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Aligning building information model tools and construction management methods

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ABSTRACT

Few empirical studies exist that can explain how different Building Information Model (BIM) based tool implementation strategies work in practical contexts. To help overcoming this gap, this paper describes the implementation of two BIM based tools, the first, to support the activities at an estimating department of a construction company and the second, to support risk management activities on a large infrastructure project. Using the cases, we illustrate that it is possible to closely align the functionality of existing BIM based tools with specific and well established construction management work processes. In this way, we illustrate that it is possible to implement BIM based tools in construction organizations in a "technology pull" manner. With these findings, we complement existing implementation theories in construction management that advocate "technology push" implementations during which existing work processes need to be radically changed to align with the functionality of the BIM based tools.

1. Introduction

The introduction of building information model (BIM) based tools to support the work of construction management organizations is still a problematic task in practice. It is not surprising, that many researchers have tried to address the problem by trying to explain why and how implementations were successful or unsuccessful. Influenced by Rogers' [1] diffusion of innovation theory this existing work mainly analyzes technology implementations from a technology push view. These views mainly proliferate the vision to use BIM to best support as many business processes as possible across all different organizations that are involved throughout the life-cycle of a building project [2,3]. It is not surprising that most of the prior work has identified the loosely coupled structure of the construction industry [4,5] as the main barrier for implementation. As a solution, these authors suggest that project teams need to align their work processes to the new "collaborative and integrated ways of working" that BIM based tools require [2]. The argument that follows from these assumptions is then that a top-down technology-push implementation is necessary to successfully change construction organizations and, in turn, to allow for the meaningful use of BIM based technologies [2].

Within practical BIM based tool implementation settings this top-down view is limited as it is seldom feasible to significantly change existing work processes to enable the implementation of new technologies. This is mainly because the working practice of construction project management teams are already well structured around generally accepted construction project management practices. For example, projects all over the world, whether they are small or large, use formal critical path scheduling techniques to estimate project duration or structure cost estimates into cost categories using generally accepted work breakdown structures of the physical project work. Hence, in practical settings, technology pull implementation perspectives that focus on the possibility to align existing BIM based tools with current work practices might be complementary to the prevailing technology push implementation perspectives.

To further the above notion, this paper provides case based evidence for the benefits of a technology pull view and for its practical feasibility in "real world" BIM based tool implementation settings. To do so, it describes the BIM based tool implementation effort of two construction organizations. The first case focuses on the support of cost estimating activities with BIM based automated quantity take-offs. The second case focuses on the support of project risk management activities with BIM based 4D models — a BIM based technology that allows the visual simulation of planned construction activities over time. Both cases illustrate well that it is possible to align organization and technology by gaining an in depth understanding of the underlying project management methods that guide the operation of a project team and by aligning the existing functionality of BIM based tools with these methods. In this way, the paper's findings

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not only show that it is possible to align the functionality of BIM based software applications with generally established project management based working methods, but also that implementations from a technology pull perspective can be successful.

The paper is structured as follows: it starts with a review of the existing BIM literature with respect to technology implementation and theory in construction settings. After this review, the paper then describes the action research methodology that we applied during the case studies and how we supported, but also traced the implementation of the technologies on the two cases. The paper then continues with an in depth comparison of the technology pull based implementations on the two cases. We then discuss these findings in light of the existing theories and develop a number of practical recommendations for practitioners that want to implement BIM based technologies. The paper concludes with a number of limitations of the here presented work and with a brief outlook.

2. Views on BIM based tool implementation efforts

"Building information modeling (BIM) is a digital representation of the building process to facilitate exchange and interoperability of information in digital format" [6]. In this way, the implementation of BIM in construction practice promises to improve the communication and collaboration between participants through higher interoperability of data [7]. However, to implement BIM on a construction project, practitioners need to configure and align BIM based tools, project work processes, and the business models of the companies that work together on a project [8,9]. Currently, there is little practical knowledge available to support practitioners with this necessary configuration.

To overcome these practical problems, several authors have developed different "views" on a BIM implementation with the intention to help practitioners to understand what BIM could mean within a specific implementation context. Some of the most widely suggested views are:

- BIM technology dimensions, i.e. categorizing a BIM implementation according to its soft- or hardware [10–12]
- industry level dimensions, i.e. whether a BIM implementation occurs at the industry, company, or project level [10],
- construction business functions, i.e. what function the BIM implementation should serve in the context of a construction project or for a construction firm [2,10,11]
- implementation maturity dimensions, i.e. how advanced and routine a BIM implementation is [13],
- and policy and regulative dimensions, i.e. what are the regulations and standards related to the implementation [13].

While these views certainly offer practitioners a guiding hand to manage a BIM based tool implementation, their developments, so far, have been purely theoretical endeavors with no or little empirical data that illustrated the application of these views in practical contexts. Another problem of these views is that they describe BIM based tool implementations from a top-down perspective focusing on technical and organizational dimensions at a very high level.

Such top-down views can help to strategically understand and draft large scale BIM implementation efforts with the goal to support as many business processes in and across organizations with the same set of underlying data structures and models as possible throughout the life-cycle of a building project [3]. While such strategic visions are appealing, BIM applications in current practice are rather characterized by the use of a multitude of models that are supported each by a different set of BIM based tools. Hence, the utility of the higher level frameworks is limited for the actual implementation of BIM based tools at the operational level [14]. After all practitioners have to understand how to best configure BIM based tools to support specific work processes [15]. Because of these reasons, the above summarized strategic level dimensions still are limited in guiding BIM based tool implementations in practice.

It is not surprising that several researchers have tried to complement the above described high level frameworks with concrete methods of how to support specific construction management work processes with BIM based technologies. Studies have, for example, developed processes that allow the use of BIM based tools to support specific construction management work processes. For example, researchers have developed BIM tool supported processes for constructability review [16], site management [17], scheduling, workflow-based or location-based planning [18], safety planning [19], or the identification and resolution of time-space conflicts [18].

Further, authors have derived more detailed and targeted BIM based tool implementation guidelines in close relation to empirical data collected in real organizational contexts. In this way, a number of studies have identified several drivers for BIM based tool implementations in practical contexts. Some of the more important identified drivers are

- the personal motivation of the implementing actors to use the tools [20],
- the availability of contractual frameworks to allow for the use of the tools, the availability of sufficient technical knowledge and skills [20],
- the availability of opportunities to apply the technologies [20],
- the existence of strong social networks to align goals and processes of an implementation [21],
- or the availability of high quality support from IT departments and top management support [22].

There is no doubt that these research efforts have significantly furthered empirical understanding about the meaning of the industry level, organizational, and regulative views summarized above. However, due to the underlying assumption of most of these studies that BIM technologies are not malleable, they only focus on how organizations and their work processes can be changed to adapt to specific technology characteristics. Little is still known about the possibilities to change BIM technologies and their functionality to existing organizational work processes.

To overcome this limitation of existing studies, this paper presents an empirical study with the main goal to increase the practical utility of the above "business function" views in relation to the technology related views. To do so, the paper empirically shows that existing construction management best practices are a good vehicle to understand and guide BIM based tool implementations. In particular, the paper describes two BIM based tool implementation efforts and uses generally accepted project management "business functions" as a post-priori view to describe and analyze the implementations. Before the paper describes and analyzes the two implementation cases in more detail, it will first summarize the research method that we applied to collect data from the cases in the next section.

3. Research method

We collected the empirical data for this study while supporting the implementation of BIM based technologies in two construction organizations. The goals of these two efforts were to explore bottom-up technology implementation efforts in relation to the context of the two organizations instead of observing technology implementations independent of their context. To allow for an in depth understanding of the existing contexts, the second and third authors of this paper, therefore, worked closely together with the members of the two organizations trying to get as deeply involved in the practical organizational work routines as possible. Hence, the research strategy we applied on the two case study projects can be best described as case based action research [8,23].

The choice of the two organizations was rather by chance and admittedly did not follow any of the formal theoretical sampling strategies mentioned in the mainstream case study literature [24,25]. In contrary, the fieldwork was initially triggered not by a specific theoretical idea, but because the two organizations, one estimating department of a company and one project team, struggled with the implementation of BIM based tools in their local organizational context. To address these struggles both organizations hired a research student – the second and third authors of this paper – to help them with the implementation.

Before entering the field, both research students went through an in depth training about existing BIM technologies and participatory research methods for the period of one month. During this training period, the students familiarized themselves with the existing technologies, their functionality, and best application practices. The students worked through official tutorials of the software vendors and consulted software experts, both at their university and at the companies of their host project teams. Additionally, the two students familiarized themselves with the existing project management literature in their respective fields of cost estimating and risk management to understand the local organizational contexts better. This initial training program ensured that the students entered the field with a good basic knowledge that helped them to understand the dynamics of the BIM based software implementation in detail. Additionally, this knowledge allowed them to support the project team with the implementation of the technology.

After entering the field, the two students worked with the project teams together for a period of about three to four months. They spent every work day in the respective office of the project team supporting the teams as best as possible with the implementation. During their field work the students recorded their daily observations in diaries as the main source of field data. The students also collected documents that were relevant to their work, such as project reports, project schedules, project risk inventories, cost estimates, or project drawings. A final source of data was obtained by formally interviewing project team members in face to face interviews at a number of selected points in time before, during, and after the fieldwork.

As it is characteristic for participatory research methods [26] and contrary to the quite linear representation of case study research in the literature [24,25], the final theoretical idea that we present in this paper only emerged slowly and iteratively. Our data analysis can be best described by what Corbin and Strauss describe as theoretical memoing [27]: we started data analysis and theorizing while the fieldwork was still in progress and for both of the case projects separately. Both students discussed their ongoing data collection efforts in bi-weekly meetings with the first author of this paper for the risk management case and with the fourth author of this paper for the cost estimating case. In these meetings the students first summarized initial findings from their data. Afterwards, the students and the first and fourth authors discussed theoretically interesting themes that emerged from these findings and brainstormed ideas of how to best collect data that would provide a more in depth follow up of these themes. After leaving the field, both students independently drafted two reports about their findings that reflected the final outcomes of their fieldwork and data analysis activities. Only after a comparison of the two student reports the theoretical idea of this paper – that it is possible to successfully implement BIM based tools by aligning the tools closely with best project management practices – emerged. Using the initial reports and the collected case data, we then began to trace how the implementation of the two BIM based technologies was guided by existing project management best practices in retrospect.

We did not conduct any formal internal validation efforts to further establish the causal relationship between the bottom-up implementation and the final BIM tool application. According to Yin [24], case study methodology does not require internal validation as the method established causal relations directly from the data instead of deriving it from statistical relations between dependent and independent variables. Further, the action research strategy with its close participation of practitioners can be seen as intrinsic internal validation. This close participation entailed, for example, that members of the two case organizations read and commented on the two preliminary student reports and the involvement of the fourth author, who was one of the practitioners who was involved in the one of the case studies, in writing this paper.

The next two sections, present the results of this process tracing efforts in detail. Each case description starts with a short summary of the project management processes practitioners wanted to support with BIM based technology. This description is followed by a short introduction of each case and an in-depth analysis of the organizational work practices in the respective case setting. Afterwards, we explain how the organization implemented BIM based technology to support these practices and summarize the implications of the implementation for the organization.

4. Case 1: BIM based cost estimating

4.1. Background of BIM use

Estimation is the process of looking into the future and trying to predict project costs and resource requirements [28]. According to Halpin [28], estimators generally take certain steps in developing an estimate:

1. Break the project into cost centers.
2. Estimate the quantities required for cost centers that represent physical end items. For physical systems, this is commonly called the quantity take-off.
3. Price out the individual quantities determined in step 2 using historical data, vendor quotations, supplier catalogs, and other pricing information.
4. Calculate the total price for each cost center by multiplying the required quantity by the unit price.
5. Add profit, overhead, and contingencies.

The main benefit of applying BIM based tools to estimate project costs occurs during the quantity take-off step [6]. Estimators can extract quantities automatically from the BIM and use this information in downstream cost estimation applications. In addition to the possibility to automatically extract quantities, 3D visualizations generated from the information in a BIM can also provide important insights because it enables estimator to analyze the design in different ways.

4.2. Case description

The organizational setting for the first case research was the estimating department of a large 4000 employee construction company in the Netherlands. Previous to our fieldwork the company had developed a new modular system to design parking structures. This system offers the possibility to configure a certain parking structure in many different ways, while each possible design consists out of standard elements, such as columns, beams, or floors. Using this modular system, designers of the company were able to significantly save time designing new parking structures. Additionally, the modular system allowed the company to reduce costs and construction time because construction crews could construct the structure more easily. In their continuous effort to improve their operations, the company started an effort to explore the possibilities of BIM based tools to support the estimating process and hired the research student.

After entering the field, the research student, observed the estimating process and collected existing documentation from previous projects, such as drawings, construction schedules, and estimates. He also conducted informal interviews with a number of estimators and observed the day-to-day practice at the company. Altogether, this enabled him to gain integrated knowledge about the current process of estimating the costs of modular parking structures. Based on this in depth knowledge, the research student together with the company's estimators, a 3D modeler that had not worked together with the parking structure group before, and the company's BIM program manager aligned the use of BIM based tools with this process.

4.3. The organization's cost estimating process

To estimate the costs of a parking structure, estimators at the company followed generally established estimating processes as, for example, discussed in Halpin [28] that is outlined in Fig. 1. In the first step of this process, estimators used a standard work breakdown structure (WBS) that was previously established at the company to hierarchical subdivide the project in sub-parts. This WBS broke down all functional systems of into objects with related activities to physically build the systems. This breakdown enabled the estimators to reduce the complexity of the estimating task by dividing the overall project in small and manageable parts. In the next step, estimators extracted the quantities manually for each of the WBS items from 2D drawings that represented the configuration of the modular parking structure for the specific project. On some projects, designers already provided estimators with a detail take-off of the quantities and thus reduced the labor intensive task of manual quantity extraction. Nevertheless, in this case, estimators still had to check whether the quantities delivered from the designer were accurate.

After the extraction of the quantities, estimators then started to price each of the cost items by using historical company records and catalogs that compiled cost information from previous modular parking structure projects the company had completed. Next to pricing physical items using historical cost data, estimators also had to account for other aspects that incur costs, such as site conditions, duration of construction, work schedule, and working methods. These conditions, dependent on a specific project, influenced costs related to required equipment, total hours of labor, or costs incurred by the need to obtain special building permits. This step required in depth knowledge and experience and was the least structured step in the estimating process. After accounting for project specific cost factors, estimators then rolled up the costs of each of the WBS's cost items to a first complete estimate of the total project costs.

To increase the accuracy of this first estimate, estimators consecutively started to replace parts of the estimate by requesting prices from sub-contractors and suppliers. They submitted such requests for main cost items, such as, foundation (piles), columns, floors, or staircases. Acquiring these prices took several days and, therefore, it was important that estimators request these prices as soon as possible after the quantity take-off. After estimators received the requested prices they then updated their estimate and compared this new version with the estimate based on historical data. Additionally, this step allowed estimators to decrease the overall estimated project costs by choosing the cheapest sub-contractors and suppliers.

In a final step of the estimating process, estimators then included the company's overhead costs and profit margins as a percentage of the final estimated cost. Estimators then discussed the estimate with a number of senior managers. These discussions served as a final control for the estimate. During the discussions estimators and senior managers paid most attention to project specific elements of the estimate, such as assumptions made by the estimator. According to the outcomes of these final discussions, estimators generated the final formal bid estimate.

4.4. Aligning BIM based tools with the cost estimating process

After observing the current estimating practices at the company, the research student, together with the companies' estimating team and one of the company's 3D modelers started to align the use of BIM based tools with the existing estimating processes. From the analysis of the existing estimating processes it became clear that BIM based tools could support the estimators on the project mainly by the possibility to extract quantities automatically and to understand project specific configurations of the parking structure modules through the possibility of BIM based tools to visualize project details in dynamic 3D based views. To allow for the alignment of BIM based

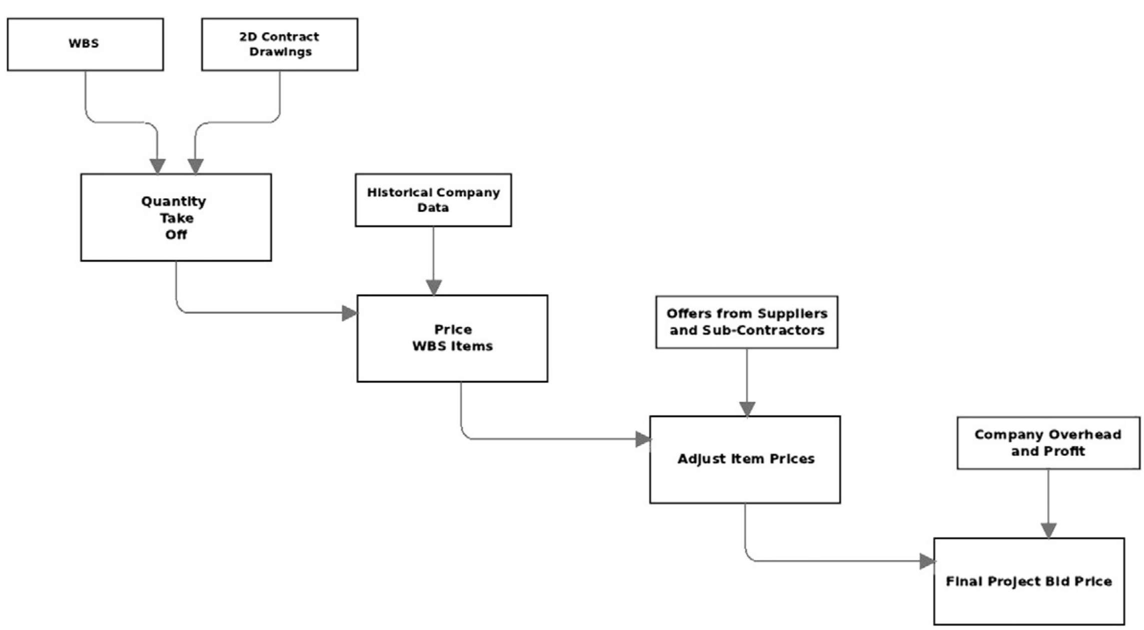

Fig. 1. The estimating process used by the estimating department of the first case's organization. The process followed generally accepted estimating guidelines as summarized for example in Halpin [28].

tools with the estimating process for the purpose of automating the quantity take off it was important to align the content of BIMs with the existing formal methods used for estimating at the company. In particular, BIMs of modular parking structures needed to fulfill the following requirements:

- the BIM needed to provide the required level of detail to generate an estimate
- the BIM based tools needed to allow estimators to extract quantities of the building components grouped by the company's WBS, and
- the BIM based tools needed to allow the take-off of accurate quantities for each of the cost items defined in the WBS.

To achieve this alignment the research student supported the 3D modeler and the estimators to iteratively adjust the BIM based tools. The first part of these iterations was the grouping of the BIM objects according to the WBS used by the historical estimating data and pricing catalogs of the company. Additionally, the historical estimating data was converted to so called cost estimating recipes [6] that can be linked to quantities calculated for these BIM object groups for the calculation of the costs for each cost item.

4.5. Implications of the bottom-up implementation

During the above described adjustment of the BIM based tool's functionality to the cost estimating process, we could observe two improvements in the estimating process. First, the use of BIM based tools allowed the estimators to save time during the quantity take off. However, a direct comparison with the time spent on the observed projects that applied traditional estimating, the time savings due to an automated quantity take-off were rather insignificant. We attribute this to the modular character of the parking structure that allowed for the quick take-off of standard quantities from drawings and specification. Current BIM software is unable to identify specific conditions such as unusual wall or unique designs conditions [6]. Thus even with the application of BIM based tools, estimators still have to find a way to account for special project conditions without the help of a BIM based tool.

We also observed a second advantage of the use of BIM based tools. In the current practice, the incorporation of changes of modular parking structures caused by requests of the client is a time intensive practice. Estimators need to compare the new design documents representing the changed with the old ones to understand how the changes influence the costs. With the direct alignment of a BIM representing the parking structure design with the cost estimate through recipes, changes within the BIM were automatically updated in the cost estimate. The automatic incorporation of these design changes in the estimate allowed for significant saving of estimating hours. Even more importantly, the latency between the time of the design change and the time estimators could inform earlier contacted suppliers for a new quote was also reduced significantly through the BIM based tool alignment.

During the bottom-up implementation we observed a clear shift in the perceptions of the organizational members on the project. While at the beginning there was the feeling that the BIM based tool implementation would require a change in estimating processes, the estimators became more and more aware of the possibility to adjust the technology closely with their work processes. Examples for this were the discussions about the required level of detail in the 3D models. At the beginning of these discussions, estimators initially criticized the models as not suitable for estimating work. However, by working closely together with the 3D modeler for a number of weeks, estimators became more and more aware of the possibilities of the 3D modeling software. This awareness then lead them to closely work together with the 3D modeler to develop adequate 3D models.

5. Case 2: BIM based risk management

5.1. Background of BIM use

On large construction projects, it is of key importance for all decision makers to understand possible project risks well. To support such an understanding, traditionally, project risks are communicated in a tabular form as a risk inventory and are further explained in written reports, Gantt charts, and sketches. However, due to the complexity of large construction projects that integrate multiple designing disciplines, multiple sub-projects and sub-project interfaces, and different stages of construction, these tools do not allow project managers to, quickly and completely visualize and understand risks, their location on site, and the risks' implications on quality, costs and schedule of the project. In practice, this means that it is hard for decision makers to collaboratively assess and mitigate project risks.

4D models are BIM based applications that combine three dimensional representations of the construction design with construction schedules. In this way, 4D models allow project managers to visualize all stages of the construction process in time and space. 4D models capture both the temporal and spatial aspects of schedules and communicate schedules more effectively than a Gantt chart [6]. In the past 4D models have been used to evaluate and analyze design constructability, sub-contractor coordination, and schedule optimization [16–19,29]. This case shows that if aligned well with existing risk management processes, design teams can also use 4D models to visualize project risks in time and space.

5.2. Case description

The case describes our effort to integrate the use of 4D models into the ongoing risk management processes of a large scale 620 Million infrastructure project within an European metropolitan. To support the project's planning activities the project management team of the owner, a large 1000 employee municipal organization, decided to generate a 4D model. After the initial generation and some rudimentary uses to communicate a number of design and construction issues to project stakeholders the use of the model on the project halted without evidence for any organizational changes in the work routines of any of the project's team members. To revitalize the 4D modeling effort one of the project's managers contacted the first author to discuss possibilities for improving the overall application of the model on the project. In a discussion the project manager and the first author of this paper decided to send a research student to the project to conduct ethnographic action research [8] to align the use of the 4D model tightly with the existing risk management processes of the project.

To gain initial understanding of the specific project context the research student also read project-specific documentation, such as the project plan, the project's base-line documents, the existing project's risk inventory, and the risk related start-up report. These documents gave him an overview of the projects organizational structure and helped him to identify the project organizational context and the project's formal work routines with respect to risk management. Afterwards, the research student interviewed the project manager, the project planner, the design manager building engineering, and the design manager construction. During these interviews the research student discussed the risk management process on the project, the current use of 3D/4D visualizations and whether they saw possibilities to use 4D models to visualize project risks. The research student also asked the project participants to indicate with whom, and how much, they communicated during their risk management activities. Using the information collected we were able to gain in depth insights about the current risk management process on the project. With this insight the research student then started to align the existing 4D model with the project's risk management process.

5.3. The project's formal risk management process

The project practitioners of this project applied the RISMAN [29] method summarized in Fig. 2, a formal risk management method for projects. The method prescribes a process that allows decision makers to assess the chance of occurrence and the impact of project risks in a systematic way. The core philosophy of the method suggests that project managers (1) make risks explicit and control them, (2) approach risks in a pro-active way, and (3) consciously approach risks and determine control measures [30]. Similar to other risk management methods (see for example Ref. [31]), the RISMAN risk management method distinguishes between the linear risk analysis process used to determine the chance of occurrence and the impact of a risk, and the cyclic process of risk management and mitigation, used for implementing control measures and monitoring the effect of these measures.

Implementing the RISMAN method, the project team divided the project in a number of sub-projects. All risk management activities were then executed at the sub-project level. To identify risks for each of the sub-projects, a specifically instantiated risk specialist asked a number of selected project team members to describe the five most sub-project threatening risks. The risk specialist then analyzed each of these risks and compiled a risk start-up report and generated a risk inventory containing the risks that project participants mentioned during the risk start-up session. Following the RISMAN method, the risk specialist attended project control meetings and he kept track of the design progress by discussing the progress with other practitioners. He also supported each project manager of the sub-projects by giving advice on specific risk control measures and played a facilitating role during project team meetings. Each of the subprojects managers was responsible for the successful risk management on their sub-project. In particular, each of the project managers was responsible for the proper application of the risk management cycle.

5.4. Aligning BIM: implementation of a 4D risk management system

After observing the existing risk management practices on the project, the research student, together with the project's practitioners, started to align the project's existing 4D model with the project's formal risk management process. Generally, 4D models can support the visualization of three different risk related properties: the location of the risk, the time-frame during which a risk may occur, and additional information, such as an in depth description or different measures to mitigate the risk. In particular, the research student improved the existing 4D model with a number of different visualization methods:

1. Viewpoints. Viewpoints show a certain time during a construction from a certain viewing angle within the model and can be stored for future reference by any user without the need for additional 3D modeling activities. Viewpoints are a powerful tool that allows users to quickly navigate the 4D application to a predefined position that visualizes a certain risk. In this way, viewpoints are well suited to visualize risks that are clearly observable from a certain angle without the need for much further description.
2. Text overlay. Text overlay allows the generation of text that is overlaid on the existing model. While text overlay offers the possibility to clearly display important information to users of the 4D system, text overlay is not very flexible. In the used 4D application, it was not possible to link text overlay to certain different views on the model. However, it was possible to link text overlay to a certain time period. With this functionality text overlay is well suited to show general project wide risks that occur at a certain time and that are not related to a certain position in the model.
3. Risk specific objects. Risk specific objects can visualize certain project risks at a specific time and location in the 4D model. These objects can have any shape, color or property and it is possible to dynamically link additional information with risk objects using smart tags. Those smart-tags pop-up within the software's main interface at the moment the pointer moves over the object and, thus, offers further context information about the risk such as a short description or suggested risk control measures. While risk specific object present the most powerful possibility to visualize risks, a schooled 3D modeler is required to integrate such objects into the 4D model. An example of such a risk specific object is an arrow that points to a certain location within the 4D model at a certain point in time and in this way clearly visualizes a specific risk that might occur during the project. Overall, the research student integrated 20 of such risk objects of different shapes, such as arrows, circle's, see-through solids, clouds and icon's, into the model.

5.5. Implications of the bottom-up implementation

While applying the model within risk management meetings, project managers acknowledged the potential of the 4D model to support

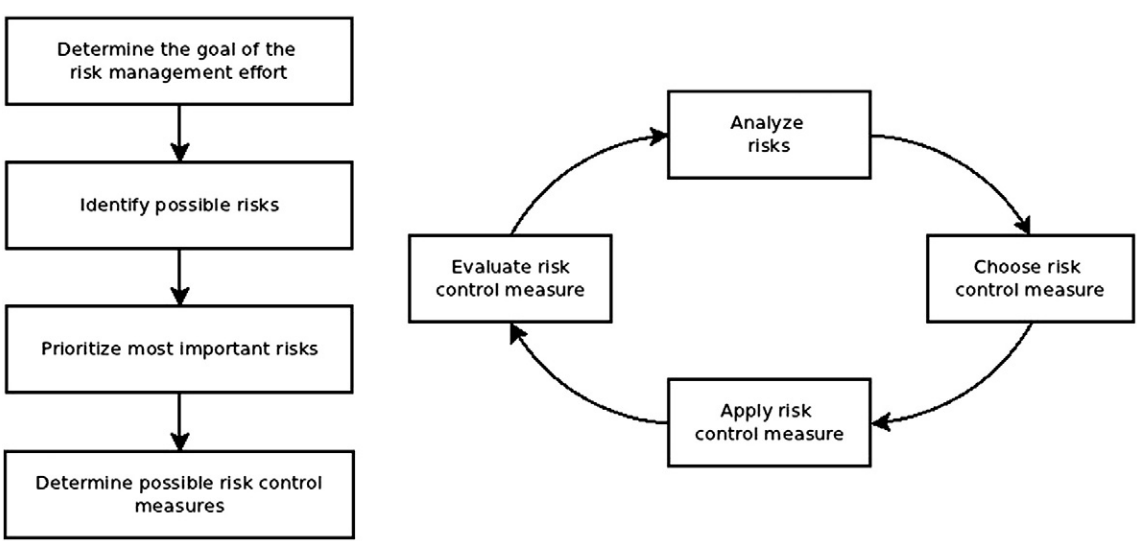

Fig. 2. Process of the RISMAN method, the formal risk management method followed by the organization of the second case. This risk management method is described in detail by van Well-Stam et al. [30].

their project management activities. According to personal discussions after the meetings, most meeting participants indicated that the presentation of the risks in a 4D model could improve the possibility to communicate risks in risk management meetings. Similar to the first project, we observed a clear shift in the perceptions of the project managers who at the start of our action research effort did not perceive 4D models as beneficial. During the meetings we were able to observe meaningful interaction of project managers with the model in efforts to understand and discuss certain project risks. The personal discussions with the project managers themselves showed equally good results. Each of the six project managers to whom we showed the 4D model indicated that the model helped to attract the attention to a risk, and helps to indicate the location and the period during which the risk may occur. All project managers also mentioned some shortcomings of the model that required further technical adjustments. This possibility to engage project managers meaningfully in the technology adjustment process is further evidence for the utility of technology-pull implementation.

In summary, similar to the estimating case, this case illustrates how project managers only perceived the application of BIM based tools useful after close alignment between the tool and the existing work processes was established. Only then project team members slowly started to recognize the added value that the 4D system offers. Additionally, this case of aligning BIM based tools with risk management activities complements the estimating case in that it shows that it is also possible to closely align BIM based tools with the existing management routines at the project level. It further shows that it is possible to allow for the support of inter-organizational processes using BIM based tools because the risk management process on this project involved the collaboration of different specialists from different backgrounds.

6. Theoretical implications

If nothing more, the above two cases show that existing project management best practices can be a helpful guide to understand and support BIM based tool implementations at the operational level of an organization. In both cases, we closely analyzed the existing work routines and then tried to match them with project management best practices. This enabled us to closely align the BIM based tools to the local project management practice without little disruption of existing work practices. Hence, we provide evidence for the flexibility of the existing BIM based tools and the possibility to implement them from a technology pull perspective.

The cases show that generally accepted project management best practices allowed us to understand existing work processes easier and more thoroughly. The large project management body of knowledge proved to be a valuable source of information to grasp actions of practitioners we observed while conducting our two field studies. The, in this way, gained deep understanding of the local work routines allowed us to specifically customize existing BIM technologies according to the needs on the local projects.

At the same time, the focus on existing project management best practices allowed us to implement the BIM based technologies in a way that was easily understandable for the project managers working on the projects. This helped the implementation in two ways. First, all project managers could more easily make sense of the benefits the BIM based tool implementation would mean for them with respect to improve their work processes. Second, project managers were able to participate in the necessary configuration of the BIM based tools to their specific requirements. The possibility to involve project managers in the implementation was, in particular, obvious on the second case. At the beginning of our efforts most project managers were rather negative toward the implementation of BIM based tools. These negative perceptions, however, shifted during the implementation. At the end, all project managers that we interviewed were much more positive about the utilities of the BIM based tool to support their risk management activities.

Next to these rather practical contributions, we provide empirical evidence of how Jung and Joo's [10] proposed view of construction business functions can be a valuable help to understand and guide a BIM based tool implementation. Both case implementations, were actually closely guided by business functions and only an in depth understanding of the business functions and the close alignment of the BIM based tool implementation with these business functions led to a successful implementation. We expect that the two empirical examples help practitioners to understand and contextualize Jung and Joo's rather abstract dimensions better.

Of course this study is not free of limitations. For one, the chosen case study approach cannot provide evidence that the here suggested focus on well established project management practices during BIM based tool implementations will work on any project. Despite us providing evidence from two largely different organizational settings, the specific dynamics in other organizational settings might make it necessary to also radically change existing and established routines to successfully implement BIM based tools. Hence, we suggest that researchers try to replicate whether the here proposed focus on accepted project management processes can support successful BIM based tool implementations in other settings.

Another danger of focusing on local and established routines is that the success of a BIM based tool implementation will only be limited to improve a few business processes at a time. Researchers (see for example Ref. [13]) have since long advocated that one of the main advantages of the implementation of BIM based tools is the global improvement of all project processes for all organizations that work together on one construction project. Focusing on a number of business processes of one single organization within a project context might actually hinder the full leverage of all benefits on such a global project level. On the other hand, however, research shows that the implementation of incremental innovations works better in construction settings than the implementation of disruptive innovations [5]. Hence, it might actually be helpful to start supporting a number of localized business processes first and only incrementally try to also reap some of the benefits at the global project level that the introduction of BIM based tools promise in theory. Again, future research efforts should explore the ideal balance between implementing a BIM technology incrementally versus implementing it disruptively using future empirical studies.

Another limitation of this research is the relative short time that the research students were involved with the two case organizations. It is hard to finally judge the real value of the implementations after only being involved between three to four months with an organization. While the research students observed some short term benefits of the BIM based tool implementations we cannot claim anything about the sustainability of the two implementation efforts we reported about. Additional longitudinal studies are required to shed more light on the sustainability of BIM based tool implementations that focus on the support of specific well established project management processes.

Finally, it could be argued that an organizational change already had taken place in both case organizations before the research effort. On the 4D case, for example, the previous decision to generate a 4D model indicates some change in the large public organization. Along the same line, the availability of a 3D modeler to support the parking structure division for the estimation case also indicates some change. Nevertheless, our data also shows that this seemingly change at higher levels of the two organizations had not reached the project team level that we focus on in this paper. Nevertheless, we suggest that future research explores the emergence of organizational change around BIM based tools at different levels within an organization by applying multi-level organizational research methods [32].

Another closely related shortcoming of this study is that the processes on both cases did only require limited collaboration with different parties. One can argue that only this limited collaboration has enabled the here described bottom-up implementation in the first place and that processes that require more collaboration between different organizations require more top-down implementation strategies. This, in particular, was true for the estimating case that was characterized by a relatively homogeneous organization that was characterized by relatively stable communication routines with external sub-contractors and suppliers. Interestingly, on this case, however, the estimating department started to use the standard work breakdown structure other departments of this company already routinely applied to support the BIM based tool implementation. Hence, while unintentionally, the bottom-up BIM based tool implementation fostered the internal collaboration between disciplines. This might be an indicator that bottom-up implementations of BIM based tools might be beneficial for organically grown collaborative structures. While our case can only provide very limited evidence for this phenomenon, it seems to be a very interesting topic for further exploration.

Along these lines, we would like to stress again that the second case was already characterized by the need for much more interdisciplinary collaboration because of the design–build delivery mode of this mega-project. Our project data shows that the 4D model actually allowed planners, cost estimators, project managers, and client representatives to collaboratively work together. Hence, the second project can serve as some initial illustrative evidence that bottom-up implementation can also work across discipline and organizational level. Again further research should explore the scalability of bottom-up implementations in more detail in relation to increasing organizational complexity.

7. Conclusion

Concluding, the two case studies we presented in this paper provide evidence for the benefits of a technology pull view on BIM based tool implementations in construction management settings. In particular, the paper described two cases of technology-pull directed BIM based tool implementation efforts. The first case focused on supporting cost estimating activities with BIM based automated quantity take-offs. The second case focused on the support of project risk management activities with BIM based 4D models. Both cases illustrate well that it is possible to align organization and technology by gaining an in depth understanding of the underlying project management methods that guide the operation of a project team and by aligning BIM based tool functionality to these processes. The cases do not only show that it is possible to align the functionality of BIM based software applications with generally established project management based working methods, but also that implementations from a technology pull perspective can be successful.

With the focus on construction management processes, the findings of this paper can offer a fresh viewpoint for technology managers that plan to implement BIM based tools within their organizations. For one, the two cases show that it is possible to configure the functionality of existing BIM based tools to a great extent. With this possibility technology managers can actually align the existing tools closely to the work practices of their construction teams or company departments without the need to implement cumbersome work process changes at the same time. Such a technology pull strategy might offer many advantages to the usually applied technology push strategy. Many of the socially related problems during an implementation that researchers have identified, in particular resistance to change, can be circumvented in this way. The second case we presented in this paper even shows that it might be easily possible to actively involve project managers in the implementation. Second, technology pull implementation strategies reduce the risk to replace well working existing processes just for the sake of being able to use a technology. It is often hard to understand all the implications of a change in work processes, and, hence the introduction of a technology in the past often unintentionally lead to a reduction of productivity of the implementing organization [33]. This phenomena, also called technology paradox, can be largely circumvented with technology pull implementations.

Overall, this paper sheds new light on implementation theories in construction management that are largely based on a technology push philosophy. With these new insights we hope to have furthered understanding about how to best implement BIM based tools in construction management settings. We hope that such an understanding can provide another stepping stone to move the industry toward a wide spread implementation of BIM based tools and to leverage the potential that such a wide spread implementation can offer to the industry as a whole.

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