the development process of the artefacts encompasses the following research phases according to the framework for conducting cost-benefit analyses recommended by Sassone and Schaffer [16] and the guidelines provided by Hevner et al. [14]:

2.1. Phase 1 – problem definition

As illustrated in Fig. 1, the starting point of the CBA is the definition of the problem, consisting of a detailed description of the investment scenario. Capturing the unique features of the IS investment is thereby decisive for the further course of the evaluation process [16]. This step is carried out in the motivation section. Additionally, the examination of the body of literature (e.g. theoretical background and related work) by means of systematic literature reviews uncovers research gaps, confirms the relevance of the problem to be solved *(guideline 2*) and emphasizes the importance of our research contribution (*guideline 4*).

2.2. Phase 2 – design analysis

Based on the BIM investment scenario, in this phase, the analytic structure of the CBA is developed. More specifically, all costs and benefits associated with the BIM investment are identified. In order to ensure that our artefact allows for an economic assessment of BIM investments (*guideline 1*), we combine relevant current knowledge with basic practical requirements so that the artefact can be applied in a new and innovative way (*guideline 4*). Furthermore, the design process of the artefact is conducted by means of established scientific methods *(guideline 5)*. Based on the outcomes of the systematic literature review [17,18], an assessment framework is designed.

2.3. Phase 3 – quantitative analysis

As models tend to be complex and often are based on constraining assumptions, simulations can help to study the model and its validity [19]. In this paper, the simulation method of System Dynamics (SD) is applied based on collected data from a real case study as well as other parameter settings and assumptions. Additionally, risk assessment steps consisting of Monte Carlo simulation runs are included into the quantitative analysis in order to take into account the impact of uncertainty. The modelling process is conducted by means of the multi-steps approach provided by Coyle [20].

2.4. Phase 4 – presentation and validation of results

This phase includes the iterative process of evaluating (*guideline 3*) as well as the subsequent redesign of the artefact (*guideline 6*). The evaluation is carried out by applying the quantification model to the real case study through simulation experiments. Several researchers recommend this approach as a suitable evaluation method for verifying the practicability of artefacts in a real case setting [14,21,22]. During the evaluation process, we redesigned the model when the simulated behaviour of the system did not seem realistic or led to unrealistic results. For example, in the first version of the model we only incorporated one variable for the company's staff. However, in order to capture a more realistic picture of the cost structure, we changed this to three different groups of employees, namely "staff (workers)", "administrative staff" and "management members". Being aware of the fact that the results gained from single case study research are often criticized as not generalizable [23], we did not aim at receiving generalizable empirical results when applying case study research. Rather, we intended to prove the suitability of the constructed artefact and to demonstrate that the artefact actually can be used as a solution for the organisational problem [21]. The final presentation and dissemination (*guideline 7*) starts with the discussion of the research results and their further application within other case studies.

3. Theoretical background

3.1. Systems theory and system dynamics

General systems theory was originally developed by Ludwig von Bertalanffy in 1928 as an attempt to propose a universal approach to all sciences [24]. According to general systems theory, a system is composed of interrelated elements with nonlinear relationships. This view challenged the basic principles of classical science according to which a system consists of a set of isolable elements with linear relationships [25]. Our paper applies general systems theory as a framework to