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Implementing information systems with project teams using ethnographic–action research

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Architecture, engineering, and construction (AEC) projects are characterized by a large variation in requirements and work routines. Therefore, it is difficult to develop and implement information systems to support projects. To address these challenges, this paper presents a project-centric research and development methodology that combines ethnographic observation of practitioners working in local project organizations to understand their local requirements and the iterative improvement of information systems directly on projects in small action research implementation cycles. The paper shows the practical feasibility of the theoretical methodology using cases from AEC projects in North America and Europe. The cases provide evidence that ethnographic–action research is well suited to support the development and implementation of information systems. In particular, the paper shows that the method enabled researchers on the cases to identify specific problems on AEC projects and, additionally, helped these researchers to adapt information systems accordingly in close collaboration with the practitioners working on these projects.

1. Introduction

The architectural, engineering, and construction (AEC) industry produces complex, customized, and highly unique products. Therefore, it organizes its work force on temporary projects [1]. Due to this temporary and highly complex nature of projects, work routines are characterized by a paradoxical situation. On one hand, project information that practitioners require is updated frequently, often tacitly in the heads of the engineers as routines strongly rely on individual experience [2]. On the other hand, due to the large number of the stakeholders involved, a frequent exchange of information is necessary. Information systems that support such AEC project routines are poised to overcome these problems. Therefore, it is not surprising that the AEC industry has identified the implementation of information systems as one of the most important areas to improve the productivity on AEC projects [3–5]. However, in practice, our experiences from a large number of projects show that information systems are often not leveraged to their full potential benefits [6].

From a technological standpoint this problem can be attributed to two factors. First system developers have found it difficult to gain an enhanced understanding of the tacit knowledge of the AEC professionals to develop information systems that support product and project management routines. Therefore, so far, system developers have not been able to adequately and explicitly formalize existing project routines in information systems. Second, even if information systems exist, they often cannot be adjusted easily to work routines of specific AEC projects. However, as practitioners tend to use different work routines for the same tasks from one project to another and even on one single project as requirements change [7] the possibility for practitioners to adjust information systems to local requirements is very important. These two problems of existing information system solutions have caused a large gap between how practitioners can use information systems on projects today and the potential benefits that technology managers and software companies promise. This gap, in turn, is one of the reasons for the low acceptance of information systems among AEC practitioners [8].

To circumvent these technical problems, project level models of information system implementations by project teams [8] suggest that a successful implementation of information systems on projects has to be driven by the project managers working at the operational level themselves. However, project managers often lack in-depth knowledge of software implementation and development. Therefore, it is important that technology developers support project managers during such project based implementations. This paper shows how technology developers can apply ethnography [7,9] and action research [10–12] methodologies to support project based implementations. In detail, the paper proposes that ethnographic–action research methodology is well

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suited to support project based implementations because project team members are actively involved during the development and implementation processes. The paper also provides case based evidence for this argument from the application of ethnographic–action research on a number of AEC projects. Summarizing, the findings from the cases show that the methodology is well suited to formulate work routines that AEC professionals face during their day-to-day work, to understand these routines well, and to adjust information systems to these routines as well as to changes in these routines throughout the life-time of a project and across different projects. In this way, the paper contributes to existing theories of ethnography and action research by showing the applicability of the ethnographic–action research method for the development of information systems for the AEC industry.

The paper is structured as follows: The second section describes factors that contribute to the heightened complexity of work routines and assesses the shortcomings of commercial available information systems and related research efforts. The third section summarizes the functionality that information systems need to have so that project teams can successfully implement them. The fourth section introduces the project-centric research and technology development and implementation methodology and shows how it can support the successful development and implementation of information systems. The fifth section traces information system implementations on a number of AEC projects to show how the methodology has been applied in practice and provide first evidence for the power and generality of the ethnographic–action research methodology. We, finally, conclude the paper by analyzing the cases with respect to their relevance for the field of project-centric information system development and by elaborating on the limitations and boundary conditions of the presented methodology.

2. AEC projects and information systems today

Past empirical research on more than 27 AEC projects shows that AEC practitioners so far have not widely started to embrace information systems [6]. One reason for this lack of embracement is the inability of currently available information systems and the related research to support AEC project routines. Two main problems exist that cause this gap between project routines and information systems.

The first problem for the missing support of AEC project routines is that existing information systems and AEC research results do not support the duality of product and project management. Professionals working on projects not only need to manage the product itself, but they also need to manage the resources required to build the product [13], such as productivity rates of the design team, or the costs of regional materials. An example of a project management task that includes these two dimensions is the design of mechanical, electrical, and plumbing (MEP) systems. On the product side, information systems should support the multi-disciplinary design of the MEP systems itself. On the project management side, an information system additionally should support management routines, for example, to support the different stakeholders to resolve conflicts between sub-systems, or whether and how stakeholders update project budgets and schedules throughout the design. However, currently available AEC information systems and AEC information system research does not sufficiently support this duality.

The AEC industry has a long tradition to support project management-specific routines on the project level with respect to cost, schedule and resource management with information systems. Lately researchers have started to develop architectures to integrate product management routines into these project management systems [14,15]. However, most of the state-of-the-art project management systems do not yet use underlying data models to support product management. Usually product information can currently only be stored in project management systems as unstructured data in the form of file formats that are only supported by third-party software applications. Thus, it is not easy for AEC professionals that work on projects to aggregate and incorporate AEC project information across product and project management functions using existing cost, schedule, or resource management information systems.

On the product management side, information systems enable practitioners to manage the development of a product throughout its life-cycle. For example, PLM solutions allow engineers to make decisions about the development status of a product and, in particular, they enable engineers to manage multi-stakeholder product design efforts [16]. One of the main features of PLM solutions is the storage of three-dimensional product data that enables engineers to view the product from different angles and to cut arbitrary sections through it. In this way, PLM solutions can support work routines during the development of the product visually. Furthermore, a product breakdown structure supports the management of related product subsystems. Information from each of the product's sub-functionalities can be aggregated to support the management of the overall product development processes. However, most of the commercial product life-cycle systems specifically support the manufacturing, automotive, and aerospace industries and thus do not specifically support AEC project routines. Furthermore, project management contributes to only about 5% of the functionality of an overall PLM solution [17, p. 407] and thus PLM solutions in general again do not support the duality of product and project management.

Next to these commercially available PLM solutions, significant research has been conducted in the area of product modeling. For example, researchers have developed the industry foundation classes (IFC), a quasi-standard data model to capture three-dimensional representations and related data of buildings [18]. Additionally, researchers have developed product management methodologies to enable engineers to collaboratively develop features of a product [19–23]. The leading CAD companies have commercialized some of these research results in commercially available product management applications, so called building information modeling (BIM) tools. These BIMs promise to support work routines during the design and construction of buildings. However, the practical impact of BIM so far has been insignificant and thus most of the research efforts we outline above had little impact on practice so far.

The low practical impact of these BIM research efforts is partly because researchers again do not sufficiently consider project management functionality during their product management research. Only a few studies have addressed the integration of project management functionality with BIM models, mainly in the area of change management [24–26]. Summarizing, similar to the available project management solutions, the existing product management solutions and research efforts often do not align well with the duality of product and project management work routines of AEC projects and, therefore, an adjustment to specific project routines is hardly possible.

Next to the missing support of simultaneous project and product management routines, the second technical reason for the slow uptake of existing information systems and related research results is the low adaptability of the systems to local project requirements. AEC project routines, such as building systems design [27], constructability review [15], or cost estimation [28], are highly knowledge intensive [29,30]. It is, therefore, not surprising that due to the knowledge intensiveness of project routines and due to the temporary nature of AEC projects, routines differ across projects and even change over the life-cycle of a single project. The uniqueness and changing character of project routines is further heightened as different organizations with their own social cultures work together and have to interact frequently [31,2,32]. Thus, AEC project routines are, additionally, highly sensitive to varying organizational settings [33].

Despite the clear need to support the highly unique and dynamic nature of project routines with highly adaptive information systems, much research and many software development efforts have focused on advancing generalized data models. Obviously, such research does not consider ways of how AEC practitioners can adjust information systems to the varying characteristics of specific AEC projects. Additionally, it is a recent trend that information system development started to focus on integrating product and project management information from a number of different projects to enable firm-wide resource planning. This in turn, requires a further standardization of the information systems across the different projects of an AEC company. Obviously, these standardization efforts are conflicting with the requirements to adjust information systems to local project routines.

Even worse, most software companies develop commercial information systems using the traditional product management life-cycle [34, chapter 4]. Only after an intensive invention and software development phase in the software companies' offices that often lasts a number of years, do the software companies try to implement the developed information systems on AEC projects. Obviously, it is hard to account for local project routines and the ever changing professional requirements with this development model. Even if software companies are willing to support some required project-specific functions, it usually takes one to two years until the next version of the information system that provides the respective functionality is delivered.

In summary, this section argues that there exists a large gap between the potential benefits of information systems and related research results to support AEC project routines and the ability of existing systems to support AEC project routines in a practical context. By reviewing commercial and academic efforts to develop information systems for the AEC industry, the section shows that, so far, no commercial system has been developed that supports the both dimensions – product and project management – of AEC routines sufficiently. Furthermore, we argue that the low adaptability of the systems to local project contexts is a second reason for the large gap between potential benefits and the current possibilities. Due to the information system developers' focus on enterprise wide resource management and their long update delivery cycles existing commercial solutions do not offer sufficient functionality to enable project teams to adjust the information management to specific requirements of AEC projects. To overcome these shortcomings, the next section introduces a number of technical requirements for information systems that system developers should consider to reduce this gap between the technical reality and potential benefits of information systems.

3. Implementation and development challenges for AEC information systems

The previous section argues that a project's information systems should support both product and project management, that current methods support one or the other, but not both, and that it is difficult to implement these systems on AEC projects because each project is unique. Considering these challenges, we propose that information system developers address the following issues during the development and implementation of information systems in a project context:

- System developers need to gain an enhanced understanding of the complex project routines that manage the product and project at the same time. Only if an information system's functionality matches this complex duality, the system can adequately support AEC practitioners [35].
- System developers should develop an understanding about the unique work routines on specific projects.
- System developers need to gain an in-depth understanding of the different viewpoints of practitioners [11, p. 49, 36]. Hereby, it is especially important to understand how practitioners interact with each other. How professionals communicate, in turn, is largely defined by the roles, norms and values of the professionals that change from project to project and during the life-cycle of a project. Therefore, again, an enhanced understanding of local project contexts is necessary.
- Finally, it is unlikely that stable work routines will crystallize in the short life-time of a project. Therefore, system developers should anticipate that practitioners will change existing routines, after they started using an information system. Thus already developed and implemented information systems might model obsolete routines. It is, therefore, important to enable and support the ability to constantly adapt information systems to local project conditions and project challenges [8].

The next section will propose a research methodology to support system developers with this task.

4. Ethnographic–action research

In this section, we suggest that AEC information system developers become researchers that apply action research, a well-established method to do case research on projects. Action research is well suited to solve many of the problems we discussed earlier [10]. One important characteristic of action research is that practitioners and researchers work closely together throughout the whole research process. The researchers start doing practical project work and the AEC practitioner starts doing research. In this way it is possible to gather and simultaneously verify knowledge about complex project routines and how practitioners follow these routines on their respective project. Researchers [10–12] usually describe the action research process as iterative cycles of observation of practitioners, identification of problems, development of technical solutions, and implementation of the developed solutions. This action research process in the area of the design of engineering applications has been shown by, for example [35,37].

Action research methodology stresses that during practitioner observation and data analysis, it is important to gain an in-depth understanding about local project routines from the project team member's viewpoint. This in-depth understanding, in turn, then ensures that the developed information systems integrate well into the project context. However, action research methodology, in general, does not offer detailed tools and techniques to achieve such an understanding.

Complementing action research, ethnographic research can provide such tools and techniques. While, traditionally, the ethnographic methodology was developed by anthropologists to study human cultures [9], in the last two decades, technology researchers have started to use the methodology to observe the implementation of technologies within social systems to inform the design of the technologies. For example, Suchman [38] observed the work of flight controllers at airports and their interaction with different flight control systems, Barrett et al. [39] observed how system administrators managed autonomic computer systems, or Heath and Luff [36] observed the interaction of control managers of the London Underground with technology. Recent summaries of ethnographic methodologies to support technology design with fieldwork can be found in Randall et al. [7] or Iqbal et al. [40]. A number of researchers in the AEC industry have already observed and improved the use of technologies by AEC practitioners on projects using ethnographic–action research case studies: For example, Jongeling and Olofsson's [41] exploration of how three-dimensional product models support the scheduling of work-flows, Hartmann and Fischer's [15] exploration of how three-dimensional product models support constructability review, or Khanzode et al. [42–44] exploration of how three-dimensional models can support the coordination of the product design and production of MEP systems. All of these studies have in common that they closely observed the work of practitioners within their local routines on AEC projects.

The difference between ethnographic studies and traditional research is that researchers try to understand how project team members interpret experiences and create social behavior [9]. In other words, the focus of the research is to understand how the professionals act, think, and feel during their daily work. This understanding can then be used to implement and customize information systems to the local project culture, instead of trying to force the use of a ready made system that might more or less well support the project team. During ethnographic research, it is, therefore, important to closely follow AEC practitioners during their daily work and learn the language that the AEC professionals speak. Ethnographic–action researchers should become students of the project team members [9, p. 4] learning how AEC professionals create, exchange, and communicate information during their work routine and what artifacts they use to do so.

Ethnographic–action researchers need to collect data from different sources, such as passive observations, participant observations, interviews and other documents such as meeting minutes or reports that can support their observations [45]. Thus ethnographic data collection requires, in general, a very close integration of project team and researchers. Ethnographic–action researchers can then analyze this collected data by triangulating the different data sources to inform information system design [46,47].

Ethnographic–action researchers should not try to formulate product and project management routines that AEC professionals might use applying previous knowledge before they start analyzing the data. Instead, ethnographic–action researchers should especially focus on identifying the work routines of the local project team members that is expressed in the data. Furthermore, ethnographic–action researchers should constantly compare previously explicitly defined routines with newly made observations [48,49]. To compare initial results ethnographic–action researchers can, for example, discuss their preliminary findings with members of the project team and with other AEC professionals.

Fig. 1 shows the ethnographic–action research process to develop information systems. At the start of the iterative loop, ethnographic–action researchers observe project routines and the required information for these routines using ethnographic research methodologies. By discussing their observations with the practitioners on the project, ethnographic–action researchers can identify those routines that an information system can support beneficially. Ethnographic–action researchers then program new information systems or re-program existing ones to support those routines. Consecutively, the project team members together with the ethnographic–action researchers implement these developed systems on the case project. Finally, ethnographic–action researchers and project team members engage in another iteration of observations, analyses, development and implementation to validate or further improve the developed systems or to find a solution to support another of the project's routines.

Summarizing, we propose that technology developers use the ethnographic–action research approaches to effectively support project teams with developing and implementing information systems. In detail we propose the following:

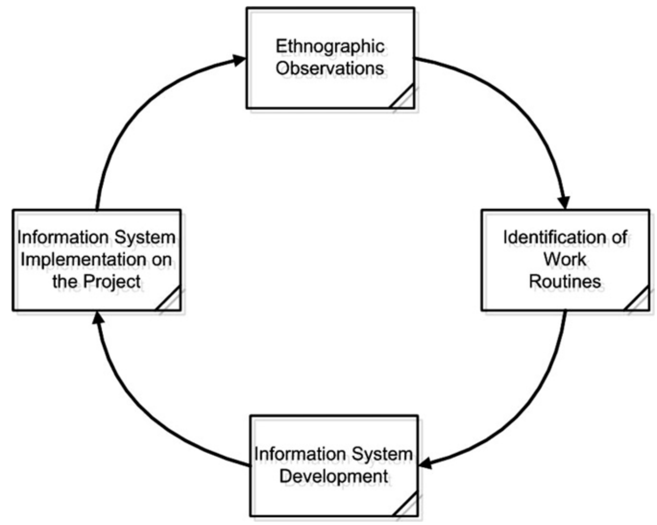

Fig. 1. Ethnographic–action research cycle for the development of an information system.

- Using the ethnographic–action research methodology, technology developers can develop an in-depth understanding about local project routines.
- Using the ethnographic–action research methodology, technology developers can develop an enhanced understanding of the complex problems that practitioners face during their daily work routines and, thus, of the tacit knowledge that practitioners possess and use while following these routines.
- Due to the iterative nature of ethnographic–action research, researchers can account for how practitioners change routines and enables researchers to react to the frequent changes that occur on projects.

In the next section, we provide evidence for the validity of our propositions from observations from projects that applied the ethnographic–action research methodology in practice.

5. Information system implementation and development with ethnographic–action research

This section traces two cases of the application of the ethnographic–action research methodology on four real world AEC projects that we supported with the implementation and development of information systems. The first case describes a longitudinal application of ethnographic–action research on one project for the period of one year (the first author of the paper was the leading ethnographic–action researcher on this project). On this project, we applied several ethnographic–action research cycles to improve an information system. As we did not have a formal understanding of ethnographic–action research when we started the effort on this project, we supported this project using the methodology unintentionally. Looking back, however, we used the formal methodology that Randall et al. [7] describe, and our reflections from the work on this project helped us to formalize the application of ethnographic–action research on other projects. The second case describes a cross-sectional application of the methodology on three different projects that shows that iterations of the ethnographic–action research cycles can be conducted on a number of different projects by different ethnographic–action

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researchers. We collected data from the projects using multiple data collection methods, such as interviews, observations, and archival sources [45]. Additionally, as we conducted participant research our personal experiences while supporting the projects served as an important source of information [50, p. 93]. We analyzed the data using Yin's [45] process of using data from case studies to provide evidence for research hypotheses and Miles and Huberman's [47] methodologies to analyze qualitative data by triangulation of different data types. The four cases are summarized in Table 1.

6. Information systems to support construction sequencing

The first case project is characterized by a highly complex objective: to connect seven subway lines underground to enable passengers to transfer easily between the trains of each of the lines and to construct an above ground transit hub to serve a highly congested metropolitan area. As a closure of the affected subway lines during construction was not a feasible option, one of the project's constraints was to maintain all subway stations operational at all times while performing the necessary construction work. Due to the complexity of this constraint – some of the subway stations serve more than 200,000 passengers a day – the construction management team decided to use a 4D system to evaluate how to best sequence the construction work without interrupting the ongoing subway traffic. Such 4D systems allow AEC professionals to link digital three-dimensional (3D) models of the project with construction schedules and visually simulate the construction sequences in the computer before they are built on site [51,52,6]. We have reported about the technical details of the implementation of the 4D system on this project in two other publications [15,53].

The application of the 4D system posed a large challenge for the project team with respect to information management. To simulate the construction sequences the project team had to create a three-dimensional computer model of the existing conditions of the project site and the proposed conditions from the submitted design drawings of the architects and engineers. Overall, the project team created 3D models representing more than 2,000,000 different building components that were stored in 228 different 3D model files. The project team then used the 4D system to link the building components in the 3D models to activities of a number of construction schedules, such as the master schedule of the client agency, or the schedules of the various contractors of the project that were responsible for conducting the construction work.

After a number of months of initial ethnographic observations on the project the researchers noticed a problem that persistently reoccurred and hindered the effective support of work routines with the 4D system. Due to the contractual framework of this project – the project team modeled the 3D models from the 2D drawings that the design company of the project submitted in

Table 1
Summary of the test case projects

Project 1	
Description	A large subway reconstruction project
Product and project management process supported	4D constructability review
Ethnographic–action research team	1 Ph.D. student
	6 Project team members
	2 Employees of the 4D software company
Project specific characteristics	Distributed 3D modeling among several 3D modelers
	Contractually defined design submission cycles
	Different project team members used different location specific 4D models
System development	Database to manage 3D model versions
	Database to manage 4D links between 3D objects and schedule activities
	Functionality to work with multiple 3D model files within 4D application
Project 2	
Description	Large hospital construction in California
Product and project management process supported	MEP coordination
Ethnographic–action	3 Project team members
Research team	2 Technology managers of one of the AEC firms
Project specific characteristics	Co-location of all stakeholders responsible for the MEP coordination
System development	Two systems to coordinate
	3D modeling efforts of the various stakeholders
	MEP conflict resolution
Project 3	
Description	Large hospital reconstruction in California
Product and project management process supported	MEP coordination
Ethnographic–action research team	1 Ph.D. student
	2 Project team members
	1 Technology manager of one of the AEC firms
Project specific characteristics	Geographically dispersed stakeholders
System development	Internet-based information system to help coordinate the 3D modeling efforts
	Conflict reports with snapshots of the conflicts to minimize the required communication during the resolution of clashes
Project 4	
Description	Large sport stadium construction in Eastern Europe
Product and project management process supported	MEP coordination
	Cost estimating
Ethnographic–action research team	1 Ph.D. student
	3 Technology managers of one of the construction firms
	2 Project team members
Project specific characteristics	Public project in Eastern Europe vs. private project in the USA
	Stadium vs. hospital
System development (ongoing)	Integration of information systems to manage 3D modeling efforts and conflict resolution
	Automated quantity take-off to support the cost estimation of key cost indicators for sport stadiums

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contractually defined design submission cycles – the 3D models often did not represent the latest design submissions. Therefore, the members of the project team had to understand which of the design submissions the respective 3D model represented to account for the version of the design during their decision making routines. However, there was no formal mechanism for the project team members to determine which of the design versions the 3D models were representing, and thus the members had to constantly compare the contents of the 3D models with the different 2D drawings of the various design submissions. As this task was very cumbersome and time consuming, this problem crystallized to one of the major technological barriers to applying the 4D system to support local project management routines.

After analyzing the observed problem the ethnographic–action researchers developed a solution to manage the relations between 3D models and 2D design drawings. They implemented a database that stores an entry for each revision of the 3D model files with fields for the date of the 2D design submission that the 3D model is based on, the name of the responsible 3D modeler, and the date when the modeler changed the 3D model. To enable easy access to the database for the 3D modelers and to enable the other project team members to easily access the database and get information about the respective 2D design version a 3D model was based on, the ethnographic–action researchers additionally implemented a graphical user interface. By implementing the database right away on the project the ethnographic–action researchers finally also followed the last step of the ethnographic–action research cycle (Fig. 1).

After the introduction of the version tracking database, the ethnographic–action researchers realized another problem specific to the local routines of the project. On the project the construction management team had established routines of creating a large number of 3D modeling files, to distribute the modeling work among a number of different 3D modelers. However, in the past, on other projects that applied the 4D software application that was used on the project, the project teams had decided to store the 3D model within a small number of 3D model files. Thus, the 4D software was designed for the use with a small number of 3D model files. Therefore, working with a large number of files was very time consuming for the engineers on the project. Additionally, the 4D application stored the links between 3D objects and scheduled activities in the particular 4D model file. However, in addition to enabling multiple modelers to work on the project, another intention of splitting up the overall 3D model into so many small 3D model files was to enable the construction management team to create different 4D models to support decision making tasks for specific parts of the site. Often, the project team required the 4D simulation of parts of the project that were contained in different 4D files that project team members had created previously. With the existing functionality of the 4D application, it was not possible to combine parts of two 4D files into a new 4D model. Thus, when creating a new 4D model, a project team member had to again manually re-link the required 3D geometry with the required schedule activities even if some of those links already existed in other 4D models. As the number of 4D models grew on the project – each based on a different subset of all the 3D model files and schedules – it also became increasingly cumbersome to maintain these 4D models as the underlying 3D models and schedules changed.

Again, the ethnographic–action researchers analyzed the problem resulting from the specific project organization and started to develop a solution. They contacted the 4D software company which granted access to their source code. Subsequently, the ethnographic–action researchers implemented the functionality required to import a large number of 3D files seamlessly. Furthermore, the ethnographic–action researcher implemented a database to store the respective links between 3D objects and schedule activities external to the 4D model files. They, additionally, developed functionality in the 4D software to import the 3D object-schedule activity links into the database and export links appropriate for a specific set of 3D objects and activities from the database into the 4D application. In this way, project team members were able to use 3D object-schedule activity links that had already been generated for other parts of the project to generate new 4D models. Again the ethnographic–action researchers introduced this functionality immediately on the project and, in this way, improved the project team's ability to support work routines with the 4D system significantly.

7. Information systems to support the coordination of building system design and construction

Researchers and practitioners see the improvement of the design and construction of MEP systems as one of the major opportunities to enable AEC projects to build facilities faster at lesser cost. They have this belief mainly because MEP systems account for about 40–60% of the total construction costs of a project and have become increasingly complex in the last couple of years [42]. One of the major issues with respect to the design and installation of MEP systems is that usually different contractors are responsible for the design of the different systems yet their design and construction are highly intertwined. Therefore, it is very challenging to coordinate the different contractors and integrate the different system designs to avoid possible conflicts during system installation.

Traditionally, practitioners manually overlay 2D drawings representing the various system designs to identify and resolve conflicts before contractors start to install the physical systems on site [28]. Systems that use 3D CAD models to automatically check for interferences in the different system designs promise to improve this manual and cumbersome coordination routine [42–44]. Furthermore, the use of 3D models enables the project participants to easily generate lists of quantities that estimators can use to estimate the cost of the project [28]. However, the application of automated clash detection and quantity take-off produces a vast amount of additional information that project stakeholders have to manage. As the existing clash detection systems do not yet support information management routines for specific project contexts, automated clash detection systems have not been applied widely in practice. This case describes how ethnographic–action researchers iteratively developed and implemented automated clash detection systems on three projects: two hospital projects in California, and a sport stadium project in Eastern Europe.

On the first project, at the start of the effort, two technology managers of one of the project's companies got closely involved with the project team. They spent a number of days per week on the project, observing the MEP coordination work of the project team. Furthermore, they conducted a number of unstructured interviews and intensively discussed issues with current work routines that the researchers identified during their observations. An analysis of this ethnographic data showed that the project team solved most of the problems with respect to the exchange of information and the management of the building systems by co-locating all the different parties into one office space. The data showed that most of the required coordination occurred directly between the different stakeholders without the need to support these integrated work routines with an information system. However, the analysis of ethnographic data also showed that the coordination of the 3D modeling effort on this project and the management of the resolution of conflicts posed problems for the project team. Often different team members did not generate required 3D models or resolved conflicts in a timely manner which delayed the work of other stakeholders. Therefore, the ethnographic–action researchers developed and implemented a coordination management system that was accessible by all project stakeholders. The system supported the project stakeholders in managing the timely 3D model delivery to run the automated clash detection for specific project parts. Furthermore, the ethnographic–action researchers supported the conflict resolution by developing and implementing a system to track responsibilities for resolving the conflicts. The results of the ethnographic–action research efforts on this project are published by Khanzode et al. [28,42,43].

Similar to the first project, on the second project ethnographic–action researchers, this time a Ph.D. student together with a technology manager of the project team's company, got involved who closely observed the project team's work. The researchers traveled to the project every second week and spent two to three days with the project team. They observed the work of the team and conducted a number of informal interviews with the team members. Additionally, the researchers collected all available documents about the construction project, like for example, schedules, meeting minutes, or construction drawings. An ethnographic analysis of the data showed that it was not possible to simply introduce the information system and the related routines that the ethnographic–action researchers had developed together with the first project's team. The analysis of the ethnographic data showed that due to the contractual relations on this project the project team was not able to co-locate all the MEP system contractors locally in one office. With this in mind, the ethnographic–action researchers started to implement information systems that could support collaborative decision making of all the stakeholders. The ethnographic–action researchers developed an Internet-based system to distributively manage the 3D modeling of the overall MEP system. The system also supported the management of the different versions of the submitted 3D models and the management of the different stakeholders responsible for the submissions. Consecutively, the ethnographic–action researchers supported the project stakeholders in developing routines to use the information system in another ethnographic–action research cycle. Furthermore, the ethnographic–action researchers on this project realized that managing the coordination of clashes by using a simple list of clashes posed problems for the practitioners as direct communication was limited due to the geographically dispersed stakeholders. Thus, it was important for all stakeholders to be able to identify the physical positions of the clashes within the 3D models easily during their clash resolution efforts. Therefore, the ethnographic–action researchers, additionally, developed an export of 3D model snapshots from the clash detection software into an issue list and implemented this feature directly on the project.

On the third project, a sport stadium construction in Eastern Europe, the ethnographic–action research efforts are still ongoing. Therefore, the following discussion of the research results on this project will not be as elaborate as in the previous cases. On this project, an ethnographic–action research team of two technology managers of the project team's company and one Ph.D. student have finalized a first round of ethnographic interviews with project team members. Analyzing the interview data to understand the project team's work routines, the ethnographic–action researchers have found two areas where an information system can support this project's project and product management routines. First, the analysis of the interviews showed that it is important for the project managers to resolve all the conflicts that they are responsible for before they submit a new version of the 3D model for another cycle of conflict detection. Therefore, the ethnographic–action researchers have concluded that a product management system that supports the integrated management of the 3D models, the 3D modeling schedule, and the issues in existing versions of the 3D models will support the project team. Furthermore, on this project the analysis of the ethnographic interviews showed that several of the project managers could be supported with the important task of estimating the costs of the MEP installation. Thus, the ethnographic–action researchers concluded that a project management system that automatically extracts key quantities from the 3D models will be helpful to support the project management routines on this project. Such a system would enable project team members to estimate whether the submitted design alternatives of the MEP contractors are within the project budget. At the moment of writing this paper, the ethnographic–action researchers have started to develop and implement systems that can support these identified project routines. In a next step, following the ethnographic–action research cycle, they plan to implement the systems on the project.

8. Implications

The findings on our cases provide evidence that Latour's [54, p. 107] claim that the traditional product management life-cycle of invention–development–implementation does not work well also holds for the development of information systems for AEC projects. The findings on our case studies show that a clear distinction between the invention, the development, and the implementation of the information system is not possible to develop and implement information systems that project participants can use and integrate seamlessly into their work routines. The iterative adjustment of the system to the respective project routines was necessary which blurred the boundaries between the stages. This finding might provide another explanation for the existence of the large gap between the potential benefits of previously developed commercial information systems and their ability to support local AEC work routines with them. The observations from the projects show that the ethnographic–action research model is a feasible alternative to develop information system for the AEC industry.

In detail, the findings from the longitudinal and the cross-sectional cases show that the ethnographic–action research methodology worked well to identify problems AEC practitioners face with specific product and project management routines, and to react to changes by a flexibly developing and implementing supportive information systems. In all the cases the researchers were able to identify complex problems that practitioners faced with their day-to-day routines using the ethnographic–action research method. For example, on the first case the researcher realized that project managers had to be aware of the respective version of 2D design documents the 3D models are based upon to be able to use the 4D system. In the MEP coordination cases, the ethnographic–action researchers identified, for example, that the management of the 3D modeling effort and the coordination of the resolution of identified conflicts posed problems for the engineers. Furthermore, both cases show that the ethnographic–action researchers gained insights about the various work routines on the projects with ethnographic observations and by conducting ethnographic interviews. On the first case, for example, the ethnographic–action researchers recognized quickly that the project team on this project worked with a large number of different 3D model files, an approach that had not been previously considered by the 4D software vendor company, but was beneficial to support local routines on this project. Thus, even though a number of projects had used the 4D software successful previously, on this project, without the intervention of the ethnographic–action researchers, it would probably not have been possible to close the gap between the potential benefits of the 4D system and how it could be objectively used on the project. Therefore, it would have been likely that the practitioners would have declared 4D modeling as not useful to support their work. The MEP

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coordination cases show how the methodology helped to provide insights into the work routines of the three different projects and highlighted the possibility for the ethnographic–action researchers to custom-tailor information systems that supported each of the respective project environments. The MEP coordination cases also show how the ethnographic–action researchers were able to understand differences in work routines across a number of projects. For example, on the second project in the MEP coordination case, the ethnographic–action researchers realized that practitioners started to understand conflicts directly within the 3D models and no longer used 2D drawings. The ethnographic–action researchers reacted to this change in the working habits by providing 3D model snapshots of clashes that enabled the easy location of conflicts within 3D models. In summary, the findings from our cases show that by using the ethnographic–action research methodology it was possible for the ethnographic–action researchers to integrate information systems closely with the requirements on the local projects. In this way it was possible to reduce the gap between the potential benefits that the information system promised for the project and the technical reality of how well the systems supported local project routines in detail. This reduced gap, in turn, led to a higher acceptance of the information systems among the project team members and in the end project members applied the systems successfully on all the case projects to support routines.

Summarizing, the findings from the cases show that ethnographic–action research can work well for the development of information systems within the AEC industry. Thus, our empirical studies complement existing theory about ethnographic and action research methodologies. One of the major criticisms to the ethnographic research methodology for supporting systems design is that its applicability is mainly shown for relatively well-defined computer-supported cooperative work (CSCW), such as control rooms for airport or underground traffic control. Therefore, researchers have criticized that ethnographic research might not be applicable for less well-defined organizations. So far, few researchers have tried to identify for which settings the methodology is appropriate and for which settings it is not [39,7, p. 7]. This paper shows that ethnographic–action research is appropriate to develop information systems within the ill-defined, more complex settings of AEC projects.

From an academic standpoint ethnographic research and action research methodologies make it hard for researchers to develop general and theoretical constructs that can differentiate the results of the ethnographic–action research from consultancy work [10]. Eden and Huxham [29] identified a number of requirements that researchers need to fulfill so that action research can be considered as qualitative research that provides general and powerful results. Table 2 argues that these requirements are fulfilled for the ethnographic research of the cases. We argue that while we agree that ethnographic or action research cannot typically produce research results that are general to a great extent, we believe that it is important for researchers in the AEC industry to realize that due to the complex and changing character of the industry it is overall challenging for researchers to develop generalized research results with any research methodology. Therefore, ethnographic–action research might actually be a good approach to generalize constructs through the iterative application of research findings from one project on a number of other projects as we showed with the MEP coordination cases. In detail, the application of ethnographic–action research on the MEP coordination cases provides evidence that the ethnographic research methodology can additionally inform information system research and is not only system development or consulting activity without any generalizability of the outcomes. Additionally, Table 2 argues that the ethnographic–action research methodology on the cases provides valid results because the researchers applied generally accepted and orderly case study research methodologies [45–47]. Finally, Table 2 argues that the use of the ethnographic–action research methodology was appropriate because researchers would not have been able to use other methodologies to reach the general and powerful results that the researchers found on the cases.

9. Limitations, boundary conditions, and outlook

This paper provides evidence that the ethnographic–action research methodology works well for the development of information systems to support construction sequencing and MEP coordination on AEC projects. In other contexts it might be appropriate to use different methods. For example, the methodology might not work well for the development of technologies that require a more

Table 2
Reasons why the ethnographic–action research on the cases is different from simple consulting activities

Criteria	Requirement	Argument to justify the validity of the case research
Generality	• Ethnographic–action research must have implications beyond the domain of the projects • Ethnographic–action research demands an explicit concern with theory • The basis for designing tools, techniques, models, and methods must be explicitly shown and related to theory • Ethnographic–action research will develop emergent theory • Theory building will be incremental, moving from particular to general in small steps • The presenters of ethnographic–action research must be clear what they expect the consumer to take from it and present the findings of the ethnographic–action research with a form and style appropriate to this aim • The result of detecting the emergent theories must be demonstrable through argument and analysis	The ethnographic–action research on the first project shows how the constructability review on AEC projects can be supported with information systems. The generalized findings have been published in a peer-reviewed journal paper [15]. The research approach has been based on previous theory [51,52], and the findings complement this theory The case of the MEP coordination shows how ethnographic–action researchers used results from one project to inform the routines of other projects and thus provides evidence that ethnographic–action researchers can generalize the findings published for the first project [42,43] for the use on other projects. Additionally, ethnographic–action researchers again consulted and extended previously developed theories about MEP coordination [27]. Also, the results have been published in a peer-reviewed journal paper [44]
Validity	• A high degree of method and orderliness is required in reflecting about the emergent research • The possibilities of triangulation should be fully exploited • The history and context for the intervention must be taken as critically	On both cases, generally accepted qualitative research methodologies have been applied [45–47] that suggest an orderly theory development process [45], triangulation of data [45,47], and considerations of history and context [46,47]
Appropriateness	• The data collection process should focus on aspects that cannot be easily identified by other methods	As there is little room for experimentation with different information system designs during the short life-time of a project, the developed information systems have to be right the first time around. Ethnographic–research supports the development of technologies in such environments [7, p. 19]. We suspect that other research and data collection methodologies would not have worked well in the contexts we present in this paper and found on many AEC projects

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profound computer science or engineering informatics background then the two systems we present in this paper, such as CAD applications or finite element software. However, other researchers have shown the applicability of iterative development methodologies for more complicated systems that, for example, compute project cost probabilities [37]. Another problem of our research is that ethnographers that wish to inform system design need to take the standpoint of one group of actors within an organization [55,7, p. 39]. As we focused on one level of analysis in this paper – the project team –, ethnographic–action research, as we present it here, does not reflect the requirements for other actors, such as, upper management. To develop systems that satisfy the needs of the different stakeholders an analysis of the different stakeholder viewpoints is necessary [56]. How such a viewpoint analysis integrates into the ethnographic–action research methodology needs to be addressed by future research.

Our findings on the cases point out a number of other limitations and boundary conditions of the ethnographic–action research methodology. Two inherent problems occur at the intersection between ethnographic research and action research. It was often not easy for the researchers to identify the right moment of when to convert the findings from the ethnographic observations into implemented software. The point of time of a technology intervention on projects is a sensitive issue [57, p. 12]. If ethnographic–action researchers intervene too early with the introduction of an iteratively improved version of the system, the project stakeholders are often not able to readily apply the new version as the ethnographic–action researchers have not yet observed important requirements that must be met to support the project team members. On the other hand, if the ethnographic–action researchers intervene too late, valuable time is lost, both to improve the product and project management routines of the practitioners and to make valuable observations of how practitioners apply the new version of the system. The second problem is that – especially if multiple ethnographic–action researchers are involved in a research effort – the results and reports of ethnographic–research efforts lack consistency and are often incomplete. Therefore, the ethnographic–action researchers on the cases often struggled with translating the findings of their observations into the analytical model representations that are required to program information systems. Models of how to translate a narrative scenario description into a formal model description are poised to help during these translation efforts [25,57]. How ethnographic–action researchers can integrate these models into the ethnographic–action research methodology, however, remains an open problem for future research efforts.

Another common critique is that ethnographic–action research is limited to the development of relatively small systems and that the methodology is time intensive [7, p. 4]. The findings on our cases show, however, that with the small iterative ethnographic–action research improvement cycles the research subjects can be almost immediately supported by the research results. In this way the subjects of the ethnographic observations can quickly profit from productivity gains and the significant costs of the application of the ethnographic methodology can be counteracted. Another problem caused by the iterative character of the method is that researchers, technology managers, and technology developers alike are usually evaluated by the immediate magnitude of the success of an implemented software system. It may be hard for each of these parties to justify the slow and piecemeal improvement process of the ethnographic–action research methodology. All participants in ethnographic–action research efforts have to understand that there will not be immediate and significant changes in the project routines and productivity, but, that changes are slow and continuous.

Additionally, during ethnographic–action research it is important to overcome the resistance of possible system users to use the system during their daily work. Resistance to use has been cited as one of the major impediments to the successful implementation of technologies [59]. The ethnographic–action research methodology will only work if the practitioners overcome their resistance and work closely together with the ethnographic–action researcher. To overcome this resistance is also one of the important factors for a sustainable success of the technology implementation after the ethnographic–action researchers have left the project. If projects cannot overcome the resistance of their members to use an information system, the use of the system often stops after the ethnographic–action researcher, who may have been driving the system implementation as a champion, leaves the project. However, the iterative character of the ethnographic–action research methodology can also improve the willingness of system users to apply the system in their daily work. The method helps to slowly close possible competency gaps [60] between existing work routines and the new routines that are supported by information systems. The method helps as the learning steps that the practitioners have to take to be able to use the system are smaller and as they realize that ethnographic–action researchers make the adjustments necessary to fit the technology to the local project routines.

A final limitation of the ethnographic–action research methodology is that while the methodology seems to be very applicable for researching software requirements, the methodology might cause problems with the development of the software itself. In particular, problems might arise if different ethnographic–action researchers make the same changes in the software. Furthermore, it is problematic to find and fix software bugs in real time. Therefore, to develop information systems for the AEC industry, new software development technologies and ways to manage software development approaches have to be applied that support a constant and iterative improvement of existing tools. Fortunately, in the last couple of years, such software tools have been developed. From a technology development standpoint asynchronous JavaScript and XML (AJAX) seems to be poised to support ethnographic–action research well. AJAX applications reside on centralized servers and use browser capabilities on client machines as user interfaces to the applications' functionalities [61]. This approach enables the central storage of all the application logic and data on a server. In this way, new versions of the applications can be updated quickly without shipping new releases to all users and the need for these users to reinstall applications locally. Furthermore, AJAX applications support the centralized storage of information and thus support collaborative work on AEC projects well. From a technology management standpoint, one of the main problems of the ethnographic–action research approach is to make information systems that have been developed for one project available to other projects that intend to use parts of the previously developed functionality or plan to extend the functionality. To support such an ongoing exchange of information systems between projects the traditional software delivery model does not work well. It is, for example, rare that software companies provide their source code to ethnographic–action researchers as it happened on one of the case projects. Open Source projects seem to be poised to support a successful and widespread application of the ethnographic–research methodology [62].

10. Conclusion

In this paper we present a novel approach of how to inform and support information system development for AEC projects. Based on the specificities of AEC projects we derive requirements for information systems to support AEC projects. In particular, we argue that information systems need to support the project specific duality of work routines that need to include both project and product management parts. Additionally, we argue that project team members need to be able to adjust work routines around information systems to specific requirements of unique projects. After deriving these requirements the paper proposes ethnographic–action research as a methodology to develop information systems that meet these identified requirements.

After a formal description of the methodology the paper qualitatively analyzes the application of the methodology on a number of construction projects. In this way we empirically provide evidence that the method works well to support the development of information systems. The application of the methodology on the cases shows in particular how the methodology enables system developers to develop information systems that support project based routines and that project team members can adjust well to local project conditions.

The paper finally closes with limitations and directions for future research. Next to a number of managerial problems during the implementation of information systems that are developed using ethnographic–action research, we also discuss the shortcomings of the methodology during the software development itself. We conclude that ethnographic–action research will especially work well together with new software development methodologies like AJAX and Open Source. In the long run, we envision that a vibrant Open Source AEC community could emerge that uses the ethnographic–action research methodology, develops information systems to support various product and project management routines in AJAX that are capable of improving the productivity on AEC projects, and shares these systems with other projects world-wide. We hope that, in this way, the AEC industry can finally profit largely from the promising potentials to improve AEC practice by using information systems.

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