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Challenges of the expansive[1] use of Building Information Modeling (BIM) in construction projects

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Abstract

Building information modeling (BIM) is an emerging modeling technology which challenges existing work procedures and practices in the construction industry. In this article we study the challenges, problems and potential expansions of BIM as a tool in the design, construction and operation of buildings. For this purpose the interfaces between different parties are examined in Finnish construction projects. The methodological approach of the study is cultural-historical activity theory, according to which a new artifact becomes a mediating instrument when the participatory subjects reconfigure the entire activity. The implementation of BIM is now spreading from the design activity to other phases of the construction projects, but its use is still limited in the projects' other three interfaces. BIM is an evolving set of software developed for various purposes which is locally 'combined' to fit the circumstances and capabilities of the stakeholders of the construction process.

Keywords

Building Information Modeling. Social interfaces. Cultural-historical activity. Expansive learning. Life-cycle project.

1. Introduction

Building Information Modeling (BIM) refers to an evolving technology in the architecture, engineering and construction (AEC) industry. Unlike computer-aided design (CAD), BIM models are built using "object intelligence" and present information about physical elements such as doors and columns (Succar, 2009; Eastman et al., 2011). BIM is considered "a revolutionary technology" that has transformed the process of designing and constructing buildings (Hardin, 2009, p. 2). It is also characterized as "an emerging technological paradigm and procedural shift" in the architecture, engineering, construction and operations (AECO) industries (Succar, 2009, p. 357). The development of the open data model standard, IFC (Industrial Foundation Classes), has enabled BIM to facilitate the exchange of information between different design partners in construction design (Laakso & Kiviniemi, 2012). However, as Neff and her colleagues (2010, p. 2-3) conclude,

> [...] even though BIM usage has doubled since 2007, work practices that support increased collaboration and knowledge sharing across organizational and disciplinary boundaries have been slow to emerge.

Thus, the development of the organization and the co-production of information between partners in all phases of building projects are still needed.

In this article, we study the uses of BIM in building projects. In the literature on the philosophy of modeling, several authors suggest that the nature of modeling can best be understood by concretely analyzing how the models are actually used (e.g., Morgan & Morrison, 1999). Yet many technical and organizational innovations are still needed to expand the use of BIM in the life cycle of buildings. The implementation of BIM involves many challenges that need to be solved in order for BIM to be a useful tool in the building industry. The development of basic technologies and the organizations of their use and implementation have different temporal dynamics (Perez, 2002). The new technologies are typically brought to organizational structures that were developed during a prior technological paradigm. The full deployment of the new technology requires changes in various collaborative practices: the division of labor, rules, complementary tools and contractual arrangements.

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[1]We use the term expansion in its activity-theoretical meaning as the potentials of transformation in an activity brought about with the use of digital BIM software.

As a 'generic' technology, BIM provides many benefits to its users. For instance, it can potentially increase the efficiency, quality and productivity of a construction project by reducing the number of mistakes and incompatibilities, providing more accurate and up-to-date information, and by giving a more illustrative and accessible exposition of a building and its characteristics to all stakeholders (Eastman et al., 2011). It is not clear, however, how and to what extent these promises can be realized. Therefore, a more realistic evolutionary view is needed in which BIM is conceptualized as a historically developing set of more or less interoperable tools that are used simultaneously with non-BIM tools (Eastman et al., 2011; Miettinen & Paavola, 2014).

In this article, we adopt the evolutionary view of BIM use as a long-term and open-ended, historically derived process. We make use of the activity-theoretical idea of contradictions as a driving force for the expansions in BIM use. We aim to clarify what kind of challenges, problems or potential expansions emerge in BIM use. To what extent does the use of BIM enable the expansion of activity? We will study the challenges and problems of BIM use at the four interfaces of construction projects. The four interfaces under study emerge between (1) the different designers, (2) the designers and construction site managers, (3) the designers, construction site managers and the operations manager of the buildings, and (4) the designers, operations manager, clients and the end-users. We propose that each of these interfaces requires specific uses of BIM technologies as well as a specific set of supplementary tools. The social-collaborative forms of BIM use and non-BIM tools at each of these interfaces must, therefore, be studied and developed (Miettinen et al., 2012).

The case under study is a life-cycle project in which four public schools and a day care center were built in eastern Finland during the years 2011-2013. Two of the schools and the day care center were new buildings, and the other two schools were refurbishment projects. A life-cycle project is a novel form of contracting, according to which one party is responsible for the long-term (i.e., up to 25 years) management, design, construction and operation of a building.

2. The activity-theoretical approach of the study

According to cultural-historical activity theory (CHAT or activity theory in short), signs and tools mediate human activity (Vygotsky, 1978). They are an integral part of the activity and cannot be considered separately from the context of their use (Engeström et al., 1999). Mediating artifacts are parts of systems of knowledge and material culture. However, to make them instruments for local practice, they need to be interpreted and reconstructed by the subjects to meet the specific requirements of their activity.

Béguin & Rabardel (2000) suggest that *instrumentalization* – a process in which cultural artifacts become instruments in a local activity – can take place on different levels. On the first level, an artifact is used in specific circumstances, in which it is given a temporary function. On the second level, the properties of an artifact are linked more permanently to functions that it can perform. However, the artifact itself is not transformed on the first or second level of its genesis. On the third level, the artifact itself becomes modified to perform new functions (Béguin & Rabardel, 2000, p. 183-184).

In cultural-historical activity theory (CHAT), instruments (i.e., tools and signs) are embedded in human activity systems. An activity is collective, oriented towards an object, and mediated by tools and signs. The elements of an activity system are a subject, an object, tools and signs, a community, rules, and the division of labor (Engeström, 1987). According to CHAT, the use of mediating artifacts (i.e., signs and tools) jointly with the production of an object and the motive of an activity is called instrumentality (Kerosuo & Engeström, 2003, p. 346). For a new artifact to become a mediating instrument, the participatory subjects have to "reinvent" the entire activity, which involves changes in the division of labor and new rules. The process of reinvention takes place through expansive learning as the subjects solve the tensions, disturbances and problems emerging in the activity. In this study, the analysis of the challenges and problems reflects the contradictions between the technological development of BIM and its use at the four interfaces, the solutions for which are the precondition for expansive learning and the expansive use of BIM.

Recent developments in the industry have set new challenges for the collaborative activity of different parties in construction projects. Design and construction is not only a step-wise process, but a complex network of activity systems. Each system holds partly different interests, motives and perspectives towards the object of the construction activity. For instance, the perspectives of designers and contractors differ radically from the perspectives of the maintainers, clients and end-users. When new tools – such as BIM – are introduced to activities outside their original use, their full deployment requires the development of new software applications. BIM, which was originally created for the use of designers, need to go through a process of instrumentalization in order to fulfill the requirements of other activities in construction (Paavola et al., 2012). The use of BIM also has implications for changes in the social organization of work, i.e., the division of labor and responsibilities, rules and the contractual arrangements in life-cycle projects (Miettinen et al., 2012; Miettinen, 2009).

Taylor (2007) differentiates between three types of interfaces in the construction industry. A *technological interface* addresses the interoperability of technology between firms and companies in a construction project. For instance, designers must be able to use building information models produced by different software applications. An *organizational interface* involves the collaboration between partners and the creation of shared interests between partners in the network of design and construction companies. A *work interface* concerns the redistribution of work, the development of standards for interactions and system understanding. Long's (2001) definition of *social interfaces* penetrates the three interfaces defined above. It refers to social processes that typically emerge at the intersections of different life-worlds, organizational fields and arenas of social action. Social interfaces can involve discontinuities in the actors' interests, values and social actions that can be negotiated among practitioners. They are a heuristic device for analyzing the critical points of intersections between different fields or levels of social organization in developmental practices (Long, 2004, p. 16). In this paper, we adopt Long's concept of interface because the social processes emerging in the different phases of a construction process involve the interaction of groups and stakeholders from different organizations and professional disciplines using BIM in specific ways.

3. The ethnographic methods and data of the study

The ethnographic methods of the study represent an iterative analysis of the emerging use of BIM in the life-cycle project of building and renovating four schools and one day care center. The multi-layered process of data collection and analysis started in February and March 2011 and continued until the end of December 2012. Data collection started with the initial twenty-five interviews of representatives of the management, design, construction and operation of the first two schools under construction. The interviews were conducted in a half-structured manner, focusing on selected themes that covered the use of BIM in daily work, the benefits, hindrances and problems experienced in BIM use, and the identification of the most important collaboration partners in the project. An outsider transcriber transcribed the recorded interview data. The analysis of the interviews involved coding the chunks of transcribed data (Fetterman, 2010, p. 97-99), including the description of BIM use and its challenges among the actors. ATLAS software was used in the analyses. The findings of the analyses of the interviews are reported in Korpela (2011), Mäki et al. (2012) and Paavola et al. (2012).

The second set of data gathered after the interviews was collected to select the key events (Fetterman, 2010) of the collaborative uses of BIM. The design meetings, the user meetings and the construction site meetings were selected for participant observation during spring 2011. The period of observation lasted from spring 2011 until autumn 2012. The observations cover the four interfaces under study and are used in the description of interfaces in this study.

The design meetings and special meetings for schools 3 and 4 and the day care center were observed (see Table 1). The data was video and audio recorded, and content logs were provided from each meeting; an outsider transcriber transcribed the data. Besides the observation data, the researchers had many unofficial talks with the participants about the tasks they were involved with. The initial analysis of the meetings involved a content analysis with the objective of identifying design tasks within the transcription. Then the topics were categorized according to the type of meetings, and finally the different meeting types were contrasted with each other (Kerosuo et al., 2012).

The user meetings and the construction site meetings were observed using data collection techniques similar to those used in the observation of the design and special meetings. In Table 1, we present the types of data and the number of data observations in the study.

In this study, the aim of the analysis is to identify the challenges, problems and potential expansions of BIM use at the four interfaces. The parts of the data relevant for the study were identified and interpreted. The analysis of the observation data is based on the

Table 1. The data collected in the four school projects and in one day care center project 2011-2012.

	School 1 and 2	School 3 and Daycare Center	School 4
Interviews	25		
Design meetings		7	13
Special meetings		2	4
User meetings		11	
Construction site meetings		9	

identification of certain key events in order to interpret the "observer-identified" classifications (Hammerslay & Atkinson, 1987, p. 178). The idea is that "[...] through organizing the writing and doing the writing of ethnography, much of the ethnographic 'analysis' is completed" (Neyland, 2008, p. 125). The process of analysis also includes the co-writing and comparison of interpretations within the multi-disciplinary research group, which can improve the quality of the analysis (Fetterman, 2010). Two of the authors are educated civil engineers, and three others represent sociology, social psychology and educational sciences.

4. The interface between the design disciplines: Problems in the integrated use of BIM during the design process

Designers are required to coordinate and collaborate their tasks with several partners during a design process. Along the history of design work, the division of labor has allowed distinct expert disciplines to evolve. Simultaneously, interfaces between disciplines have emerged, and several experts are assigned to concurrent construction projects. Each design discipline has their own disciplinary culture, which is reflected within that discipline's digital, cognitive and representational models (Neff et al., 2010). These cultures are also reflected in the work procedures, practices and the use of specific tools. Yet the tasks of the designers from each discipline are highly interdependent in terms of contents, time and practical procedures.

BIM tools were used in all the design work in the case under study; this was actually a prerequisite for inclusion in the project. In our case, the group of designers involved a main designer (an architect) and his colleagues, and structural and HVAC-E (i.e., heating, ventilation, air conditioning and electricity) engineers. Each design discipline created different expert models and used a variety of software (Miettinen et al., 2012; Paavola et al., 2012). The architects used BIM software to produce the detailed architectural designs of the buildings and to check for clashes between the different expert models of the different design disciplines. The structural engineers used BIM software in the structural designs and the designs for precast concrete units. The HVAC (heating, ventilation, and air conditioning) engineers used BIM software to design HVAC units and other BIM-based software for energy calculation and simulations to estimate the attainment of energy targets and thermal conditions.

The process of design started with the architects creating the architectural model and delivering it to the structural engineers. The structural engineers converted the architects' model into objects they could use to make the structural model with their own software. The HVAC-E designers based their design on the model created by the structural engineers. They defined the number of required penetrations in the HVAC-E models and delivered their models to the structural engineers, who planned the locations of the penetrations using the structural models.

The main challenges of the interfaces between the designers related to the problems of the integrated use of expert models. All of the design experts experienced challenges in the integrated use of BIM during the design process. Hand-overs from the architects to the structural engineers and then to the HVAC-E engineers were slow and involved tensions in the iterative design process. The architectural and structural models changed many times during the tightly scheduled process. Despite the designers' efforts, the quality of the designs did not entirely meet the needs and demands of those working at the construction sites. However, many of the interviewees reported that the quality of the designs improved compared to the designs created before the use of the BIM applications.

The creation of the open data model standard, IFC, expanded the use of the different design disciplines' expert models by enabling their integration. In our study, the designers exported an IFC model of their own expert models to the project repository every or every other week. Then, the BIM expert hired by the developer imported every design discipline's IFC models from the project repository and combined each disciplinary model into an integrated model. After that, the BIM expert detected the clashes (multiple objects occupying the same space) in the integrated model and exported the list of clashes to the project repository for the designers of each discipline to improve.

The architects and design engineers were able to use the integrated model created by the BIM expert to identify the clashes between the different expert models in their own design work. However, they experienced the long lists of clashes printed out from the integrated model to be problematic. It was not possible to identify the "real design errors" on the lists because the real design errors were in danger of being lost among small, non-significant errors. The designers were not, however, able to use the integrated model to allow others to see their improvements in real time. They had to correct the design errors in their own expert models. Then the BIM expert had to create a new integrated model of each design discipline's model, and the process of checking for clashes started all over again and continued until the designs had no more errors.

The integrated models were also used in the shared problem-solving among the designers in design meetings. The design meetings were official meetings in which the developer, the supervisor, the representatives of each design discipline and the representatives of the contractors and the building maintainer participated. In the meetings, the designers reported the current status of their work and raised many practical matters for joint problem-solving. In these meetings, only some of the designers used BIM, but instead of engaging in joint use, they used it in their own work.

The challenges and problems related to the integrated use of BIM also emerged in the design meetings. The designers kept repeating the same problems from meeting to meeting. For instance, the locations of HVAC units were one topic discussed repeatedly in the design meetings. Some of the questions the designers raised were so urgent and complex that the project manager decided to organize special meetings. In these special meetings, the designers spent the whole day crosschecking their designs and solving open questions. Integrated and expert models were the main tools used in these meetings. Unlike in the design meetings, the models were projected on the screen for everyone to see and comment on. The developer, the supervisor, the representatives of the contractors and the building maintainer also participated in these meetings, and they expressed their views more actively than they did in the design meetings. For instance, one HVAC contractor participated actively in solving problems related to the installation of HVAC units. Special meetings were arranged six times during the final three projects. These meetings usually lasted one day and were arranged by the project manager.

5. The interface between the designers and the construction site managers: The implementation of BIM without information content developed for use at the construction site

The main challenge to be solved at the interface between the designers and the construction site management related to the site personnel not being able to receive all the information that they needed at the building site. Compared to sketched-based building, the knowledge content was expected to be correct in BIM-based designs when they were handed over from the designers to the building site. In sketch-based construction, site workers were accustomed to improvising solutions to problems that could not be realized in the designs. For instance, problems situating HVAC units in structures could be fixed at the site. But after the implementation of BIM, the site management and personnel expected that the clashes between different design models would already be solved during the design phase.

Multiple simultaneously emerging problems and expansions were experienced in the use of BIM. Firstly, instead of having only one design at the site, the engineers had to use multiple models and software programs to accomplish their tasks. They mainly used the architectural model and the integrated model with the correspondent software tools. Secondly, the designs were late in being handed over from the designers to the construction site, and in some cases the work at the building site started without ready-made designs. For instance, when the first school building was under construction, the constructors had to start the installation of drains without proper designs at one of the sites. Thirdly, the subcontractors and the construction workers were not ready to use BIM themselves at the building site. Instead, the site engineers were the main users of BIM at the building site. It became their task to deliver the information from the models to the different assemblers and workers. Providing BIM-based designs to workers from subcontracting companies was one of new uses that the site engineers implemented at the building site.

> Site engineer: *We got guys queuing for the machine there. All the electricians and plumbers are waiting because they have to check this or that.* (Interview with the site engineer)

The site engineers used the designers' models in the management of the construction work. For instance, the site engineers used the models to inspect the designs, to call for bids and procurements, and to control costs. They were able to include an image from the architects' model to clarify the call for bids sent to bidders. Besides using the models created by the designers, the site engineers expanded the use of the BIM models by reworking them for their own purposes. For instance, they used the design models as a platform for scheduling by retrieving the models from the project repository. The architects' model allowed them, for example, to calculate quantities for cost accounting.

> Site Engineer: *In practice, we get the quantities from the architects' model and then import them to the scheduling software, in fact to an Excel chart, the chart can then be imported into that scheduling software quite easily.* (Interview with the site engineer)

Using BIM as a new tool in construction work and management changed the requirements for the designs and models produced by the designers.

The construction site managers and site engineers insisted on more accurate models that would be delivered on time. They also expressed the need for new combinations of information or deliverables that would be helpful in their work. One example expressed in a site meeting was the request of a subcontractor's foreman for the designers to produce a blueprint of the structural model that would also include the location of the partition walls. This information would help the construction workers to locate the partition walls accurately in the building. Traditionally, penetration information is included in a architectural model and is visible on the blueprints used at the building site. But this information was not available in the BIM-based designs handed over from the structural and HVAC-E designers to the building site.

6. The interface between the designers, construction site managers and the operations manager: Disconnections between BIM and the tools used in the operation of the buildings

We did not find any evidence of the use of BIM (e.g., the geometric 3D model) in the transfer of information during the operation phase of the buildings. The operations manager said that he had not found any way to use BIM in the operation of the buildings, and the project manager reported that BIM was only in the process of being considered in operations and maintenance.

> Operations manager: *It has not concerned my work here so far, I could say that perhaps it will in the future but not now.* (Interview with the operations manager)

> Project manager: *Using BIM in maintenance is a thing that is in fact actually being examined. We do not have any answers to that yet. It needs to be connected to those tools that the operations staff are using, but it is not yet possible.* (Interview with the project manager)

The general tool used in the operations and maintenance of buildings is CMMS (Computer Maintenance Management System) software. The most advanced CMMS contains all the documents, designs, contracts and contacts needed in the maintenance of a building. Managers and controllers can follow the energy consumption, service requests can be retrieved, and maintenance plans and tasks can be created and updated in CMMS. Some CMMS software can be used for the transfer of information from BIM to CMMS, but that is not often the general case.

The operations manager identified one critical problem that needed to be solved in order for BIM to be useful in the operation of the buildings. According to him, the critical problem was the need to update changes in the BIM-based design during the construction phase. For instance, the HVAC units might be installed differently than the design calls for because the installers considered the designs too difficult to complete. Or the caretakers may not be willing to follow the original designs when carrying out maintenance tasks. In both examples, the changes are not necessarily updated in the BIM-based designs. Knowing this, the constructors were not motivated to complete the changes they made to the as-built model during the construction phase. According to the operations manager, the challenges became questions of who would do the updates and who would have the competence to update the designs. He did not know any caretaker who had the competence to update the as-built models or designs.

The manager of the operation phase of the building was, however, socially connected to that of the design and construction. The operations manager took part in the design meetings, in which he actively brought up the perspective of the operation of the buildings. For instance, he made comments on the installation of HVAC units from the point of view of maintenance. He also outlined aspects of use from the cleaning and gardening points of view. He had a personal connection with the project manager, the architects and the site engineer. He felt that the collaboration with the site engineer was especially useful in matters of installation. For instance, the site engineer contacted the operations manager about the installation of a sliding door that would cause problems in the building.

The operations manager considered the development of CMMS software and a linking technology to automation systems as a possibility for expanding the operations management and maintenance of the buildings. For instance, he suggested that an automated component could trigger an alarm signaling a functional failure in the HVAC-E system of a building. However, he admitted that these technological expansions would have to function smoothly in order to be useful for maintenance. He saw the creation of a user interface as a necessary condition for the expansion of BIM use in general and felt that if cleaners and the maintenance personnel had BIM-based software available, it might also help their work.

7. The client and end-user interfaces: BIM used primarily to present buildings

BIM was used primarily to present buildings at the interface between the designers, site managers, operations managers, clients and end-users. The clients and end-users did not use the BIM tools by themselves. The client and end-user interfaces constituted partly separate, partly integrated interfaces. In general, a client has more say in the design and construction phases than end-users (unless the end-users represent the owner). However, the client and end-user interfaces were intertwined in several ways during the construction processes. The task of the client was to clarify the end-users' needs simultaneously as they charted their resources and prioritized those needs. The communication between end-users and designers is often settled through clients. Yet in some cases end-users may collaborate directly with the architect designers.

In our study, the user collaborated with the project management and designers, and especially with the architect, contractors, and the operations manager. The client represented the city property agency that rented the schools from the owner, an enterprise managing school property. The representatives of the client, two architects from the city property agency collaborated with the actors of the projects in the client meetings. The project management and the main designer, i.e., the architect, introduced the project details to the representatives of the client for comments and discussion. For instance, the design of an induction loop for hearing-impaired pupils was discussed in several meetings. The operations manager interacted with the technical expert from the city property agency in several practical matters outside the formal meetings. For instance, they discussed the use of the CMMS software and the management of the automated locking systems on the properties.

The end-user interface consisted of the school's principal, teachers, pupils (parents), kitchen staff, cleaners and caretakers who met with the project manager, the architect, the HVAC-E engineer and the operations manager. The end-user representative from the city property agency presented the end-users' comments in the user meetings. Their comments usually concerned practicalities in the imagined use of the buildings. For instance, the teachers thought that the storage space was limited and badly located in the designs of the future building.

In our study, the architect used new means in the collaboration with the end-users in the renovation projects. He provided a BIM-based presentation of the building to the headmaster and the teachers. The presentation visualized how the school facilities would look after the refurbishment. This was the first time that the teachers had seen a 3-dimensional presentation of the building; they had previously only seen the designs on paper. BIM-based collaboration is, however, challenging in the design of new school buildings because the principal and the teachers have not usually yet been hired during the design phase.

The operations manager had many face-to-face contacts with the end-users. He visited meetings at the school and introduced the life-cycle contract to the teachers. The developer, together with the operations manager, also used BIM to introduce the new school building to the pupils.

> Operations manager: *When we introduced this school to the pupils during the construction phase, we had a presentation from the model playing there in the back the whole time so that they were able to walk through the school corridors in the model. It's a great sales tool!* (Interview with the operations manager)

The challenges and problems of BIM use related, therefore, to the changes needed in the stakeholder relationships which would enable the end-user to become a more active partner in construction projects. In that case, the use of BIM could expand from being a tool of visualization to a tool used in collaboration between different stakeholders and end-users.

8. Summary and discussion

The findings on the main challenges, problems and expansive uses of BIM in the four social interfaces are summarized in Table 2.

The main challenge between the design disciplines related to the integrated use of BIM during the design process. Firstly, the designers did not find the integrated model useful. For instance, the contents of the list of clashes created with the integrated software did not meet the needs of the designers. Secondly, the designers could not use the integrated model for co-designing in real time, but they had to rework the changes in their expert models. Thirdly, the designers themselves did not make good use of the available BIM software in the design meetings. Some of the designers used BIM for their own work instead of for joint use in these meetings. According to the genealogy of the instruments, the artifacts themselves have been modified to perform new functions, but challenges still remain in the technical development of BIM as well as in the development of its local use. However, the interviewees themselves agreed that the quality of the designs had been locally improved during the implementation of BIM. The use of the project bank and the integrated model are signals of expansions in the individual and collaborative uses of BIM.

Table 2. Findings on the main challenges, problems and expansive uses of BIM in the social interfaces.

	Interface between the design disciplines	Interface between the designers and the construction site managers	Interface between the designers, construction site managers and the operations manager	Client and end-user interfaces
Main challenge	Problems in the integrated use of expert models during the design process	BIM implemented without developing the information content for the construction site use	Disconnections between BIM and the tools used in the maintenance	BIM used primarily for the presentation of buildings
Problems	- The lists of design errors exported from the integrated model were difficult to use. - The designers were not able to use the integrated model for co-designing in real time. - Some designers used BIM only to conduct their own work in the design meetings.	- The BIM-based 3D designs were flawed and incomplete. -The site engineers had to use multiple models and software applications. -The designs were handed over to the construction site late. - BIM was used by the construction site management but not by others.	- BIM (e.g., the geometrical 3D model) was not used in the transfer of information during the maintenance of the buildings. - Changes were not updated in the 3D model during the construction and the maintenance.	- Designers, constructors and maintainers cannot collaborate with the end-users because they may not yet have been hired during the construction process.
Expansions	- The project bank was used for the creation of the integrated model. - BIM was used jointly for problem solving in the special meetings.	- The site engineers reworked BIM models for their own uses. - The sub-contractors and construction workers used BIM-based designs in their work.		- The architect used BIM to show the headmasters and the teachers the design of the renovated school. - The developer and the operations manager used BIM to show the design of their school.

The main challenge between the designers and the construction site management was the implementation of BIM without developing the content of the information handed over from the designers to the construction site. The 3D designs were flawed and lacked the detailed information expected at the construction site. Compared to the use of computer-aided design (CAD), a new kind of information content is required in the designs completed with BIM software. The designs were late when handed over to the construction site, the site engineers had to use multiple models and software programs in their work, and the construction site management was the only party that was able to use BIM. BIM is only on the first level of its genesis of becoming an instrument because it does not entirely and permanently fulfill the functions required in the construction site. On the other hand, the signals of expansive use, i.e., the site engineers' reworking of BIM for their own purposes, point towards a more stabilized use.

The problems related to maintenance are due to two partly separated lines of developments of digital tools in construction. Both BIM and maintenance software have been developed to meet the needs of specific uses in two different circumstances, i.e., the design process and operations management. As a consequence, the main challenge is to overcome the difficulties of connecting the two sets of tools. BIM was not used in the operation of the buildings, and it was a problem to transfer information from BIM to the CMMS in use. In addition, it remained unclear whether the installers and caretakers would update the as-built model during maintenance.

Science and technology policy and the construction industry emphasize the benefits of BIM use for end-users. However, the challenges and benefits of the use of BIM tools were not much discussed at the client and end-user interface in our study. Clients and users do not have access to the project repository where BIM models created by different designers are kept for collaborative use. BIM use also requires new technological interfaces to be effective in the client and end-user interface. An operations manager stated that "BIM needs to be developed for ordinary people and not only for engineers to use."

The implementation of BIM started from the design activity and is now spreading to other phases of construction projects. The collaborative forms of BIM use are also under development in the design of buildings. But the use of BIM is still limited in the other three interphases of construction projects. The adaption of BIM is emerging slowly because the development of specific BIM technologies and a set of supplementary tools are required at each interphase of construction activity.

In activity theory, tools are often analyzed as well-bounded and defined entities. The study of BIM challenges this view because BIM is an evolving set of software developed for various purposes. It can be characterized as a multi-functional technology (Engeström, 2007) or a configuration technology (Fleck, 1994), which is locally 'combined' to meet the circumstances and capabilities of the stakeholders in the construction process. This poses a challenge for studying the implementation process of BIM. It includes both using several software programs and organizing the collaborative use of BIM by defining the division of labor, responsibilities and rules.

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