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RESEARCH ARTICLE

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Building information modeling and its impact on users in the lifeworld: a mediation perspective

Abstract Building information modeling (BIM) is expected to have a large impact on users in the lifeworlds in a construction supply chain. The impact of BIM on users in their lifeworlds is explored using the concepts of Heidegger, Habermas, and Ihde from the perspective of technical mediation. This impact is explored by a case study. BIM mediates and shapes the relationship between users and their lifeworlds and can be characterized as either a hermeneutic or an alterity relationship. BIM conflicts with existing work practices in a ready-to-hand work environment. For users that cannot work with BIM, the work environment remains present-at-hand. The many heterogeneous BIM applications and systems used by the various parties involved result in interoperability problems that are a major barrier to enframing the supply chain by BIM. Although invitation and inhibition of certain actions by BIM may stimulate the rationalization of the lifeworlds, the lack of intrinsic motivation and mutual background knowledge inhibits an alignment of BIM and working practices.

Keywords building information modeling, mediation, enframing, lifeworld, rationalization, Heidegger, Habermas, Ihde

1 Introduction

Firms in the construction industry have been increasingly expanding their investment in building information modeling (BIM) since the beginning of the 21st century. BIM is "a process focused on information management among participants of the project and a technology representing a digital model, where information about the project can be stored and transferred" (Kehily and Underwood, 2015). BIM provides a means for information to flow among different disciplines in the construction supply chain, thereby facilitating participants in sharing their work. BIM can support communication between firms involved in a project by enabling working practices to become integrated (Porwal and Hewage, 2013; Papadonikolaki et al., 2016). Reduced failure costs and new ways of collaboration are among the benefits claimed for BIM.

The impact of BIM as an information technology can be analyzed from several viewpoints (Burrell and Morgan 2017). From a positivist perspective, BIM is regarded as a neutral provider of input for decision making, and the decision maker is a passive recipient of this information (Adriaanse et al., 2011). Here, BIM is perceived as a "problem solver" that improves decision making (Adriaanse et al., 2011). BIM increases the efficiency and effectiveness of the building process (Cecez-Kecmanovic, 2005). Within the interpretive perspective, a reaction on this positivist perspective, researchers assume that human beings create "their own subjective and intersubjective meanings as they interact with the world around them" (Orlikowski and Baroudi, 1991). Here, a user of information technology is not treated as a passive receptacle but as an intelligent being in a shared social context (Ngwenyama and Lee, 1997). Given that we expect BIM to have a large impact on users in their shared social context, or *lifeworld*, of BIM users, we start with this interpretative perspective in seeking to understand the impact of BIM (Bechky, 2003).

Each organization in a supply chain has its own lifeworld, and our objective is to explore the impact of BIM on users in these lifeworlds. A lifeworld can be defined as the symbolically created, taken-for-granted universe of daily social activities of organizational members, which involves language, social structures, and cultural tradition as the background knowledge that members share (Cecez-Kecmanovic et al., 2002). For

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members of an organization, this lifeworld amounts to the background environment of technology, working practices, and attitudes. These lifeworlds are also referred to as interpretive schemes (Broadbent et al., 1991). The lifeworld of an organization forms the context for mutual understanding by its members. BIM and other communication standards are also part of these lifeworlds. BIM is not an isolated system but forms part of a larger whole when it becomes part of an organization's working practices. Ciborra and Hanseth (1998) state that information infrastructures as formative contexts can shape not only the work routines but also the ways people look at practices and are "natural."

Users will experience the effects of BIM on their lifeworlds. To explore these effects of BIM, the philosophy of technical mediation is used. The philosophy of technical mediation implies that our perceptions and our actions are always constituted and transformed by technologies to a varying degree (Verbeek, 2005). Technologies mediate and shape the relationship between human beings and their lifeworlds. In other words, humans' perceptions and interpretations of reality are transformed when the latter is mediated by technology (Ihde, 1990; Verbeek, 2012). Verbeek (2001) expresses that "naked perception and perception via artifacts are never completely identical." Technologies mediate our relationship with the lifeworld. Ihde (1990) and Verbeek (2001) schematize the differences between unmediated and mediated perceptions as follows: *I – world* and *I – technology – world*. Verbeek (2005) describes the concept of mediation along two dimensions: One dimension is termed "hermeneutic" and is about our "perception of the world"; the other is "existential" and is about "our action in the world."

In this study, the mediating effects of BIM on the lifeworlds of BIM users within organizations in a construction supply chain are explored using the concepts of three famous philosophers: Heidegger, Habermas, and Ihde. Heidegger was one of the first important philosophers to systematically study technology and its impact on human beings and their lifeworlds (Verbeek 2005). Heidegger (1977) was rather pessimistic in arguing that technology results in nature and people becoming no more than resources, means, or instruments. The human freedom and will to choose are lost. Heidegger's view contrasts with Habermas' theory on the interaction between lifeworld and technology (Habermas, 1984; Habermas, 1985), which also recognizes the potential negative impact of technology but believes that an alignment between technology and the lifeworld of human beings is feasible by changing technology. Although Heidegger and Habermas are critical of the impact of technology on human beings' lifeworlds, Ihde (1990) distinguishes four context-dependent forms of human–technology relationships; his views can be regarded as more pragmatic (Rosenberger and Verbeek, 2015).

In this study, the concepts of the three famous philosophers are first discussed and then used to explore the relationship between technology and lifeworld. Thereafter, an exploratory case study on the impact of BIM on users in organizations in a construction supply chain is described. The results of this case study are then discussed from the perspective of technical mediation. Finally, conclusions are drawn.

2 Technology and lifeworlds

In this section, the mediating effects of technology on the lifeworld of human beings are described from the perspectives of Heidegger, Habermas, and Ihde using the core concepts of their philosophies. According to Heidegger (1977), technology may result in *enframing* the lifeworld. From the perspective of Habermas (Habermas, 1984; Habermas, 1985; Ihde, 1990), technology may result in *rationalizing* the lifeworld. By contrast, Ihde (1990) states that technology *mediates* in multiple and ambivalent ways between human beings and their lifeworlds.

2.1 Technology enframing the lifeworld

Heidegger conceptualizes the mediating effect of technology on human beings in the lifeworld on two levels. A core concept in studying the effects of technology on human beings is Heidegger's "readiness-to-hand." To study the effects of technologies on human beings on an abstract level, Heidegger introduces the concept of "enframing."

Heidegger's "readiness-to-hand" concept is related to a core theme of his philosophy: "the primacy of practice, or rather practices that we are socialized into, prior to any theoretical understanding" (Dias, 2006). The practices of human beings are characterized by "pre-theoretical" shared agreements, and "the basis for our everyday action is the ability to act pre-reflectively when 'thrown' into a situation" (Turk, 2001a) – a typical Heideggerian concept.

Heidegger uses the hammer as an example to explain his philosophy (Dias, 2006; Verbeek, 2005). In hammering a nail, Heidegger argues that human beings "do not require conscious reflective knowledge about the physical properties of a hammer and the physics of hammering. The tool is ready-to-hand and we simply hammer the nail into the wall" (Turk, 2001b). The nature of a hammer cannot be understood without the knowledge of everything that makes a hammer into what it is in a certain equipmental context; equipment needs to be appropriate (*angemessen*), which indicates it has to have its place in the totality of other equipment, shared practices, and user skills and social orthodoxies (Riemer and Johnston 2011). Equipment is ready-to-hand when it is being used in a practical, absorbed, and even invisible way, without any need for reflection (Riemer and Johnston 2011).

"Intuition" and "commonsense" are similar pre-reflective *ready-to-hand* concepts that are sometimes used by professionals to explain their creative processes. However, the existence of such a situation has a history of training and learning routines. Intelligent acting that uses intuition and commonsense is based on "thrownness" but not on reflection (Turk, 2001b). This "thrown into a situation" contrasts with "the reflective analysis of a detached observer" (Turk, 2001b). Reflective analysis occurs in "situations where one is inspecting, designing, building, or theorizing" (Riemer and Johnston, 2011) equipment. Equipment is the object of attention and is *present-at-hand* in the event of a breakdown, such as a broken hammer. Equipment is also present-at-hand when someone "does not know anything about and hence fails to understand skillfully what it is" (Riemer and Johnston, 2011). An "in-between" state is when equipment is *unready-to-hand*. Unreadiness-to-hand occurs when a user is learning and acquiring the skills necessary to be involved with equipment in an absorbed way (Riemer and Johnston, 2011): "through training, people acquire skillful routines in which the human body and technologies function as one single assembled unity" (Dorrestijn, 2012a).

For studying the mediating effects of technology on an abstract and critical level, Heidegger introduces the concept of "enframing." This concept is "abstract" in that enframing is about a general conceptualization of how technology mediates human existence and is "critical" because enframing is an example of general dystopian thinking that all technology is accumulated into a system that dominates humanity (Dorrestijn, 2012c).

According to Heidegger, working practices may be enframed when equipment is implemented. For Heidegger, enframing or "ge-stell" is the essence of modern technology. In German, the verb "stellen" indicates "to put in place, to order, to arrange, to furnish or supply, and, in a military context, to challenge or engage" (Depaoli, 2012). To Heidegger, modern technology amounts to all nature and humans becoming involved in a transformation, from being objects to be controlled to "standing reserves" (Heidegger, 1977; Dias, 2003). The reason is that "everything is ordered to stand by, to be immediately at hand, indeed to stand there just so that is may be on call for a further ordering" (Heidegger, 1977): nature itself loses the property of being an object (*gegen*-stand) and becomes *be*-stand, that is, a standing reserve of available resources to be exploited (Ciborra and Hanseth, 1998).

Technology is understood as a mode that challenges nature by being based on extraction and exploitation (Sikka, 2001; Dias, 2003). The Heideggerian process of ordering multiple actions and their enchainment by enframing highlights an important aspect of technology. In instrumentalization, methodical planning becomes dominant. This quantitative and calculative mode of thinking is useful for humans when shaping the environment and organizing productive efforts. However, enframing becomes a problem when nature and people become no more than resources or instruments. By enframing, the world is conceived only in technical terms – as a stock of resources to be exploited: humans will be reduced to mere means. Accepting enframing also means that modern technology requires human beings to view the world in a different way: it constructs a worldview that is imposed upon man and nature. By enframing, the use of technology creates a new lifeworld (Heidegger, 1994).

2.2 Technology rationalizing the lifeworld

Habermas' view contrasts with Heidegger's critical approach to technology. He also recognizes the potential for the negative mediation effects that technology can accumulate to turn into a system that dominates humanity but believes that technology can align with the lifeworld of human beings. In his analysis, Habermas distinguishes between the *lifeworld* (that is, the sphere of everyday communicative interactions) and the *system* (that is, institutions such as the market mechanism and a bureaucratic organization) (Adriaanse et al., 2011). The mediating effect of technology is represented as a struggle between the two spheres in which the lifeworld must be protected against "colonization" by the system (Dorrestijn, 2012b, 2012c).

According to Habermas (1985), social integration is based on the *lifeworld* concept and on actions that are focused on achieving mutual communication or understanding. A shared background allows participants to reach a shared understanding if they want to. This mutual understanding "is possible because of the lifeworld, but the lifeworld is also reproduced through processes of mutual understanding" (Adriaanse et al., 2011).

The *system* concept can be defined as the "formally organized domains of action" (Adriaanse et al., 2011). Within this system concept, actions and decisions are regulated and coordinated by the so-called steering media. Examples of such media are the market and the bureaucracy. An organizational system can be defined as concrete facilities (aggregations of actors), physical artifacts (machinery, buildings, and technology), processes, and structures that are integrated to achieve certain goals (Cecez-Kecmanovic et al., 2002). Production, financial, and administrative systems are also part of this organizational system.

For Habermas, the way organizations align their working practices and technology can be based on two integration concepts: (1) rationalization of the lifeworlds of participating organizations based on mutual understanding, or (2) an initiating organization changing the steering media of other organizations, thereby directing their systems and subsystems and potentially colonizing their lifeworlds. To Habermas, this alignment should be based on the first of these integration concepts, that is, by mutual understanding between organizations. Here, technology supports rather than restricts the working practices of the organizations involved. In Habermas' view, technology needs to be integrated into the lifeworld (Habermas, 1985).

By comparison, the second integration concept may constrain the rationalization of the lifeworld. Activities and decisions regulated through the market and or a bureaucracy can become an alternative to communicative understanding. Here, common understandings and shared values play a diminishing role because the markets and bureaucracies deliver results without discussion (Feenberg, 2000). If these systems become too complex, then they can become independent of the lifeworld. Here, steering media based on built-in structures begin to coordinate autonomously (Honneth and Joas, 1991), and the system "escapes from the intuitive knowledge of everyday communicative practice" (Habermas, 1985). System integration (by the steering media) becomes decoupled from social integration (by mutual understanding).

In this second scenario, actions are split from the lifeworld and only become integrated through steering media and their systems (Adriaanse et al., 2011). Actors act because they are required to act in accordance with these systems. These systems are no longer aligned with their lifeworlds. The imperatives of the systems may "suppress forms of social integration even in those areas where a consensus-dependent coordination of action cannot be replaced, that is, where the symbolic reproduction of the lifeworld is at stake" (Habermas, 1985). Habermas describes this process as "mechanization" or "colonization of the lifeworld." This critical conceptualization of the relationship between humans and technology is similar to Heidegger's concept of enframing. That is, technology becomes "autonomous" at the cost of human autonomy (Ellul, 1964), and humans are absorbed as parts of a "megamachine" (Mumford, 1970). Heidegger and Habermas share a dystopian vision of technology that is in line with the classical philosophy of technology (Dorrestijn, 2012a).

2.3 Technology mediating the lifeworld

Heidegger and Habermas are critical of the impact of technology. By contrast, Ihde offers a more pragmatic analysis and distinguishes four context-dependent, human–technology relationships (Ihde, 1990; Verbeek, 2012).

In the *embodiment* relationship, perceptions of human beings are reshaped by an artifact or device, whereas this device does not receive the human's attention (Ihde, 2009). An example is a pair of glasses. A user looks through the glasses but does not, per se, perceive these glasses. The artifact become "quasi-transparent" and technology is embodied by the human being (Ihde, 2009). Ihde's embodiment relationship with technology reflects Heidegger's "readiness-to-hand" view. Ihde schematizes this embodiment relationship as follows: *(Human–Technology) → World*. A human perceiving the world through glasses is shown as *(Human–Glasses) → World*. He or she has embodied the glasses. This form of human–technology relationship is important because it shows how technological mediation shapes human perceptions in its embodied form (Verbeek, 2006).

In the *hermeneutic* relationship, humans turn their attention to a technological artifact. Technology provides humans with a representation of a specific aspect of the world. They perceive, read, and interpret this particular aspect of the world that is provided by technology (Verbeek, 2001; Ihde, 2009). Hermeneutic indicates *interpretative*; that is, that meaning is not objective but is only achieved by interpretation (Rosenberger and Verbeek, 2015; Turk, 2001b). The use of a particular technology indicates that a certain aspect of reality for a human is amplified when the experience of other aspects of reality are simultaneously reduced. For example, the thermometer represents or amplifies one aspect of reality (temperature), whereas other aspects of reality (humidity and/or UV radiation) are reduced (Ihde 1990). Hermeneutic relations are represented by Ihde in the following way: *Human → (Technology–World)* (Ihde, 2009). A specific aspect of the world is represented by (*Technology–World*). This representation is read and interpreted by a human being.

In the *alterity* relationship, the focus is on the technology. Human beings do not perceive the world by technology (as in embodiment relationships) or interpret the world by technology (as in hermeneutic relationships); by contrast, they are related to or with a technology (Ihde, 2009; Verbeek, 2005). Technology is characterized as the "quasi-other" (Verbeek, 2001). For example, when a person is buying a ticket from an automatic train ticket machine, the focus is on the interaction between the buyer and the machine. The buyer chooses the destination, checks the time-table, pays the fee, and then collects the ticket (Verbeek, 2005). Ihde's alterity relationship with technology reflects Heidegger's "present-at-hand" perspective (but in a situation of normal use of technology and not a break down). Ihde uses a *Human → Technology (–World)* schematic to represent this alterity relationship (Verbeek, 2008). The human focuses on the technology but not on the world.

Finally, in a *background* relationship, technologies are part of the environmental context of users (Rosenberger and Verbeek, 2015). These technologies may exert subtle indirect effects upon the way the world is experienced (Ihde, 1990). As opposed to an embodiment relationship, the world in a background relationship is not perceived by a technology. Unlike in an alterity relationship, the focus is not on the interaction between humans and technology (Verbeek, 2005; Ihde, 2009). Technology does not play a central role in our experience. Ihde (2009) uses the thermostat as an example of a human–technology background relationship. The thermostat keeps the temperature at a certain level without human interaction. Initially, when a human adjusts the thermostat, he or she enters into an alterity relationship with it, but then the attention shifts to other things and, eventually, a background relationship will be established between the human and the thermostat. The background relationship can be schematized as *Human (–Technology/World)*.

Technological artifacts, by technological mediation, can also direct actions of humans by invitation or by inhibition: certain actions are "invited," whereas others are "inhibited" (Verbeek 2006). When a person uses a technology for a specific aim, the use of that technology invites or causes a human to act or behave in a certain way and discourages them from acting in another way. By analyzing how a technology invites or inhibits actions and behaviors, the effects of that technology on the lifeworld can be evaluated. Invitation and inhibition can be related to the concept of delegation as elaborated by Latour (1992). Technology may enforce certain behavior on humans by carrying a *script* that guides users in much the same way as a film script helps actors. In this way, action is delegated from humans to things. The mediation effect is that the technology may influence users or direct people in certain directions (Dorrestijn, 2012a).

According to Ihde, the role of technology in the lifeworld of humans involves far more than enframing or colonization. For Heidegger, enframing by modern technology constructs a worldview that is *imposed* upon humanity. Human beings must view the world only in technical terms as a stock of resources to be exploited. Habermas states that mutual communication is possible because of the lifeworld, but the lifeworld is also reproduced by processes of mutual communication. The lifeworld must be protected against colonization of technology when replacing human communication. For Ihde, tools or technology are necessary for humans to understand their lifeworlds. By contrast, Heidegger and Habermas argue that the interaction between lifeworld and technology can be represented by two potentially *conflicting* spheres; for Ihde, technology *co-institutes* the lifeworld as perceived by humans in different context-dependent forms (Verbeek, 2001; Dorrestijn, 2012a).

3 Case study methodology

To explore the mediating effects of BIM in the lifeworld, an exploratory case study has been conducted that focuses on the implementation of BIM in the working practices and attitudes of users of organizations in a construction supply chain. The focal firm in this case study is an innovative Dutch construction firm with an annual turnover of more than EUR 1 bn. Several years ago, to make the construction process efficient and effective, the firm decided to implement BIM. However, problems still exist, including lack of comprehensive data exchange between the various parties involved in construction projects. This problem is a consequence of several parties having difficulties in providing the desired information for BIM because BIM has not become an integrated part of their working practices. An investigation has been made into the reasons for the difficulties in parties that provide the desired information to a BIM model.

3.1 Firm selection

To explore the relationship between BIM and the working practices and attitudes of BIM users, we focused on major partner firms involved in two construction projects of the focal construction firm in which BIM was used. The first project is a housing project that consists of 22 houses. From the suppliers active in the construction process of this project, we identified and interviewed representatives of six long-term partners of the construction firm. Three (all part of the Dutch construction industry) were leading suppliers of prefabricated concrete elements, and the others were suppliers of limestone, staircases, and wooden prefabricated elements. The second project was a five-story building for healthcare services. Three long-term partners of the construction firm were selected: a supplier of prefabricated concrete elements, a supplier of grounding elements, and a mechanical engineering firm. Additional partners/interviewees were selected from the first of these projects because this project involved a large number of regular partners. In addition to the nine partners, three other long-term partners of the construction firm were interviewed. The three partner firms supply windows and window frames, facades, and steel, respectively. All the partners selected had some experience with BIM. Within the construction firm, four employees were interviewed. Three of them work in the BIM department, and the remaining one in the supply chain management department.

3.2 Interview protocol

The BIM users from the 12 selected partners and from the construction firm were interviewed in two rounds. The starting point for the first-round interviews was the idea that BIM can be thought of as an information system, which is, or becomes part of, the everyday working practices of an organization. BIM, as an information system, can be characterized by a number of subsystems, namely, hardware, software, data, and procedures. These subsystems are closely related with one another and jointly determine the functioning of the BIM model. However, BIM is part of a larger whole. This larger whole can be defined using components of the IT interaction model of Silver et al. (1995). These other elements, such as strategy, business processes, people, culture, and organization structure (Silver et al., 1995), interact with the BIM model as an information system. In addition, factors from a firm's external environment, such as contractual agreements and requesting actors, can affect motivation for the development and use of BIM.

Based on the elements of the IT interaction model, themes for the interview are identified and related questions for the interview protocol are developed (Appendixes A and B). The BIM interview protocol is divided into six main themes: strategy, organizational structure, people and culture, processes and procedures, ICT (infrastructure), and data (structure). Each main theme consists of one or several subthemes (Appendix A). These subthemes have been deduced from descriptions in literature (Silver et al., 1995) and topics contained within existing maturity models, especially important contributions from the Penn State BIM Assessment (Messner and Kreider, 2013) and the Supply Chain Management Maturity Model (Lockamy III and McCormack, 2004). After this first round of interviews, a second round of in-depth interviews has been conducted, with the same interviewees, focusing on problems that users had experienced with elements of the BIM system and solutions either proposed or implemented.

3.3 Interpretation and analysis of the interviews

On the basis of the interview data, the mediating effects of BIM on the lifeworlds of the BIM users in the organizations in a construction supply chain are explored on two levels using the concepts of Heidegger, Habermas, and Ihde, namely, an abstract and critical level and the level of practices (Table 1).

Table 1 Two levels of exploring the mediating effects of BIM

	Concepts	
Abstract and critical level	Heidegger • Enframing	Habermas • Rationalization
Level of concrete practices	Heidegger • Ready-to-hand • Unready-to-hand • Present-to-hand	Ihde • Embodiment relationship • Hermeneutic relationship • Alterity relationship • Background relationship • Invitation • Inhibition

To interpret the mediating effects of BIM on an *abstract and critical level*, the concepts of enframing and of rationalization and colonization are used. These critical conceptualizations assume that technology accumulates to create a system that dominates humans. The concept of enframing is used to explore if and how BIM shapes working routines: does implementing BIM result in an enframing of the lifeworld; and to what extent do the standardizing interfaces, protocols, and various hardware and software components of BIM shape working routines?

Concepts developed by Habermas are used to explore the extent to which suppliers and subcontractors align their working practices, and BIM is conceptualized to these working practices to capture the potential benefits of BIM. Such an alignment can be based on (1) the rationalization of the lifeworlds of the construction firm and of its suppliers and subcontractors by mutual understanding or (2) the construction firm steering its partner firms toward using BIM in a way that is not in line with their lifeworlds and potentially colonizing the lifeworlds of these organizations.

To interpret the mediating effects of BIM, on the *level of practices* that BIM users are socialized into adopting, the four human–technology relationships identified by Ihde are investigated. These relationships are related to Heidegger's concepts of *ready-to-hand*, *unready-to-hand*, and *present-at-hand*. The extent to which BIM is ready-to-hand in the working practices of the firms involved is explored: in what situations is BIM still unready-to-hand, and are users still learning and acquiring skills; and in what situations is BIM still present-at-hand with users who do not understand how to skillfully use BIM?

In an embodiment relationship, reflecting Heidegger's "readiness-to-hand," users perceive the world by BIM. In a hermeneutic relationship, BIM provides representations of specific aspects of a building or infrastructure object, and then this representation is read and interpreted by the user. In an alterity type of relationship, which reflects Heidegger's "presence-at-hand," the BIM is the center of the attention. In a background relationship, BIM helps shape the context in which users experience the world. Ihde's *invitation* and *inhibition* concepts are used to analyze if BIM encourages or discourages certain actions.

4 Case study findings

The results of the interview analyses are now presented on the basis of six elements of the IT interaction model.

4.1 Strategy

Implementation and use of BIM require management support and BIM expertise within the organization. According to most of the partner representatives interviewed, their senior management fully supports BIM development and implementation. The BIM engineer of the construction firm indicated that management support was present: "management is BIM minded and decisions need to be made faster with BIM." A planner of one partner firm indicated "that the need for BIM is not always recognized by the management," and full support for BIM implementation was thus lacking. Those interviewed considered that sufficient resources and project budgets were made available to use BIM and that these funds were sufficient to further develop and deploy new BIM applications. Support in the immediate future was ensured at most partner firms by the appointment of a BIM steering committee.

To have BIM expertise present inside their organization, BIM experts, BIM working groups and a BIM-related department at the construction firm had been appointed. These actors filled advisory and supporting roles in the BIM implementation process. At the construction firm, the BIM engineer reported that adequate time was provided for BIM implementation and that BIM experts "were active across all layers of the organization." One of their BIM experts was part of the senior management. All the partner firm representatives claimed that their organizations had BIM experts, with most of these experts having sufficient time for and influence on the BIM strategy. However, most partners also indicated that the time available depended on the number of projects. "Time remains an issue," according to a project manager of the steel supply firm. When the workload was high, time for BIM implementation processes was not always available.

4.2 Organizational structure

The organizational structure in relation to BIM use can be observed in the distribution of tasks and responsibilities among employees and departments. An organization's structure influences the ability to share information in a timely manner and the fit between functions and the BIM process. Here, many of the subcontractors and suppliers had not formalized changes in their structure, function, or job descriptions to match the requirements for implementing and using BIM. A majority of the partner firms viewed BIM as an additional tool to support existing roles and responsibilities. A representative comment was made by one of the prefab suppliers: "Tasks and responsibilities still have yet to be adapted."

BIM users at the subcontractor and supplier firms experienced lack of clarity over who was responsible for the various parts of the BIM model, although the partners in the healthcare project noted that roles and responsibilities in relation to the use of BIM were clearly documented in the project. In general, no specific contractual arrangements occurred between the construction firm and its partner firms related to BIM. The BIM engineer of the construction firm mentioned that "the general contract is the basis, but it's all about trust."

4.3 People and culture

A common barrier mentioned in both projects was that *personal motivation* was reduced because partners were unable to catch up in the BIM process. According to the construction firm, the suppliers needed to put additional effort into implementing and using BIM. At the suppliers and subcontracting firms, the users' motivation to make the transition to working with BIM was reduced by data structure problems. These users perceived few benefits for their own work from BIM, and the efforts required to adopt the BIM working method outweighed the benefits in accordance with their experience. "The added value lies mainly with the customer. We are not going to work more efficiently by BIM" according to one of the prefab suppliers. The perceived lack of benefits from using BIM results in low motivation and support, and this situation impedes efficient data exchange by BIM.

To be successful, one or more people who act as *requesting actors*, or drivers, for the implementation and use of BIM must be present within each organization. Although all the partner firms were reported to have BIM champions, these BIM champions do not always have sufficient time. The suppliers' representatives indicated that the major driving force to implement BIM was the contractor as an external requesting actor. A steel supplier indicated, "we do not need BIM within our firm, but it is requested by the contractor." Users at the partner firms viewed BIM as a means to acquire projects but that it had only limited value for their own way of working.

A frequently cited barrier related to the speed of BIM implementation mentioned by all the firms was related to *education, training*, and *support*. The acquisition of sufficient knowledge and experience was considered a long-term, step-by-step development. Training was provided at all the partner firms and tailored to the needs of individual employees. When training is tuned to personal needs, the process requires time. Adopting BIM requires adapting existing software and implementing new software, and new knowledge is required to use this software. Users currently learn to use the new software by trial and error. According to the BIM manager of the construction firm, a lack of sufficient knowledge and experience with BIM software slows the implementation and extension of BIM applications.

4.4 Processes and procedures

The interview findings regarding processes and procedures relate to the *organizational structure* criteria. Here, we reported that a small number of documented works existed, although half of the interviewed partners indicated that they were in the process of documenting BIM processes in the form of procedures and work instructions.

The development of new procedures, work processes, and job descriptions is viewed as complicated and time consuming. As a result, little is documented in the form of work instructions and procedures. "We just made a start," said the BIM manager of the construction firm. Another barrier is that existing procedures do not facilitate the early involvement of key participants. This situation hampers understanding of each other's work processes, which is necessary to achieve optimal information exchange.

However, some of the partners who were active in the housing project claimed to have well-documented procedures and work instructions.

4.5 ICT infrastructure

ICT infrastructure refers to the software, hardware, and network environment. In this regard, BIM users most frequently mentioned the loss of data by interoperability problems as an issue linked to the ICT infrastructure. In particular, half of the users encountered information and data loss when exporting and importing IFC file formats from the building model. "If you get an IFC file, you do not get all information you need for Navisworks," according to the BIM modeler of the mechanical engineering firm. Given that IFC files are large, loading them into a particular software package can be a time-consuming process. Regarding the hardware and network environment, interviewees regularly indicated that other links in the system (the data lines and the servers) were often inadequate to handle the huge amount of data at an acceptable rate. In trying to resolve these problems, the construction firm and its partners had invested considerably in hardware.

Given these limitations, several users had reverted to the "old" software because they could not work with the new software. Other users tried to solve these problems by reporting interoperability limitations to their partner users and software vendors by updating the software when a newer version became available and by filling gaps in the information themselves when data were unsuccessfully imported. Some users had developed their own software, but this step created new problems: someone then had to work out which file formats were interchangeable with other software packages. Overall, developing new software, updating existing software, agreeing on the modeling in BIM, and the related learning process consumed considerable time.

4.6 Data structure

Several system problems related to the data structure were reported, such as object structure decomposition, object libraries, and their attributes. Object structure decomposition plays an important role in the exchange of data within BIM, and the major problem that all users were encountering was lack of widely accepted object standards. Each client used its own approach to object decomposition, with various institutions and companies all having attempted to establish a standard. Over time, many self-developed standards had emerged. Users at the subcontractors and suppliers must address and switch between different object structures used by their various clients. This variety in standards requires additional time when modeling objects in a BIM environment. Users in the supplying firms often adopt the structure and methodology used and provided by a client (the main contractor) because they try to be as accommodating as possible. Given the lack of widely accepted, clearly defined standards that are fully implemented in the software for the exchange of data (especially in an exchange standard such as IFC), BIM usage is regarded as inherently inefficient.

Users at the subcontractors and suppliers also reported facing the barrier that no uniform library of objects exists and that their clients adopt different levels of detail in their BIM objects and often fail to use existing developed tools and object libraries. Firms develop separate libraries for each project and for the various software packages that are used. Three firms (including the two steel suppliers) noted that they have object libraries aligned with the sector standard. Other firms have object libraries at the organization level, but these libraries are not aligned with external organizations because of the diversity of software packages and the absence of standards. Users also encountered problems because the level of detail was unclearly defined for the BIM models. Users at subcontractors and suppliers address these barriers by checking objects, and their level of detail, in the object libraries, and then changing the modeled objects as necessary. In addition, users in the subcontractors and suppliers organize sessions with their partners to align library objects by applying uniform parameters. Another major problem is the lack of linkages between the document management system and BIM within all the organizations involved.

5 Discussion

After the views of those involved with BIM in a construction supply chain have been obtained, the mediating effects of BIM on the lifeworlds of BIM users will now be discussed from the perspectives of Heidegger, Habermas, and Ihde. The mediating effects of BIM on an abstract and critical level are discussed first. Second, the mediating effects of BIM on the level of practices that BIM users are socialized into are investigated.

5.1 Mediating effects of BIM on an abstract and critical level

BIM entails standardizing interfaces, protocols, and various hardware and software components. The reliance on standards is also a key aspect in the Heideggerian notion of *enframing* (Ciborra and Hanseth, 1998). Therefore, standardization of communication through BIM can be interpreted as a process of enframing. Ideally, BIM will not only facilitate communication but also support the alignment of building processes and manage workflows within and between the firms involved in a construction project. The Heideggerian process of ordering multiple actions and their enchainment by enframing matches an important goal of BIM.

However, the case study shows that enframing is hampered by interoperability problems on technical, syntactic, and structural levels (Turk, 2016). First, the case study indicates that technical interoperability, that is, data transfer from A to B, is often not optimal. Second, some applications cannot always read data from other applications because of suboptimal syntactic interoperability (users fill information gaps when data are not imported or exported). Third, the structural interoperability, that is, the lack of compatibility in the data structures (object structure decompositions and object libraries) of different firms' applications, is problematic.

The many distinct applications and systems used by the various parties and the need for flexibility and adaptability result in interoperability problems that form a major barrier to enframing the supply chain. These system problems related to the ICT infrastructure and the data structure interact with user problems and hamper rationalization of the various lifeworlds. Enframing emphasizes that the inertial effects of systems and applications are a key determinant in the quasi-autonomous nature of technology in modern organizations. Given the interoperability problems of BIM, such a quasi-autonomous nature remains absent at the supply chain level.

To capture the potential benefits of BIM, users at the construction firm, its suppliers, and its subcontractors need to change their working practices and align their lifeworlds and BIM on the basis of mutual understanding. The most important constraints on the rationalization of lifeworlds by mutual understanding (Habermas, 1984; Habermas, 1985) are lack of intrinsic motivation and limited shared background knowledge.

One of the reasons for the reluctance to use BIM is the perceived uneven distribution of the benefits. Users at suppliers and subcontracting firms perceive few benefits from BIM for their own work. Consequently, intrinsic motivation is lacking, and BIM is only applied because the construction company requests it. At suppliers and subcontractors, the motivation to adopt BIM is further reduced by the interoperability problems between heterogeneous BIM software packages and systems, and the additional efforts required to adopt BIM (Turk, 2016). BIM is also a relatively new concept for users at the subcontractors and suppliers. Consequently, these users have only a limited understanding of BIM, the way BIM can be used, and the way this application should be implemented. Having insufficient knowledge and experience of BIM hampers the speed of implementation and the extension of BIM applications. Given the limited shared background knowledge of the organizations involved (an important aspect of their lifeworlds), users face difficulties in reaching a mutual understanding. Although education and training are offered with regard to BIM applications, time is still needed to increase this mutual understanding.

Given the lack of intrinsic motivation for using BIM and the limited shared background knowledge, some of the subcontractors and suppliers have decided not to invest in customizing BIM to match their internal working practices. Thus, they have not "internalized" BIM and consciously decided not to take the step of rationalizing their own lifeworld. As a result, working practices and BIM are not aligned. This situation restricts not only the rationalization of lifeworlds but also the autonomous coordination by the BIM models based on their inbuilt structures (Honneth and Joas, 1991).

5.2 Mediating effects of BIM on the level of practices

Heidegger's concepts of ready-to-hand, unready-to-hand, and present-at-hand have been used to explore if and how BIM shapes working practices. Using BIM starts with being instructed: only through contextual learning do users acquire skills and know-how (Dreyfus and Dreyfus, 1996). Ideally, they gain the skills and expertise necessary to deal with BIM in an unreflective way. BIM becomes ready-to-hand as it gradually blends into the totality of shared practices (Riemer and Johnston, 2011) and equipment used, and it no longer needs any reflection when using it. This situation is when BIM is no longer encountered as a technology that can only be used by following instructions but has become ready-to-hand in one's everyday practices. In this situation, a user "embodies" BIM. In Ihde's terms, this situation can be interpreted as an embodiment of the BIM–lifeworld relationship.

However, in the case study, BIM was not yet "ready-to-hand." The acquisition of sufficient knowledge and experience was regarded as an ongoing, long-term, and step-by-step development. Users were learning to use BIM by trial and error. BIM conflicted with the existing ready-to-hand work practice environment. The development of new software, new procedures, work processes, and job descriptions, updates to existing software, making agreements on the modeling in BIM, and the related learning process, consumed considerable time. Thus, these aspects of BIM better reflected an "unreadiness-to-hand" situation. Given these problems, several users had reverted to the "old" software because they could not work with the new BIM software. For these users, BIM remained "present-at-hand." The switch from being either ready-to-hand or unready-to-hand to present-at-hand indicates that the BIM–lifeworld relationship changes from an embodiment to an alterity relationship. Users are no longer related to the world by BIM (as in an embodiment relationship) but are directed to the conditions to let BIM work (as in an alterity relationship).

In a hermeneutic relationship, users turn to a BIM application to read and interpret a specific representation that it provides (Rosenberger and Verbeek, 2015). When viewing the BIM–lifeworld relationship as a hermeneutic one, two key concepts can be taken from Ihde (1990): the reduction and amplification of representations. BIM mediates different views by providing multiple representations of technical data in different forms. These representations and visualizations are different because different disciplines or groups of professionals have different needs in terms of data, object structures, and contextual information (Hartmann and Vossebeld, 2013). BIM models are judged in the light of specific contexts of specific domains: in each domain, professionals have different techniques, educational levels, and languages (Li et al., 2016). Representing different object structures and design representations in BIM amplifies the detection of design conflicts by clash-checking. Reduction also takes place because the representations present in the BIM model are reduced to views that can be expressed using the three-dimensional objects and properties adopted. According to Heidegger, professionals also risk "blindness" (Turk, 2001b) when they rely excessively on BIM rather than recognizing their "thrownness" into a particular project context. Construction professionals are primarily committed to "being-in-the-world" rather than to "being-in-a-model-of-the-world" (Heidegger, 1977; Dias, 2006; Turk, 2001b).

BIM also mediates certain actions through invitation and inhibition, two of Ihde's other key concepts (Ihde, 1990). BIM invites users to act in a certain way and inhibits acting in other ways (Verbeek, 2006). That is, using BIM enhances the design process by enabling different disciplines to modify their own object designs while considering possible conflicts. The visualization of construction schedules using BIM also "invites" professionals to optimize the planning of the actual building process by considering the realization process alongside design aspects. Conversely, a specific product model will "inhibit" professionals from using solutions that product models from other disciplines suggest.

By inviting and inhibiting certain actions, BIM can lead to processes being aligned and adopted. Users from different companies align their object libraries and coordinate their design and realization processes. They can all change their working practices and align their lifeworlds and BIM by invitation and inhibition. Thus, invitation and inhibition can stimulate the rationalization of the lifeworlds. However, the lack of intrinsic motivation and shared background knowledge also inhibits alignment between BIM and working processes because the development of new procedures, work processes, and job descriptions is viewed as excessively complicated and time consuming.

6 Conclusions

This study aims to explore the mediating effects of BIM on the lifeworlds of organizations in a construction supply chain by using concepts of Heidegger, Habermas, and Ihde.

On an abstract and critical level, the concepts of enframing (Heidegger) and rationalization (Habermas) are used to interpret the mediating effects of BIM. The many heterogeneous BIM applications and systems used by the various parties, coupled with the need for flexibility and adaptability, resulted in interoperability problems that formed a major barrier to enframing the supply chain by BIM. Enframing also emphasizes that the inertial effects of systems and applications amount to a key determining factor of the quasi-autonomous nature of technology in modern organizations. Given the interoperability problems seen with BIM, such a quasi-autonomous nature remains absent at the supply chain level, the lack of intrinsic motivation for using BIM, and the limited shared background knowledge, some BIM users decided not to invest in customizing BIM to match their internal working practices and consciously decided not to take the step of rationalizing their own lifeworld to bring it into line with the systems.

The level of practices that BIM users are socialized into Heidegger's concepts of ready-to-hand, unready-to-hand, and present-at-hand and the human–technology relationships proposed by Ihde are used to interpret the mediating effects of BIM. In Heidegger's terminology, BIM becomes ready-to-hand once as it has blended into the totality of the shared practices and equipment employed and therefore no longer requires reflection when using it. However, our case study showed that BIM has not reached this state because it conflicts with existing work practices. Some users had reverted to their previous software because they could not work with the new BIM software. In this situation, BIM switches from being (un-) ready-to-hand to become present-at-hand. In terms of Ihde's relationships, BIM has switched from an embodiment to an alterity relationship.

BIM also mediates certain actions by invitation and inhibition. BIM "invites" users to optimize the planning of the actual building process by considering the design and the realization processes and "inhibits" divergent actions. In this way, BIM users at the construction firm, its suppliers, and its subcontractors should adapt their working practices to align their lifeworlds and their BIM. Although invitation and inhibition may stimulate the rationalization of lifeworlds, the lack of intrinsic motivation and of a background of mutual knowledge inhibited alignment between BIM and working practices.

If the organizations who participate in these supply chains aim to obtain the benefits of BIM, they must align their working practices and customize BIM to reflect these practices. Time must be allotted to conduct these activities. Given that, in many instances, the lifeworlds are not yet rationalized toward BIM, the actors involved are often unaware of its potential benefits, thereby resulting in resistance to its use. Educating the participating firms about BIM, how it can be used, its potential benefits and disadvantages, and solutions to overcome the latter will reduce the distorted perceptions of BIM. Furthermore, BIM must be customized to the purposes, needs, and working practices of the actors involved. This way will eliminate, or at least reduce, resistance to using BIM. This result is important because, with BIM, the benefits for everyone increase as the number of actors adopting it increases. Financial incentives (such as dividing resulting savings among participating organizations or linking payments to BIM use) and contractual arrangements can also be used to stimulate actors to use BIM.

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Appendix A Interview themes

Strategy	The vision and objectives for BIM, how these are supported by the management, and how the introduction of BIM involves experts and specific designated groups.
Management support	The extent to which the management supports the implementation and further development of BIM by making budgets available and through communicating the relevance of BIM.
BIM expertise	Depending on the organization size, a BIM expert, a BIM working group, and/or a BIM-related department can be appointed. This player will often have leading, advisory, and supporting roles in the BIM implementation process.
Organizational structure	An organization's structure includes the formal structure of the organization, including the hierarchical structure and job descriptions. The project structure defines how, in relation to BIM duties, responsibilities and risks are organized among the different parties in a project.
Tasks and responsibilities	The extent to which the tasks and responsibilities related to BIM processes are formalized, and the way in which they are addressed.
People and culture	Factors that are related to the characteristics and competencies of individuals and the organization as a whole. Individual motivation and/or a trait within the corporate culture will determine not only the current BIM use, but also the transition to new working methods and technologies.
Personal motivation and readiness to change	Individual drivers to accept and support BIM implementation. This motivation will determine the willingness of people to adjust their way of working to use BIM. The prevailing organizational culture has a major influence on the extent and speed of change processes.
Requesting actor (internal)	A requesting actor acts as a driver for the BIM implementation process. This so-called BIM champion steers and stimulates other people in the organization to use BIM.
Education, training, and support	Education, training, and support for BIM include both general organization-level information as well as specific instructions and guidance for particular people/target groups. Also involves the development of competences to execute BIM-related tasks.
Processes and procedures	The extent to which organizational and project-based processes are documented, e.g. in procedures and work instructions. This affects the consistency in the performance of processes.
Job instructions and procedures	The extent to which the organization's internal processes for the various BIM applications are formalized in job instructions and procedures.
ICT (infrastructure)	The ICT-related resources that facilitate BIM, including both hardware and software.
Hardware and network environment	The physical elements and systems required to use and to store software and data. The quality of the network environment determines the ease with which a construction model and associated data can be exchanged both internally and externally. The ability to work simultaneously within the BIM environment also depends on the network environment.
Software	Operating and application tools that facilitate BIM applications.
Data(structure)	The management, structure, (re-)use, and exchange of project-related data.
Information structure	Use of a document management system (DMS), such as SharePoint, to save project data in a structured way and to make it accessible.
Object structure and decomposition	The decomposition/breakdown of a construction work, where physical or functional elements of a building are defined on different levels of detail. The structure that this creates can be used to provide insights into different parts of the construction work, to draw up and manage work packages, or to link information to specific elements.

(*Continued*)

Strategy	The vision and objectives for BIM, how these are supported by the management, and how the introduction of BIM involves experts and specific designated groups.
Objects library and object attributes	In constructing a building model, standardized objects from an object library (a database of objects) can be used. An object's attributes add additional, non-graphical information to objects in the building model, including characteristics and properties of an object.
Data exchange	The exchange and sharing of data via or from the building model with other parties. This creates various possibilities such as working on the basis of partners' data (part models).

Appendix B Interview questions

Strategy

Management support
1. Is there support for BIM from the management? What aspects do they support: financial, propagating the importance of BIM, etc.?
2. Are sufficient resources made available to apply BIM (do investments in BIM implementation depend on project budgets or are additional resources available)?
3. Are these funds sufficient to further develop and deploy new BIM applications? How is the support for the future guaranteed? (Has a multi-year program been prepared in which the support is defined?)

BIM expertise
1. Is there within the organization, a BIM expert, a BIM working group or a central department appointed to implement BIM?
2. Is sufficient time and priority given to the BIM expert/group? From which part/components and layers of the organization is this person / are these people from?

Organizational structure

Tasks and responsibilities
1. Is working with BIM integrated into the duties of regular functions (planner, designer, etc.) or are specialists needed, for example to operate software?
2. What is the impact of a changing environment on the BIM definitions of roles and responsibilities?

People and culture

Personal motivation and readiness to change
1. BIM is in many ways different from traditional practices. You should therefore see it as a change process. Does the motivation for this transition result from the organizational culture, or does it depend on individual drivers or those within a project team?

Requesting actor (internal)
1. Are there within the Organization one or more people who act as drivers for the implementation and use of BIM?
2. Do these drivers have enough time to optimally fulfill this role? On which layer/layers of the organization is/are this/these driver(s) active and do they act on behalf of the management?
3. Do the drivers of the BIM implementation process work together with partners, other organizations, or agencies to further encourage BIM development?

Education, training, and support
1. Is there education or training within the Organization linked to BIM software/BIM applications?
2. If so, what is the content (general education and/or specific training and guidance)? Are there opportunities to learn from experience and practical situations (both good and bad practices)? What is the target group of this education and training, who qualify to take part?
3. Are there IT employees/professionals who can offer personal guidance and technical support on BIM use? Is there an education program with a plan for education/training (or is it ad hoc)?

Processes and procedures

Job instructions and procedures
1. Are detailed procedures or work instructions prepared in which the processes related to BIM are described (or does this depend on the competences of individuals/teams?) Do these procedures/work instructions exist for all specific BIM applications?
2. How is it ensured that these procedures are followed consistently by everyone? Are there, for example, quality targets established for performance measurement?
3. What is the influence of experience gained and results on the work instructions (are these more static or dynamic documents)?

ICT (infrastructure)

Hardware and network environment
1. Do the organization's physical systems- the hardware- facilitate the BIM software to function properly (and to support any BIM applications)?
2. Is advanced BIM software also supported? On all workstations in the organization, or only in specific spaces?
3. To what extent does the network environment support the cooperation of different parties in BIM? Are files exchanged across the network, is there also simultaneous working on a building model within a network environment?

Software
1. Is the software able to exchange (parts of) a BIM with external parties?
2. Does the software have restrictions whereby not all the desired BIM applications can be used?

(*Continued*)

Strategy
Data (structure)
Information structure 1. Is a document management system (such as SharePoint) used? Is this system used for all BIM applications/all projects? 2. Is use of the document management system included in work procedures and/or job descriptions? 3. Is this system linked to the BIM platform? 4. Is the document management system only for internal use or does it act within a project as an 'umbrella ' system, in which all parties can store their information?
Object structure and decomposition 1. Is systematic object decomposition used, such as a System Breakdown Structure (within the framework of the Systems Engineering method), the Stabu or the RGD BIM standards (Government Buildings Agency)? 2. Is this decomposition prepared per project, or used as a uniform decomposition with standardized object encodings? 3. Does decomposition take place in cooperation with external partners? Are general agreements made or agreements on a project basis? Is your organization involved in further standardization of object structures in the sector?
Objects library and object attributes 1. Is an object library used in the construction of building information models? 2. Has the organization built a generic object library or is a specific library created for each project? 3. Are objects in the object library exchanged with project partners (using open standards)? Are objects from the objects library aligned with industry standards? Are there standard sets of properties associated with the object types in the objects library? What (non-geometric) information has to still be added to the separate objects in the building model (properties materials, requirements, etc.)?
Data exchange 1. Is an object library used in the construction of building information models? 2. Has the organization built a generic object library or is a specific library created for each project? 3. Are objects of the object library exchanged with project partners (using open standards)? Are objects from the objects library aligned with industry standards? Are there standard sets of properties associated with the object types in the objects library? What (non-geometric) information has to still be added to the separate objects in the building model (properties materials, requirements, etc.)?