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Beyond barriers – exploring resistance towards BIM through a knowledge infrastructure framework

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ABSTRACT
Building information modelling (BIM) is a digital tool that offers the possibility to collect and share a multitude of data about a building and increase collaboration across professional borders. However, the uptake of BIM in the construction industry has been relatively slow, and previous research has shown how BIM creates tensions in the workplace. In this article, we explore the impact of BIM on socio-technical knowledge practices, to understand how these are enabled or restricted by the use of BIM. Through a qualitative case study in Sweden, this article analyses BIM through a knowledge infrastructure framework to explain the relatively slow uptake of BIM in a new light. The results show that BIM lacks embeddedness in governmental and corporate practices and regulations and that it sometimes leads to the marginalization of some professions through changed organizations and the slow process of changing complex knowledge infrastructures. This suggests that a critical discussion of the role of BIM in relation to professional flexibility, construction project process organization and power over technological development is vital for the future development of the construction sector.

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Building information modelling; BIM; knowledge infrastructure; professional practice; construction industry; digitalization

Introduction

Professional roles are expected to change radically in the construction industry, as automation will take over many assignments (Succar 2009, Azhar et al. 2015). One important tool in this digitalization process is building information modelling (BIM), which is often defined as a 3D model of a building that holds information about all parts of a construction process (Bazjanac 2006). However, research on BIM has shown that cultural barriers between professions can be a problem (Becerik-Gerber *et al.* 2012, Alankarage *et al.* 2023) and that BIM implementation imposes challenges regarding changing work practices and professional roles (Vass and Karrbom Gustavsson 2017, Akintola *et al.* 2020). Furthermore, the inability to adjust processes and working arrangements has been reported to be the largest barrier to a successful implementation of BIM (Merschbrock *et al.* 2018). To understand these challenges there is a need for theoretically grounded and empirically informed studies to provide a view of BIM technology in practice (Hetemi *et al.* 2020). In addition, BIM requires new forms of expert knowledge and, to reach its full potential, new coordination strategies (Park and Lee 2017). While the construction industry is recognized to be knowledge-intensive, as it involves many different professions with various types of knowledge backgrounds and diverse project processes, how knowledge is dealt with in relation to BIM in construction projects is still understudied (Wang and Meng 2019). Although BIM and its impact on professional work have been critically addressed before (cf. Dainty *et al.* 2017, Akintola *et al.* 2020, 2021), a critical discussion of what impact the implementation of BIM has on the organization of knowledge practices in the construction industry is missing from the academic literature.

Definitions of knowledge have been discussed in various academic fields. In the organizational literature, there is often a distinction between cognitive and practice-based perspectives on knowledge (Gherardi and Nicolini 2000, Marshall 2008). Cognitive perspectives view knowledge as something “out there” – objective knowledge that can be received, stored and possessed by individuals (Marshall 2008). Consequently, it is often described as a static view of knowledge, building on dualistic reasonings (Cook and Seely-Brown 1999,

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Marshall 2008). Knowledge is thereby often discussed in terms of dichotomies, such as tacit or explicit knowledge and individual or group knowledge (Cook and Seely-Brown 1999). Furthermore, a cognitive perspective privileges explicit knowledge over tacit knowledge (Cook and Seely-Brown 1999). A basic assumption is that tacit knowledge can eventually be converted into explicit knowledge and can be articulated and codified through various codification methods (see Nonaka 1994). Looking at the construction industry, some for example claim that as much as 80% of useful construction knowledge is tacit (Sheehan *et al.* 2005). Others explain that using formal information tools, such as BIM, shifts focus towards explicit knowledge as BIM cannot capture important tacit knowledge (Addis 2016). In contrast, practice-based perspectives reject dualities and emphasize the dynamic and relational character of knowledge, considering knowledge as continuously enacted in practice (Gherardi and Nicolini 2000, Marshall 2008). A practice-based perspective also acknowledges that not all knowledge can be articulated, but places importance on learning and knowledge sharing through socialization by communities of practice (Cook and Seely-Brown 1999). While both described perspectives recognize that not all knowledge can be articulated, they offer different views on how this can be handled for improving professional work in construction. The concern of this paper is however not with the various types of knowledge types per se, but with how the implementation of BIM changes the organization of knowledge and the conditions for different types of knowledge practices. Using practice-based perspectives on knowledge as a starting point, this paper makes use of a socio-technical approach where the focus is on the interaction between people, technology, and their everyday practices. How things are made visible, audible, tangible, and knowable are in focus when studying socio-technical knowledge practices (cf. Mol and Law 2002). In line with Orlikowski (2007), the paper argues that knowledge is an ongoing social accomplishment, constituted and reconstituted in everyday practice. Knowledge is produced and negotiated in practices in different networks and is therefore never stable but an outcome of continuous processes of translation and the enrolment of various actors to a truth claim (Latour 1999). To aid in these translations, inscriptions – i.e. visual representation in some form – are used as a representation. Styhre (2008, p. 38) writes: "Knowledge is thus a practice/concept assemblage enabling for a seeing and doing as well as a saying and writing". In line with Styhre (2008) and our socio-technical inspirations, we will study BIM as an object of knowledge production by focusing on the practices of using BIM, its properties, and its networks. This will show how tensions related to BIM are grounded in everyday professional practice, which in turn can provide novel insights into how resistance can be mitigated or make different paths forward visible. The aim of this paper is thus to contribute with a deepened understanding of the tensions related to BIM by focusing on socio-technical knowledge practices and the infrastructure that comes with them.

BIM has an impact on professional roles (Merschbrock and Munkvold 2015) as well as role-taking, trust, communication, and leadership (Liu *et al.* 2017) and the importance of the connection between BIM and work organization is well established. BIM needs to be studied from a socio-technical perspective to capture the collaborative aspects of the technology since if BIM only is seen as an information-gathering tool and not a facilitator for collaborative practices, it might weaken the collaborations (Sackey *et al.* 2015, Merschbrock *et al.* 2018) Socio-technical systems have been proposed as a useful framework to understand BIM (Dossick and Neff 2011, Plesner and Horst 2013, Sackey *et al.* 2015, Merschbrock *et al.* 2018, Lindblad 2019) and these studies have made important contributions by showing the co-evolution of organization and technology. However, more empirically grounded socio-technical research covering BIM use in practice is needed (Plesner and Horst 2013, Gade and Svidt 2021) and there is still a need to discuss the socio-technical system of BIM to further understand its elements and dynamics (Sackey *et al.* 2015).

BIM implementation varies in different parts of the world, and this paper focuses on the Swedish construction sector, where some BIM structures are in place while others are lacking. Sweden is interesting since the institutional practices around BIM have not been settled and it is, therefore, a topical matter for debate. The lack of legal regulations for BIM models in Sweden also requires companies to work with 2D drawings as part of legal contracts, and this is reported to be hindering the implementation of BIM (Sundkvist *et al.* 2020). The Swedish construction sector is dominated by a large proportion of small companies, often with a low level of BIM implementation, and a few larger companies. Even though small companies dominate in numbers, the 30 largest companies in Sweden had a turnover of SEK 256 billion of the SEK 890 billion that the entire industry turned over in 2020 (Byggbranschen 2020). This corresponds to 22% of the entire industry's total net sales, and the engineering sector has ten larger companies which are leading the national development of BIM (Davies *et al.* 2015). One study of medium-sized Swedish companies showed that 58% of contractors used BIM in some projects, albeit mostly limited to visualizing capabilities (Bosch-Sijtsema *et al.* 2017). In a Swedish context, it is therefore interesting to follow a larger consultancy company as these markets themselves as having a prominent position within BIM development in Sweden. This article builds on a case study of a large consultancy firm in Sweden with a high digitalization profile.

Literature review

The introduction of BIM is sometimes argued to be a revolutionary turn in the construction industry through its use of 3D CAD software programs (Crotty 2013), creating a paradigm shift regarding how buildings are designed, constructed, and maintained (Elmualim and Gilder 2014). According to previous studies, the introduction of new technologies has the ability to influence and challenge traditional professional boundaries and change the nature of cooperation (Merschbrock and Munkvold 2015, Lindberg *et al.* 2017, Liu *et al.* 2017). The inability to adjust processes and working arrangements has also been reported to be the largest barrier to a successful implementation of BIM (Merschbrock *et al.* 2018). Likewise, positive expectations of BIM are argued to be dependent on the perceived compatibility of the technology with preferred and existing work practices (Davies and Harty 2013).

In relation to BIM, knowledge has been discussed in various settings, for example regarding clients' lack of knowledge and BIM as a knowledge management tool for maintenance (Motawa and Almarshad 2013), how to incorporate BIM into education (Succar and Sher 2014), and BIM in relation to knowledge-sharing (Ho *et al.* 2013). In one study, "messy talk" (the interstitial dialogue between and after formally organized agenda items) was studied in relation to BIM (Dossick and Neff 2011). The results showed that BIM does not replace talk for problem-solving or finding optimal solutions as these are distributed across disciplinary boundaries. However, BIM does support problem definition and explicit knowledge creation, but not tacit knowledge exchange (Dossick and Neff 2011).

The discussion of BIM as an important tool to revolutionize the construction industry has been met with critique (Smits *et al.* 2017). Dainty *et al.* (2017) argue that the debate on BIM is dominated by technocratic optimism. Likewise, Fox (2014) reports that descriptions of BIM are often characterized by hype and naïve claims about the technology as exceptionally unique and deeply socio-technical. Fox (2014) argues that other technologies within the construction industry are just as complex as they involve socio-cultural work, technology, and different actors. Likewise, researchers have criticized the tendency to transform the potential of BIM into a depiction of future realities, with little reflection on the constraints or situational aspects that will influence the possibilities to implement BIM (Miettinen and Paavola 2014). Inter-organizational studies of BIM have shown that BIM collaborations build on both formal and informal structures, and that cross-cultural case studies would add to the understanding of the complex socio-technical phenomenon of BIM-enabled partnering (Papadonikolaki *et al.* 2017). Socio-technical perspectives of BIM have also been presented in Lindblad (2019), who suggested that BIM needs to be embedded in a flexible way to avoid creating tensions, as it could risk becoming too rigid. Studies focusing on both technical and social factors in relation to BIM have shown how barriers towards BIM are both social and technical, but that social behaviour and social arrangement of the construction industry are the primary causes of barriers (Oesterreich and Teuteberg 2019). Merschbrock *et al.* (2018) studied BIM with a socio-technical framework which focused on the components: technology, tasks, actors, structure, processes, and interpretative flexibility, as well as their relationships both between themselves and external components. The findings from the case studies in this research project have demonstrated that similar technological setups still were faced with different challenges, which were argued to depend on social components and differences in collaborations (Merschbrock *et al.* 2018). Furthermore, the study showed that managers involved in BIM projects need to possess a wide range of knowledge, skills, and abilities also within social aspects and can benefit from prioritizing intuition, empathy, and proactivity over technical aspects. Close collaboration with stakeholders and long experience with different projects were also suggested as important for managers (Merschbrock *et al.* 2018). Building on the same framework as the previous mentioned study, Mani *et al.* (2022) show how the local context shapes the nature of BIM-induced changes. The study argues that even within one market and in an identical socioeconomic context, the nature of the client and the type of funding for a project is influential for BIM collaborations and thus, generic change management plans for all companies in one market are not a productive solution.

Some researchers argue that there is still a lack of interest in in-depth socio-technical research around BIM (Gade and Svidt 2021). These in-depth studies could benefit from moving beyond already identified phenomena of user resistance which often are reduced to cultural resistance in the form of habitual change and rely on a deterministic view of technology, independent of social concerns (Gade and Svidt 2021). With that purpose, Gade and Svidt (2021) explore BIM practices from an integrated socio-technical view, inspired by Orlikowski (2007). The aim of their study is to understand how technology is used in relation to the environment, by focusing on practices that constrain and facilitate technological development. Their results show that a strive for rule-based practices sometimes creates clarity in work practices, while in other settings it decreases the involvement of the users (Gade and Svidt 2021).

The significance of the context in relation to BIM has also been studied from an activity theory perspective with a focus on how socio-historical constructs guide BIM practices (Zomer *et al.* 2021). The introduction of BIM is shown to result in tensions due to a new division of labour. As an example, BIM created tensions concerning who had the responsibility for keeping the model updated. Likewise, the authors argue that power relations prohibited facility managers to be involved in the early stages of planning, which resulted in the client not being satisfied with the level of information. These tensions are argued to occur due to a linear understanding of the planning process, an unclear division of labour and institutionalized practices, which have existed for decades and are embodied within the work practices of the professionals (Zomer *et al.* 2021). For implementation to be effective, Zomer *et al.* (2021) argue that emphasis must be placed on the context and the interaction between new and institutionalized practices.

None of the socio-technically grounded studies focuses on the limitations and possibilities that BIM imposes on different types of knowledge practices. Building on previous studies, we argue that a socio-technical analysis of the organization of knowledge is missing from the academic literature on BIM and that this perspective would be beneficial to understand the tensions BIM brings.

A knowledge infrastructure framework

This article utilizes a theoretical framework inspired by knowledge infrastructures (Edwards 2010, Edwards *et al.* 2013, Bowker 2016). Knowledge infrastructures are "robust networks of people, artefacts, and institutions that generate, share, and maintain specific knowledge about human and natural worlds" (Edwards 2010, p.17). Thus, the collaboration between professional actors with digital tools in construction projects should be understood as a social and material web including organizational practices, traditions, and taken-for-granted understandings of the use of and access to these tools. However, in line with the practice-based perspective, knowledge infrastructures are not coherent, deliberately designed systems, and need to be studied in practice to understand the complex relationships involved. Knowledge infrastructures are dynamic systems, and their various elements are constantly changing – whether they are produced anew or maintained (Star and Bowker 2002). Knowledge infrastructures are often difficult to make visible, as they are taken-for-granted, functioning knowledge systems that rarely need to be discussed (Star and Bowker 2002). It is only when knowledge infrastructures are formed, somehow destabilized, or broken that they become visible (Bowker *et al.* 2010, Star and Bowker 2002). When a knowledge infrastructure has become invisible and has sunk into the fabric of everyday life, it brings a range of assumptions and power relations that may also become taken-for-granted. For this reason, it is important for researchers to bring infrastructures to the foreground and study the associated assumptions and the invisible work that goes into creating and sustaining the infrastructures (Bowker 1994). In recent studies, Bowker et al. (2009) have shown how digital infrastructures in research come with embedded values and argue that the decision we now make in relation to digital infrastructure will have long-term consequences. The introduction of BIM to the construction industry is in this paper considered as a change in the traditional knowledge infrastructures, and the paper addresses this change through three aspects of infrastructures: embeddedness, learned as part of membership in communities of practice and distributional consequences. Embeddedness is a central term regarding knowledge infrastructures, originating from Star and Ruhleder's (1996) work of analytically conceptualising infrastructures. The term embeddedness is in this paper helpful to discuss how supported and integrated BIM as a new knowledge infrastructure is in the national and local context. Since the implementation of new technology requires a change in the conventions of professional practices, a community of practice then sheds some light on how BIM shapes professional work and is, in turn, being shaped by communities of practice. Finally, according to a knowledge infrastructure framework, the introduction of new knowledge infrastructure, such as BIM, always involves distributional consequences (Edwards *et al.* 2013) as certain practices become privileged, resulting in others becoming undermined. The concept of distributional consequences offers a deeper understanding of which types of knowledge practice the implementation of BIM privileges and which types become marginalized.

Embeddedness

A basic assumption of a knowledge infrastructure framework is that knowledge infrastructures are tied to local practices, which means that changes are gradual and need to be negotiated and adjusted according to the other involved aspects of the system (Edwards 2010). Knowledge infrastructures are built on an existing base and are embedded into other social and technological structures (Star and Ruhleder 1996). Embeddedness in related infrastructures is vital for a knowledge infrastructure to become invisible and integrated into the everyday practices of an organization. The network around the knowledge infrastructure must support the included practices in the knowledge infrastructure, for example through professional learning networks or government regulations. When a knowledge infrastructure is not embedded in other networks, tension arises, and the knowledge infrastructure becomes visible.

The construction industry has several knowledge infrastructures in place, some of them more tied to traditional ways of working while others involve digital technologies. BIM is in this article understood as a knowledge infrastructure embedding several knowledge systems, which differ in structure and practice but can still be connected to the use of BIM. Therefore, BIM knowledge infrastructure is throughout the paper conceptualized as one infrastructure, despite recognizing its multifaceted and complex nature. This allows discussions regarding the changes in knowledge practices tied to BIM in a clearer way.

Membership in communities of practice

Star and Ruhleder (1996) suggest that the use of infrastructure is learned through different communities of practice. The idea of a community of practice was first made popular by Lave and Wenger (1991) and has since been inspirational to research in different disciplines. A community of practice is seen as a learning community consisting of groups of people connected by a common interest, who define their identities by the roles they play and the relationships they share in the group's activity. Membership in a community has been described to bring about familiarity with organizational arrangements and leads to certain practices being learned and eventually becoming taken for granted (Star and Ruhleder 1996). In relation to BIM, a community of practice shares an interest in constructing buildings and its professions work with BIM in some way, either directly or indirectly. Membership in a specific community of practice involves becoming familiar with and learning the conventions of that practice. As this is accomplished, infrastructures support these standard, routine, everyday practices and become invisible.

Furthermore, Star *et al.* (2003) argue that in modern organizations, community of practice and information artefacts (i.e. technological tools used to share information) are so intertwined that they are difficult to tell apart. "Put briefly, information artefacts undergird communities of practice, and communities of practice generate and depend on these same information resources. *Convergence* is a term for this process of mutual constitution." (Star *et al.* 2003, p. 244.) Professional socialization in the construction industry revolves tightly around convergence, where professionals are taught to use information artefacts as a central part of their work. Convergence might happen both formally, for example, education, and informally, such as from shared experiences between professionals. However, a convergence that is too tight risks coupling social worlds and their information artefacts too much, constraining possible actions and the use of imagination, as it is not part of the routines (Star *et al.* 2003). In relation to BIM, this article studies the connected communities of practice to understand the ways in which BIM reaches convergence and what consequences this brings to different professional practices.

Distributional consequences of knowledge infrastructure

Infrastructures are complex systems which give rise to tensions as they are formed. Edwards (2010) notes that since the building of knowledge infrastructures involves making choices, it will inevitably benefit some and disadvantage others. Moreover, as new infrastructures are formed and established, they hinder older ones from being maintained (Edwards 2010). In other words, the development of new knowledge infrastructures is not neutral but has distributional consequences for which practices become prevalent and which are undermined (Edwards *et al.* 2013). In relation to information artefacts, the convergence of information technology and the community of practice often does not take place as planned (Star *et al.* 2003). A lack of transparency and the fact that people belong to many different communities of practice and participate in many information worlds contribute to the difficulties in seamlessly intertwining some technologies in everyday life. It is important to pay attention to these consequences, as they may otherwise give rise to marginalization of some professions and in turn create some form of resistance to the new infrastructure. In this paper, focus is placed on how BIM organizes the processes of construction to understand its distributional consequences and the way it risks marginalizing some professions.

Limitations of knowledge infrastructure as an analytical framework

There are limitations to working with a specific theoretical framework in that it will, by definition, prioritize some matters over others in the analysis. The framework of knowledge infrastructures is helpful to see the possibilities and limitations that come with the implementation of digital technology, in this case, BIM. However, due to its practice orientation, knowledge infrastructure reduces the analytical focus to professional action. This narrower perspective could risk leaving out insights about the knowledge not spoken about or enacted in practice. However, since previous studies have focused on knowledge from different perspectives, we argue that a knowledge infrastructure framework can complement these studies with novel insights.

Since knowledge infrastructures are by nature complex and multifaceted, involving a broad network of socio-technical relations, it can also be challenging to understand all the relations that are involved (Karasti *et al.* 2016). In this study, we have focused on different professions and ways of working with BIM, and while we have not managed to capture all types of relations, we have been able to show tensions and relations that have proven to be useful to discuss in relation to previous research.

Methodology

The methodological choices in this study are guided by a socio-technical approach which emphasizes the interaction between people and technology, focusing on everyday practices (Mol and Law 2002). In accordance with this approach, BIM is studied through its practices and networks, paying close attention to the relationships, interactions and connections between professionals and BIM.

The paper builds on a qualitative case study of a large consultancy firm within the construction industry in Sweden. One advantage of a case study approach is gaining an in-depth understanding of context-dependent knowledge (Flyvbjerg 2003), which is central when focusing on the interplay between professional practice, technology (BIM) and knowledge-making. The choice of studying this consultancy firm was grounded in the company having a high digitalization profile and marketing itself as having a prominent position within BIM development in Sweden. The study was carried out during 2019–2020 and made use of different qualitative methods, including workshops and individual interviews, to create a nuanced picture of the practices regarding BIM. Since qualitative methods are particularly suitable for studying complex processes (Miles and Huberman 1994), this approach is considered highly relevant when studying socio-technical knowledge practices. Workshops provided the opportunity to use unfamiliar tasks to challenge participants (Cornwall and Jewkes 1995, Tanggard and Stadil 2014) and to facilitate reflections and discussions beyond the respondents' preconceptions. Interviews were then conducted to achieve an in-depth understanding of the tensions regarding BIM.

Participants for the workshops and interviews were chosen in cooperation with a contact at the consultancy company. Being a large company, an important aspect of choosing participants for the workshops was the inclusion of employees from different departments, with various professions and with different levels of experience. Consequently, most of the participants at the workshops had never met before. Since many of the workshop participants were relatively newly employed, interview respondents were sought among more experienced professionals. Thus, some of the respondents have extensive experience within the field, resulting in some of them also having strategic and managerial roles in the company. To preserve anonymity, we refer to all respondents by their job titles.

Three workshops were conducted with between seven and ten employees from different professional groups and with various levels of experience, including engineers, architects, environmental consultants, BIM coordinators, BIM specialists and managers at different levels. These served as a starting point for the researchers' understanding of the organization of work regarding BIM within the company and the benefits and challenges that professionals see in their everyday work with BIM. Workshops were documented through ethnographic notes, sticky notes that were used in various activities and pictures of the participants' categorizations of the sticky notes. The analysis of workshop materials was an ongoing process during, in between, and after the workshops. Central themes which arouse during the workshops were challenges with communication, competence, lack of coherent standards, and lack of client interest and knowledge. These themes were later used as inspiration when developing the interview guide and the interviews in turn gave rise to new themes.

Interviews were conducted individually with ten professionals and were semi-structured. The professionals interviewed were a constructor, a piping engineer, two building designers, an architect, an energy consultant, a digitalization leader and three BIM coordinators. An important aspect in designing the interview guide was how to gain more knowledge about possible challenges with BIM, as articulating challenges with BIM was a sensitive topic during the workshops. Central themes in the interview guide were the organizational context regarding projects in terms of co-operation and communication, whether and how BIM is used, challenges when working with BIM, whether there are different practices regarding BIM, and what standards are used. The interviews were around one hour long and focused on establishing conversations with the professionals and being attentive to emergent thoughts, reflections, and ideas. Even though we recognize that the number of interviews is low, we consider the number of interviews sufficient to provide insights into how BIM has changed different work practices, as we believe that we have reached a data saturation point (Saunders and Townsend 2016). We claim this due to the themes and content during the interviews becoming repeated as interviews progressed, in addition to our interview results being supported by the findings from the workshops.

All interviews have been transcribed and analysed by making use of a knowledge infrastructure framework for the interpretation of the empirical material. The analytical process started with a close reading of all the interview material and using initial coding, which is an open-ended coding method for finding similarities and differences in the material (Saldaña 2013). Then we analysed the codes, refined them, and derived themes from them through a focus on when the respondents hesitated, repeated themselves, used metaphors found it difficult to explain a topic, and what is left out (Ryan and Bernard 2003). As knowledge infrastructures are invisible until they break or are re-made, a focus on tensions or unclarity was considered helpful to make the knowledge infrastructures visible. These themes were analysed with a knowledge infrastructure framework where BIM became visible as an emerging knowledge infrastructure.

Results

The empirical findings are structured in accordance with the knowledge infrastructure framework and revolve around *embeddedness*, *membership in communities of practice* and *distributional consequences*. In order to apply these concepts to BIM, the paper focuses on situations where knowledge infrastructure becomes visible, such as in cases where working with BIM causes tensions, confusion or resistance.

Embeddedness of BIM

How well a knowledge infrastructure is embedded in other practices is central to its possibility to function effectively and become an integral part of everyday professional work. This chapter explores the ways in which BIM is embedded in other practices and where the embeddedness fails. Focus is on situations where BIM practices are especially visible and create confusion or added workload, as these situations make the knowledge structures visible. For example, BIM is not embedded in some formal work practices which creates tensions and extra work for some professionals. Building permits in Sweden still require paper documents that cannot be produced in BIM, and this will lead to more work as companies need to create both paper documents and the BIM model.

Working with BIM in practice involves different processes aimed at standardization which is used to embed BIM with other knowledge infrastructures. One of the processes that the respondents in both the workshops and the interviews often mentioned revolves around a document called the BIM manual. This document controls the level of detail used in the model, how elements and files are named, and how information should be used in the model. The BIM manual is central in terms of how BIM is interpreted and used in construction processes. However, even though its primary function is to reduce confusion and misunderstandings, it still involves communication challenges.

> We had an American client who had read about BIM rules, and thought that … "Yes, BIM is fantastic. We will have BIM in our project." […] And then they say: "Hello, we want you to build a building. We will have a level of information 500, because we have read that in a BIM manual, some BIM consultant said that we should have this." And then I say: "Sure, okay. We can do it. But just so you know, you're asking me to

> model brick by brick throughout the building. [...] I can do it, but it will take a lot of time and you will never use it in your life." And when I started sending them examples, they said: "Oh no, we don't want this." (Respondent 1, piping engineer)

These discussions would not have taken place if an accepted definition and standard ways of working with BIM had been in place. Instead, the lack of established structures becomes visible and new possibilities (almost endless in terms of detail) are presented. BIM is useful because of the large amount of information it can hold, but at the same time, it is inefficient for the same reason. While some of our respondents argue "the more data, the better", others think that BIM creates an overload of available data:

> I very often populate models with data that have no value or no function, because there is an official set of rules that says that now we have a set of rules. [...] I do not need to know what the windows are called. If anyone knows what the windows are called, it's up to them, as it were. And it will be more or less the same for the piping as well, that I need to keep track of my pipes, but I see... no one else needs to follow that information in detail, but it is more... who owns... who needs that data? (Respondent 1, piping engineer)

As shown in this quotation, respondent 1 ends with an important question about who actually needs all the data in the model. These examples where BIM practices are discussed add unnecessary workload, or create tensions, making the knowledge infrastructures visible. It is indicative of BIM knowledge infrastructures not yet being embedded in working practices. The lack of embeddedness hinders efficient and suitable work practices for some professions and can thus create resistance towards the implementation of BIM.

BIM not being embedded in everyday working practices is specifically visible regarding client requirements. Traditionally, clients are responsible for setting requirements regarding documentation practices, however, both the workshops and interviews point towards clients seldom being the driving force in the introduction of BIM in projects. A common reason given by the respondents was that clients rarely have any interest or competence in using BIM in the maintenance phase. Several respondents described that clients need to be educated about the usefulness of BIM to be able to see its value. One BIM coordinator describes this problem:

> In most projects [...] there is a BIM model or a BIM manual, but far from all of them. So, then this question of interpretation becomes very diffuse and many work on... They cheat their way through the projects. Setting client requirements is something that is usually lacking. (Respondent 7, BIM coordinator)

"Cheating" in this context, the respondent explains, means that the engineers use 3D drawings but do not use correct naming or provide details of dimensions and product properties. The client's knowledge is vital in this respect but is often seen as lacking. The knowledge infrastructure of BIM becomes visible through the tension of missing BIM manuals or cheating employees, as the technology lacks embeddedness in related networks. BIM is a technology closely tied to knowledge, not only as a provider of knowledge about buildings but also as a technology requiring a specific set of knowledge to understand its usefulness. This also shows that there are values and traditions embedded in the existing knowledge infrastructure which are difficult to translate to a BIM knowledge infrastructure. Clients are traditionally responsible for setting requirements and deciding on certain documentation practices, but in relation to BIM they often find this task difficult. To overcome this problem, the studied company has two main strategies: it offers education to clients, and it is developing its own BIM manual which it recommends their clients to use. Both these strategies come with changes in work practices and involve shifting some responsibilities from clients to the construction company as the construction company is now in more control of clients' knowledge, setting requirements, process design and documentation. The lack of embeddedness of BIM as a knowledge infrastructure with clients' knowledge thus risks creating lower process transparency and a change in power relations. As changes in knowledge infrastructures can have long-term consequences, it is vital that these changes are made with an awareness of the embedded practices and shifts in responsibilities.

BIM in relation to professional memberships in communities of practice

The introduction of new technology to an organization requires changes in professional roles and the community of practice, as information technology and sharing information, experiences and common practices are tightly coupled. In this chapter, the focus is placed on the role of BIM and its technological characteristics in relation to how it shapes, and is shaped by, the community of practice for different professions.

During both the workshops and the interviews, BIM was linked to a range of different software. Revit, Navis, Solibri and BIM 360 were often mentioned. Some of these, such as Revit, can be used by professionals in their disciplinary work practices (such as designing plumbing systems), while other types of software, such as Solibri, are mainly used to merge different disciplines' models into one. They have different purposes, and in many projects professionals are faced with several different types of software. Choosing which software to use is seen as a strategic choice, and in large companies, different departments choose different strategic software. These tools are then designated as central to the activities within the company's division, and training and development are focused on these programs. At the same time, several respondents emphasized the importance of choosing software according to purpose. One respondent explains:

> We work very much … what can we say, program neutral, that is to say, if we have a lot of machine installations, we will see which formats we can get from those who deliver machines. It [the choice of software] varies from case to case. (Respondent 1, piping engineer)

For this respondent, working with a particular type of software is not a matter of strategy, but a matter of circumstances. When the information suits a specific software, that one is used. This 'neutrality' allows for professional flexibility and more powerful tools. The discipline-specific software can handle more relevant data and is easier to navigate as it focuses only on a certain aspect of the construction. Instead of loading a complete BIM with a model full of information, both relevant and irrelevant, the discipline-specific software only gives access to relevant information. Working with 'software neutrality' is a way to work towards more flexibility, but it also involves challenges. For example, as both discipline-specific software as well as collaboration-focused software are needed, the professionals are faced with multiple digital tools which due to time restrictions make it challenging for the professionals to reach a deeper knowledge of all these tools.

The different types of software are closely linked to professions or disciplines, as they have special applications for specific tasks and thus relate to the community of practice of that profession. Some dimensions of construction planning and design, such as piping for industrial purposes, are difficult to include in the BIM tools. Other tasks, such as energy calculations and environmental data, are not included in most BIM software at all. An energy consultant told us that he did not work in BIM, and that he was not even sure whether it was possible to do the calculations he needed in BIM. He worked with the energy calculation tool that is commonly used in his profession and used Microsoft Excel to perform initial calculations. These simpler tools allow for flexibility and creativity that cannot be achieved with the standardized, complex software. Structuring information in highly standardized ways that can be used by everyone affects disciplines' knowledge production processes. The change in knowledge infrastructure from disciplinary work to interdisciplinary collaborations brings possibilities for broader understanding and more efficient collaborations, but also imposes constraints on creativity and disciplinary flexibility, which are highly valued by members of these communities of practice. We argue that BIM cannot be a strategic choice that is easily implemented throughout an organization if it does not allow for professional depth and is adjusted to the governing community of practice of its professions.

While changes within a community of practice are often slow processes, some respondents argued that the implementation of BIM has sped up recently due to the coronavirus pandemic. As the interview study started approximately half a year after the outbreak of the pandemic, the respondents had seen and experienced the consequences of remote working. Several of them mentioned the change that the situation led to regarding BIM.

> […] it has helped greatly, this coronavirus issue. Because we have seen that when everyone is at home, it is so incredibly tough to work on different projects on our internal project servers. So, then we have pushed for it and uploaded as much as possible to BIM 360 and it has had so many more consequences, how much time we have saved on it. Partly since we access the models faster and because the development in the industry has progressed somewhat enormously in just six months – we have been able to collaborate in a completely different way, regardless of which company you work at. (Respondent 7, BIM coordinator)

BIM suddenly became an interesting option, as the traditional knowledge infrastructures which involved more informal meetings did not work adequately in this new situation. Seeing this opportunity, the BIM coordinator describes how they made sure BIM was used as much as possible. Another respondent emphasized that while working remotely, several projects have been run entirely in BIM and proved to be successful. Both respondents noted that the results have since received positive attention within the construction industry. Whether or not this change in work practices will remain after the end of the pandemic, shows how knowledge production is closely tied to local practices but also to global events. BIM thus needs to be analysed through its community of practice as an inclusive network of technologies and actors at all levels.

Distributional consequences through changes in knowledge infrastructures

In some construction projects, BIM was central to the organization of the project and was an important part of the meeting structure. This brought consequences for some professions that were left out of key meetings. The environmental managers who took part in our workshops reported that they did not know how BIM worked and that they were not involved in any meetings regarding BIM. This resulted in them not being invited to some start-up meetings focusing on BIM and other important project decisions, which in turn made it difficult for them to influence the early parts of the process. The environmental managers' lack of knowledge about BIM and the community of practice on the part of the BIM managers who convened these meetings, thus resulted in a distributional consequence where environmental professionals became marginalized. This in turn restricted the opportunity for environmental issues to be an integral part of the construction project from start to finish. Environmental issues are essential to the sustainability of the built environment, and a community of practice where the coupling of BIM and meeting organization becomes too tight has the potential to have significant political consequences.

In addition to marginalizing certain professions, the driving force to implement BIM software has also had an impact on some professions. BIM implementation in the Swedish construction industry has been slow, despite considerable efforts. A common explanation given by some of the respondents was that this is due to a 'generation difference', claiming that it is difficult to convince the older generation to work differently. The following section discusses this view and shows that there are more factors than just age behind the tensions that arise due to the shift in work practices.

BIM coordinators, project managers and interviewees in other strategic roles describe BIM as the new and progressive working method, while AutoCAD and working with paper drawings – the traditional working methods – are argued to be outdated and ineffective. However, several of the respondents mention that the use of BIM is not self-evident for senior professionals, referring to a generational difference regarding the use of BIM.

> Yes, but it's a generational issue, I think. It's like, people have worked the same way all their lives, and all of a sudden there is a bang that "Now we are going to do everything digitally". And it's not so easy to change how someone has worked for 30 years, so that was a bit … yes, that's the answer to the question, I think. You are usually comfortable in your role, you know exactly how to do it, and all of a sudden someone comes and changes your whole way of working. (Respondent 2, BIM coordinator)

The introduction of BIM-related tools brings a change regarding previously established and learned knowledge practices in the community of practice. It further challenges the professional roles of senior professionals working in the industry. According to most respondents, a traditional hierarchical system within the construction industry is built on seniority. Consequently, senior professionals with extensive practical experience in the industry are seen as having a strong position in relation to the younger generation. Traditionally, technical know-how is considered less valuable than long professional experience and practice-oriented knowledge.

> […] we have these senior engineers who decide how it should be. And then they have brought in younger ones who almost become "drawing slaves". And it should not be like that anymore, but the tradition itself remains in some way. When new novices come in, it's easy that what you've learned in school, it disappears a bit, because the senior consultants say: "This is how we are going to work." […] Of course, the senior consultants have more experience as such, but it is very important to see that their ways are not always the best. And [I] worked very hard to prove these more effective ways of working. (Respondent 7, BIM coordinator)

The conventions of traditional practice and the accepted experience-based knowledge are particularly visible due to the efforts of BIM coordinators and managers to prove to senior professionals that BIM is a more effective tool. The traditional way of working is valued lower by these employees than by more modern and digital methods. Even when met with resistance, the more modern ways can be forced through.

> I still think we are starting to get to such a level that everyone is used to and comfortable with the tools, design tools and 3D models they work with. And it is still quite a low level in many projects in the BIM models, and there are not such high requirements. So it is very rare in fact that they refuse to deliver something that is in such a BIM manual. Or yes, they cannot refuse, because then … They will be forced in the end anyway. (Respondent 2, BIM coordinator)

The formal strategy in the company of working with BIM has priority over the informal and traditional community of practice. The senior professionals must change and work with BIM, which consequently can lead to their ways and professional experiences being marginalized. This process of marginalization is not yet enforced throughout the company, but in some settings, BIM has become a prerequisite for professional success within the construction industry.

> [...] it turns out that those who are more experienced in AutoCAD and have not jumped into it [BIM software] get fewer jobs. These are often "basement consultants". So they get to take these smaller jobs, for which a few simpler drawings are enough. So that's really it. The larger companies benefit more [from the development of BIM as an industry standard]. (Respondent 6, building designer)

Due to the risk of being "transferred to the basement" if a consultant only works with AutoCAD, the strategy of working with BIM is an important decision. According to these respondents, professional practices within the construction industry are changing as the established tools are no longer enough, and knowledge infrastructures are changing with them. In this case, consultants with older ways of working are being marginalized both in the way their knowledge is valued and in the working methods they have experience of. These results stand in contrast to our previous results, where BIM is met with resistance due to a lack of embeddedness and tensions in relation to the professional community of practice. This can be explained by the existence of both old knowledge structures, connected to experience and less digital work practices, and emerging knowledge structures with BIM existing simultaneously.

Discussion

This article has discussed BIM from the perspective of knowledge infrastructures to further understand the change processes taking place in the construction industry. Analysing knowledge infrastructures can be a way to understand technological implementation, as explained by Edwards *et al.* (2013): "As knowledge infrastructures evolve, attending to the social relations both created and broken by new modes may help societies reduce the negative distributional consequences of change" (Edwards *et al.* 2013, p. 23). The distributional consequences shown in this article will in this section be discussed to revisit resistance towards BIM in light of previous research and the framework of knowledge infrastructure.

Firstly, the embeddedness of BIM in supporting networks is essential to understand the implementation process. The embeddedness of knowledge infrastructures in relation to BIM can be connected to the national context, as different support structures are in place in different countries, and thus BIM is implemented differently. In Sweden, there is still a considerable focus on paper documents being legally binding, and in many situations, construction drawings are still the norm. This is in line with previous research which has highlighted the importance of the national and the local context of BIM for successful implementation (Merschbrock *et al.* 2018, Gade and Svidt 2021, Zomer *et al.* 2021, Mani *et al.* 2022). Our study further adds to the understanding of local components and in which ways they can be of importance for implementation and the values they come with. This is shown in relation to clients having difficulties understanding the use of the technology and setting adequate requirements. While some of our results are in line with previous research on tensions in working with clients (Bosch-Sijtsema *et al.* 2017, Zomer *et al.* 2021), the use of a knowledge infrastructure framework makes it possible to bring tensions to the fore, with respect to the context and enables a discussion of the embedded values that come with different knowledge infrastructures. Working with BIM is shown to come with changes in power relations, as the role of clients is also changing due to a discrepancy in levels of knowledge between the consultancy company and the client which in turn leads to lower process transparency. Not only are clients failing to see the usefulness of the new technology, but they also risk losing transparency and influence over the process which can further explain why clients sometimes are hesitant towards BIM.

Communities of practice and information artefacts (such as BIM) must converge, that is, being mutually constitutional where use and design align (Star and Bowker 2002), to stabilize as a new knowledge infrastructure. The shift in work practices due to the introduction of BIM has various forms and sometimes gives negative consequences as seen in both previous research (Plesner and Horst 2013, Merschbrock and Munkvold 2015, Sackey *et al.* 2015) and in this paper, through for example putting "nonsense data" into models. While the most common reasons given for the implementation of BIM are higher efficiency, decreased project costs and heightened collaboration, our results show that BIM sometimes leads to negative effects regarding professional practice, as standardizing through BIM becomes a burden taking unnecessary work and time from the "actual work", instead of facilitating professional practice. Our results can be used as critical input to a process of continuous improvement of implementing BIM tailored to the needs of professionals. It further raises questions of to what degree should one standardize work processes in knowledge-intensive industries like the construction industry? Despite the global reach of standards, standards are local as they need to be adopted in specific communities and contexts (Lampland and Star 2009). These results show that professionals need more flexibility for professional depth than BIM can provide at this time and that BIM thus is unable to converge with the different communities of practice of professions. Gade and Svidt (2021) in a similar way argue that flexibility is the core of implementation issues with BIM as the balance between rules and flexibility is central to effective implementation. In relation to previous research, collaboration and communication have proven to be the main problems in the implementation of BIM (Oesterreich and Teuteberg 2019). While some of our results agree with previous research, we also argue from our socio-technical approach, that changing forms of collaboration is not enough. Additionally, to make things work in practice, there is a need to adapt the software and incorporate different options, that can be tailored to professional needs and prevent additional workload or lowered quality in projects due to inadequate tools.

BIM has been shown to shift responsibilities in our study and previous research (Zomer *et al.* 2021). It is therefore vital that the implementation of BIM is discussed in terms of what consequences it brings for different practices and actors in its specific context. As new knowledge infrastructures shape work practices (Edwards *et al.* 2013), BIM will also create new distributional consequences and divisions between actors. For example, Autodesk, the leading provider of software to the construction sector, is responsible for the development of products including AutoCAD and Revit. The results of this study suggest that road and water planning software and environmental issues are not prioritized in the software development by Autodesk, leading to difficulties for some professionals in taking part in construction processes that are tightly centred around BIM. Similarly, even though there are BIM tools to calculate energy, this is one of the most difficult BIM features to implement (Bhoir *et al.* 2015). BIM has become a tool of power, as it structures processes where certain professions are given a more central role than others. Changes in knowledge infrastructures result in winners and losers, as they have distributional consequences for which practices become prevalent and which ones are undermined (Edwards *et al.* 2013). Therefore, it is important that the organization of the planning process does not revolve too closely around BIM in its current use and thus risks excluding some professions in the early phases, especially as previous research has shown that early considerations regarding energy and environmental choices can have a positive effect on energy and environmental performance (Picco *et al.* 2014, Echenagucia *et al.* 2015).

In our case, how knowledge is valued has changed due to the introduction of BIM, where expertise in IT is sometimes prioritized over construction experience and other forms of knowledge that previously were highly valued in the construction industry. This shift in priority regarding different types of knowledge affects power relations and creates tensions when it comes to memberships in communities of practice. Consults with long experience risk losing their higher status and as communities of practice change, they also risk being side-lined within their profession. One also needs to consider the effects on knowledge production and group communication in relation to the change from working with physical objects (such as construction drawings) towards only using screen representation. Understanding these processes can aid in explaining the underlying forces when resistance from “the older generation” is presented as a main issue when implementing BIM.

The challenges discussed in BIM implementation can be understood as a consequence of organizational structures embedding both old and new technology and connected practices at the same time (Orlikowski and Iacono 2001). The tension in the different ways of using older tools or BIM suggests that the new knowledge practice has not replaced the old, established one. Instead, they co-exist. In line with Akintola *et al.* (2020), this article argues that the implementation of BIM should be viewed more as an evolution rather than a revolution. Changing knowledge infrastructure takes time, as it involves negotiation to be incorporated into communities of practice and adjustment with other aspects of the systems involved (Star and Ruhleder 1996). The co-existing between old and new knowledge infrastructures allows for a critical discussion of in what ways BIM should be part of the future of the industry as it has proven to be difficult to converge with existing communities of practice.

Analysing the implementation of BIM through the lens of knowledge infrastructures has helped with understanding both the social and the technical limitations of BIM and in relation to different knowledge systems, thereby showing the resistance towards BIM in a different light. The three aspects of knowledge infrastructure used in this article, embeddedness, professional membership in communities of practice and distributional consequences, were used to show BIM in relation to the local and global, technological and social, mind and matter (c.f. Star and Ruhleder 1996). Looking at how BIM is embedded in its context allows for an analysis of BIM in relation to the supporting system on a local and national level. Understanding how BIM is failing to become included in the community of practice enabled us to show the limitations of the technology in relation to professional practices and through a focus on the distributional effects of BIM, we can understand how organizations are changed by, and in turn change, BIM. These different concepts together bring about a new picture of BIM where its "context" is opened up to be discussed to further the understanding, not about if, but of how, context matters in BIM implementation. The presented framework also allows for a discussion of the intertwining of knowledge, distributional consequences, and power relations within construction projects and can be used as inspiration for further discussions about the role of information technology within academia and in practice.

Limitations of the study include the relatively low number of interviews, but as the results from the interviews are in line with other research and with our workshops within this project, we are confident that the study can be used to shed some light on the organization of knowledge practices in relation to BIM. Furthermore, the study is situated in Sweden, and as previous research has shown, the context of BIM is essential for understanding successful implementation (Zomer *et al.* 2021, Mani *et al.* 2022) whereby its generalizability to other countries is limited. Likewise, conducting a qualitative case study of one large consultancy firm has been a fruitful way to gain a deeper understanding of knowledge practices in a particular context, but also incurs limitations on the ability to generalize the results even in a national context as large parts of the Swedish construction industry consist of small and medium-sized enterprises (SMEs) (Bengtson *et al.* 2019). There are existing power asymmetries between large and smaller firms which are deeply troubling for those who lack the resources to embrace the new technology (Dainty *et al.* 2017). However, as the results in this paper have shown, there can be a shift of power within larger companies as well, where competence in BIM methods is sometimes needed in order not to be marginalized (or, in the words of one of our respondents: "transferred to the basement"). This shift in power through BIM, both between companies of different sizes as well as in BIM, competency needs to be further studied to understand the consequences that come with BIM and the connected new ways of valuing knowledge and experience.

Conclusions and further research

Analysing BIM with the concept of knowledge infrastructure has provided a theoretical lens that puts the internal workings of technology, its organization, and its social relations into focus. By attending to the change in knowledge infrastructures in relation to BIM, we have learned that BIM causes tensions when it is not embedded in other networks as it clashes with supporting infrastructures, as well as when BIM is not part of the community of practice for the involved professionals. Furthermore, the paper has shown that BIM changes organizational practices which risk marginalizing some professions or experiences. This marginalization creates tension and resistance towards BIM, as well as shifts in power relations. A knowledge infrastructure framework has aided in this analysis by bringing infrastructure to the fore and, building on previous research showing the importance of the context of BIM, facilitated a deepened analysis of these environmental factors beyond thinking in terms of barriers. Instead, an integrated perspective of technology, organization, and practices presents new understandings of the challenges that come with the design of the technology and its complex implementation. The main advantage of this theoretical framework has been that it helped to show that the introduction of new technology, such as BIM, does more than just add new ways to create knowledge to already existing ones. This emergent knowledge infrastructure has a transformational impact and reorganizes knowledge and restructures work practices. In the process, the meaning and forms of expertise also change, and various forms of knowledge practices may get lost as they are no longer considered relevant. In other words, a change in knowledge infrastructure means that authority, influence and power become redistributed. Pointing at the tensions that the implementation of BIM creates and its redistributive consequences, gives us the opportunity to put forward these concerns and emphasize the need to find ways to reduce the negative consequences of change.

Further research is needed to understand how the industry can shape knowledge infrastructures that will support professional practices that do not only include automation and efficiency, but also value experience, creativity, and flexibility. Focusing on how different software shape knowledge production and how they support or restrict professional practices would aid in this endeavour. Studies focusing on how BIM shifts power relations through practice, both in other larger companies and in SMEs, would also be beneficial to understand the values embedded in BIM and its consequences for the industry.

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Due to the sensitive nature of the research, supporting data are not available.

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