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Hans Voordijk

Civil Engineering & Management, University of Twente, Enschede, Netherlands

ABSTRACT

Digital technologies and users of these technologies interact with each other in different ways. This study explores the influence of this interaction on users' behavior in construction practice: where and how do digital technologies in construction interact with their users, and what is their effect? The theory of technical mediation is applied to understand these influences. This theory deepens the analysis of human-technology interactions by adding that humans and technologies co-shape each other. Based on a literature review and studies of construction projects, technologies such as Building Information Modelling, Radio Frequency Identification, and Augmented/Virtual Reality are studied. Mediating effects of these technologies are analyzed from two perspectives: from which side does technology grasp the human body, what are the force and visibility of these impacts? It is shown that digital technologies in construction practice play different 'actant' roles by influencing or directing users in certain directions: digital technologies become natural extensions of the body (physical influence), function as 'quasi-others' (cognitive influence) or determine possible human–technology interactions through a 'decisive' design (contextual influence). Different preconditions for successful implementing and using these technologies can be related to these actant roles.

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Introduction

Digital technologies have come to play a significant role in construction practice. Building Information Modeling (BIM), Augmented and Virtual reality, the Internet of Things, RFID, and 3D scanning are all seen as promising digital technologies (Lu et al., 2015). BIM is a key digital technology that serves as a software platform representing a digital model in which information about a project can be stored and transferred among different parties in a construction project (Azzouz & Papadonikolaki, 2020; Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016; Hasan & Rasheed, 2019). BIM as a digital platform is also the basis for Virtual Reality and Augmented Reality applications improving communication, planning and training in construction (Williams, Gheisari, Chen, & Irizarry, 2015). BIM models can also be filled with actual data from technologies that monitor a building or parts of building during its whole life-cycle.

In construction practice, digital technologies and users of these technologies interact with each other in different ways. Having a better understanding of these interactions may help companies in the construction industry with successfully implementing new applications of digital technologies.

CONTACT Hans Voordijk j.t.voordijk@utwente.nl

The objective of this study is to explore the influence of these different ways of interaction on users' behavior. A major question is where and how do digital technologies in construction interact with their users, and what is their effect? Assessing this interaction is also the focus of the philosophy of technical mediation (Ihde, 1990). The theory of technical mediation deepens the analysis of human-technology interactions. Technical mediation adds that these interactions are not only understood as an encounter between two independent entities, humans and technologies, but that they co-shape each other. This study therefore applies the theory of technical mediation to understand the different forms of interaction between digital technologies and their users in construction practice. We specifically study technologies that are now regularly used in construction practice such as BIM, VR/MAR, and RFID applications.

Below, the various digital technologies and the context of the construction industry are described first. Subsequently, the mediation framework is elaborated on. Following this, by using this framework and based on a literature review and empirical studies, various uses and of BIM, RFID, and VR/AR are categorized and their influences are analyzed in terms of their force and visibility. The final sections close this study with a discussion on the findings and the drawing of conclusions.

Digital technologies in construction

The construction industry is traditionally characterized by fragmented supply chains, the one-off nature of works and project teams made up of many diverse actors (Saini, Arif, & Kulonda, 2019). An architect makes a design which is executed by the contractor, assisted by suppliers and subcontractors. Cost, time and quality-related issues occur because of the different cultures, languages and approaches of the actors involved and the lack of structured communication between them (Riazi, Zainuddin, Nawi, Musa, & Lee, 2020). BIM provides a means for standardized information and communication among these actors. Architects use BIM to develop conceptual and detail designs. Using BIM, contractors perform constructability analyses and improve project scheduling and planning (Latiffi, Brahim, & Fathi, 2015). Based on detailed BIM information regarding building components used, suppliers can plan manufacturing and delivery to site.

A broadly accepted definition of BIM is that it is

> a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. (NIBS, 2007)

BIM can be interpreted as a 'digital boundary object' facilitating communication, information exchange and collaboration between these parties in projects (Papadonikolaki, Van Oel, & Kagioglou, 2019). 'Digital boundary objects' are digital technologies that facilitate and support cross-boundary coordination among individuals from different knowledge domains in specific projects (Alin, Iorio, & Taylor, 2013). BIM enables, as a 'digital platform', working practices to become more integrated through cooperation and coordination between organizations (Papadonikolaki, Vrijhoef, & Wamelink, 2016). BIM is an 'unbounded' innovation as it crosses different disciplines and stages of the construction process and requires interaction among and alignment with agents and other technologies (Azzouz & Papadonikolaki, 2020; Harty, 2005). In contrast to a 'bounded innovation' are the consequences of an unbounded innovation beyond the control of its implementer.

BIM is also the basis for Virtual Reality (VR) and Augmented Reality (AR) applications improving communication, planning and training in construction (Williams et al., 2015). VR and AR technologies can therefore also be interpreted as digital boundary objects in construction by providing actors the ability to interact with each other and with objects within virtual three-dimensional (3D) environments (Wang, Wu, Wang, Chi, & Wang, 2018). VR-based learning platforms provide an environment in which users and learners can navigate through, and interact with, virtual construction sites that would otherwise be difficult (and sometimes impossible) to experience in field-based training. VR-based training has rapidly evolved in the past few years from simple graphical interfaces for assessing trainees' decision-making ability to complex multiplayer scenarios augmented with artificial intelligence and immersive technologies. Based on VR, AR 'augments', or overlays, the real world with digital information. Mobile AR (MAR) devices are portable displays and include smartphones, tablets, and wearable Head-Mounted Displays (HMDs) supporting decision-making processes on-site. MAR allows users to interact with both actual and virtual objects and to monitor construction progress by comparing the as-planned and as-built status of (part of) a project and can support tasks during construction.

BIM models as digital platform can be filled with actual data from technologies that monitor a building during its whole life-cycle. Radio Frequency Identification (RFID) is an example of such a technology. RFID has been widely used in construction projects during the past two decades. RFID is defined as 'the process and physical infrastructure by which a unique identifier, within a pre-defined protocol definition, is transferred from a device to a reader via radio frequency waves' (Bank, Pachano, Thompson, and Hanny, 2007, p. 3). In an RFID system, a tag is attached to (or placed within) products and contains a unique number which can be sent to an RFID reader. When the reader acquires a tag's identification, it becomes possible to identify and locate unique products in real time. By providing accurate information about the location of products and materials, RFID improves the visibility of products. Through the use of RFID applications, planning, material, safety, waste, maintenance, and document management can be improved.

Technical mediation framework

Digital technologies as digital boundary objects require interactions among and alignment with users and technologies. Technical mediation adds that these interactions are not only understood as an encounter between two independent entities, users and technologies, but that they also co-shape each other in construction practice. The theory of technical mediation implies that human experiences and practices are always, to varying degrees, constituted and transformed by technologies (Ihde, 1990; Verbeek, 2005). When a technology is used, 'it becomes a mediator between its users and their environment' (Verbeek, 2015b, p. 218) (see Figure 1).

The concept of technical mediation takes a middle position between, on one hand, technology as a script dictating its own direction and, on the other hand, determining society (technical determinism) and technologies as neutral instruments (instrumentalism) (Dorrestijn, 2012a). Technical mediation essentially emphasize that technologies are not passive entities but actively co-shape what actors do (Ihde, 1990; Verbeek, 2005). The technical mediation approach relates to the actor network theory of Latour (1992) in studying hybrid characteristics of human–technology relationships. In the actor network theory of Latour, both humans and 'nonhumans', i.e. technologies or physical objects, should be understood as actors having their own agency. Latour refers to these elements as 'actants'. Technologies that function as 'actants' may influence users or direct people in certain directions (Akrich, 1992). A technology only acquires its function as actant in a specific use context, while this use context is at the same time shaped by a technology as actant. It is in the specific use context that the interaction between digital technologies and users in construction practice is studied.

These interactions are analyzed in terms of *locus* and *type* (Verbeek, 2013). For conceptualizing the locus, or points where mediation is applied, Verbeek (2013) refers to the framework of Dorrestijn

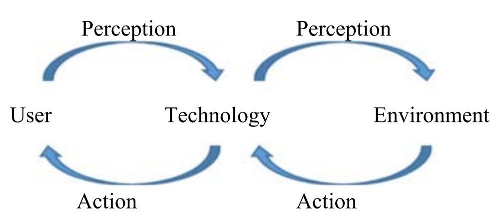

Figure 1. The concept of technical mediation.

(2012a, 2017). Dorrestijn translates the general concept of points or *loci* of technical mediation into more specific interactions between human beings and technologies. Dorrestijn categorized these interactions according to from which side technologies grasp the human body: physical, cognitive, or contextual. Tromp, Hekkert, and Verbeek (2011) have extensively studied the various *types* of influences that technologies can have on human beings. The types of mediation are categorized in terms of their influence (weak versus strong) and their visibility (hidden versus explicit) (Tromp et al., 2011).

Loci of mediation application

The framework of Dorrestijn (2012a, 2017) on behavior-influencing technology is used here to conceptualize the three loci, or points of application from which side technologies grasp the human body (see Table 1).

The first point of application of mediation focuses on how an individual physically encounters technologies (Dorrestijn, 2012b). The most direct influences that technologies have on humans are when they steer physical behavior. An important form of such influences is *coercion*. Examples are a fence to control access, and a speed bump forcing car drivers to slow down (Latour, 1992). Technologies force people into a certain direction. Another form of influence, labeled *embodied* technologies, concerns abilities such as writing with a pencil, riding a bike, or playing a musical instrument (Ihde, 1990). Here, the technology influences users during an exercising process in which the technology becomes embodied: people acquire skills and learn routines (Dorrestijn, 2012b).

The second point of application of mediation focuses on how technology impacts cognitively human decision-making (Dorrestijn, 2012b). An important form of cognitive influence is *guidance* – being steered towards an intended or appropriate use. Technology can guide behavior by giving signs (arrows, texts, light signals) which serve as inputs to a user's decision-making process. Technologies can also *persuade* people to change their behavior (Dorrestijn, 2012b) through so-called persuasive technology (Fogg, 2002). An example are websites that persuade people to 'click here'. A third form of cognitive influence is the expression of people's *image* through using certain products. For example, products such as fashionable smart phones allow people to shape and express their identity (Miller, 2010).

The third point of application of mediation addresses the contextual influence of the technological environment. This influence relates to 'the material infrastructure that has an impact on our actions and experiences' (Verbeek, 2015a). Here, technology shapes an environment in which specific forms of action and behavior can come about (Verbeek, 2013). First, technologies may have *side effects*. Even if a technology performs its intended function well, the advantages with respect to this primary function may be undone by disadvantages on another level. A car eases traveling, but too many cars cause traffic jams. Second, the successful functioning of a technology depends on *background conditions*. A technology may require an infrastructure for its maintenance, or skills for its operation. Finally, *technical determinism* reflects how technical developments may transform human values and needs. As with the prisoners in Bentham's Panopticon, the threat of

Table 1. Loci and subcategories of mediation.

Physical	• *coercion* • *embodiment*
Cognitive	• *guidance* • *persuasion* • *image*
Contextual	• *side effects* • *background conditions* • *technical determinism*

being watched through technology may generate behavioral changes. Digital technologies makes the activities of workers more visible and could lead to 'anticipatory conformity'.

This study uses these tree loci or points of application of mediation to analyze the different types of interaction between digital technologies and their users in construction practice.

Types of mediation

The second element for mediation analysis concerns the various types of influence that technologies can have on human beings. Following Tromp et al. (2011), the types of mediation can be categorized along two dimensions. One dimension indicates the force of the influence (weak versus strong), and the other its visibility (hidden versus explicit). This typology will be used to categorize the different physical, cognitive, and contextual influences identified by Dorrestijn (see Table 2).

The first type of influence is strong and explicit, and therefore apparent. People are aware of the influence and experience it as a strong external force (Tromp et al., 2011). We consider that strong and apparent influences can be both physical and cognitive. Both *coercion* (such as speed bumps discouraging fast driving) and *embodiment* (learning processes in which people acquire skills and routines) are forms of strong and explicit physical influences (Dorrestijn, 2012b). Cognitive influences such as *guidance* and *persuasion* may be strong and apparent. This is the case when people are strongly and explicitly steered or persuaded to act in a certain way.

The second type of influence is also explicit and apparent, but weak. Technologies can explicitly encourage people to change their behavior, but their influence can be experienced as weak. This type of influence can mostly be found in Dorrestijn's (2012a) cognitive category. In particular *guidance* and *persuasion* can both be apparent but also weak in their influence. Technology can guide behavior by giving signs, but these signs can easily be ignored. Technology-based influences that persuade people, such as websites with persuasive messages, are explicit but can be experienced as weak (Dorrestijn, 2012b).

The third type of influences is weak and implicit. Tromp et al. (2011) use the word *seductive* indicating that people are unaware of these influences and experience their behavior as internally motivated. These influences can be physical, cognitive, or contextual. The *embodiment* effect can be such a weak and implicit influence. The cognitive impact of creating an *image* through using certain products can also be weak and implicit. The contextual impact of *technical determinism*, where technical developments may create or transform human values and needs, can be weak and implicit too.

The fourth type of influences is strong but implicit. People experience their behavior as externally motivated or regulated, but do not see this as a deliberate influence or choice influenced by the designer of the technology (Tromp et al., 2011). Verbeek (2013) gives the example of a multistory

Table 2. Types of mediation: force and visibility.

	Hidden	Apparent
Strong	Contextual • *background conditions*	Physical • *coercion* • *embodiment* Cognitive • *guidance* • *persuasion*
Weak	Physical • *embodiment* Cognitive	Cognitive • *guidance* • *persuasion*

(*Continued*)

building deliberately designed without an elevator. Such a design strongly but implicitly decides for people that they will use the stairs. Such hidden but strong contextual influences are mostly the *background conditions* of a technology.

Methodology

The primary research method comprised the use of open-structured interviews with selected middle managers from clients, construction firms and their suppliers and subcontractors on the uses and influence of digital technologies in construction projects. All the interviewees selected had some experience with the digital technologies studied.

Case study selection

For exploring interactions between BIM and its users, the focus is on suppliers and subcontractors involved in two projects of a large Dutch construction firm. The first project is a housing project. In this project, representatives of six partners of the construction firm were interviewed. The second project was a building for healthcare services. Three partners of the construction firm were selected. In addition to these nine partners, three other long-term partners of the construction firm were interviewed. All firms had some experience with BIM. Within the construction firm itself, three employees in the BIM department and one in the supply chain management department were interviewed.

To explore interactions between RFID and its users, the focus is on suppliers and subcontractors involved in five large projects of another large Dutch construction firm. All projects, the construction of a museum, a governmental agency, a data center, an airport shopping center, and area development project are characterized by a complex planning with a tight schedule. For each project, one major subcontractor and one member of the project management team of the construction firm itself were interviewed. The interviewees were responsible for at least the logistics of the project.

To explore interactions between MAR and its users, the focus is on clients and contractors using MAR devices at three construction project. In the first project, an assembly crew testing a MAR application for a Head Mounted Display (HMD) with assembly instructions is observed and interviewed. The second and the third project focused on the use of MAR applications to visualize and augment the existing on-site subsurface infrastructure at an inner-city construction project and a university campus respectively. Representatives of the client, the utilities department of a large city and the university facility department, and a contractor are interviewed. Finally, a context-realistic VR training simulator to reconstruct actual construction sites in a VR environment using sensory data collected from real projects is discussed with instructors using this VR tool.

Data collection

An open-structured questionnaire was used and each interview started with questions about the project's circumstances. Following this, the most relevant uses and impact of a digital technology studied on the everyday working practices were discussed, including major non-technical barriers when implementing these technologies. Data on the physical and cognitive influences were collected by discussing experiences with adapting tasks and responsibilities, software, procedures, work processes, and jobs as a consequence of implementing and using digital technologies studied. The contextual influence and, in particular, the background conditions for the functioning of digital technologies studied was explored by discussing problems and technical barriers that users experience. The findings of the interviews were later sent to the interviewees for validation.

It was expected that the partially overlapping data from the interviewees in the different projects would give insights into the different types of interaction of the digital technologies studied. In addition to collecting primary data from the interviews, reference was also made to secondary data in the form of project documents, contracts (including BIM protocols, practical design guidelines) and user guides of technologies. Triangulation through the interviews in combination with documentation about the projects strengthened the internal validity of the data used.

Data analysis

The collected data comprised the interviewee transcripts. Data analysis commenced with multiple readings of the interview transcripts followed by thematic analysis. Through an iterative reading of the interview data, focusing on themes that could be interpreted as a particular mediation effect, the data were related to the different types of interaction between digital technologies and their users in construction practice. Using the framework of Dorrestijn (2012a) and the various uses of BIM, RFID, and VR/AR, it is analyzed from which side these digital technologies grasp the human body: the influences that technologies have on physical behavior of their users, decision-making in construction practice and the impact of the technological environment on user behavior. Data analysis also involved the researcher returning to literature in search of additional material relating on the impacts and interactions found in the projects (Voordijk, 2019a, 2019b).

Subsequently, the *types* of the various influences of the different uses of BIM, RFID and VR/AR are analyzed using the terms of Tromp et al. (2011): the force of the influence (weak versus strong) and its visibility (hidden versus explicit). The various uses identified were categorized using the above overview of the loci and types of human-technology interaction (see Table 2).

Uses of digital technologies

Using the framework of Dorrestijn (2012a) and a number of cases of BIM, RFID, and VR/AR uses from the projects studied, it is studied from which side these technologies of grasp the human body: physical, cognitive, or contextual.

BIM

Physical influence

BIM influences its users 'physically' when the technology becomes embodied through acquiring new skills and routines. The BIM projects showed that users learn to use new BIM software by trial and error, and gaining sufficient knowledge and experience is a step-by-step process. Users mentioned the difficulties in using BIM-software. Since this consumes considerable time, they sometimes revert to the 'old' software and procedures because they cannot work with the new technology. Half of the partner firms interviewed in the BIM housing project were also in the process of updating work procedures and instructions. Inside firms, engineers learn from each other through visualizing 3D information and addressing problems that arise during construction. Externally, firms participate in trials and pilot projects involving other construction firms, universities, and suppliers in order to access BIM knowledge and the skills required to solve specific design problems.

Cognitive influence

An example of a cognitive influence mentioned is that the use of BIM by designers and general contractors are induced by the compelling influence of other project participants strongly advocating BIM use, such as public clients. According to the interviewees the national road authority and large municipalities are examples of such influence. According to suppliers, a major driving force to implement BIM can be the contractor as an external requesting actor.

Protocols, agreements or contractual agreements between parties involved in a project can compel an organization to use BIM. Both the contractor as the suppliers see this as an important instrument for guiding the efforts required to implement BIM. A BIM protocol includes stipulations for the level of detail and clarity of information required in the project, the standards that are applicable to the project, and definitions of the BIM-related roles. Financial penalties as part of the protocol were seen as least effective because they are perceived as part of a blaming culture.

Incentives created by BIM for the prime contractor, designer, subcontractor, and suppliers to deliver the BIM data required by other project partners in exchange for the BIM data they themselves require (Eastman, Teicholz, Sacks, & Liston, 2011) are also an example of this cognitive influence. These organizations benefit from aligning processes among themselves and sharing information through BIM. All the interviewees stated that an integrated contract model is an important precondition for getting these benefits through BIM. When organizations reduce costs through BIM, sharing these savings among the involved parties are viewed as an important incentive to use BIM.

BIM is also used to create a certain *corporate image*. Cao, Li, Wang, and Huang (2017) give an example of a Chinese case where designers and general contractors were motivated to implement BIM in their projects in order to create an image that they were deploying innovative technologies. Similar organizations lacking BIM capabilities may need to implement BIM to improve or re-establish their innovative image.

Contextual influence

The contextual influence addresses the impact of the technological environment on user behavior. According to one of the builders using BIM enhanced transparency by the discovery of clashes in the design process. This transparency enables different disciplines to modify their own designs but it also makes the activities of designers more visible. This transparency made some parties hesitant to share data with others in a project. The opposite of this behavior is the optimistic belief that BIM will create an open collaborative working environment and the deepening of collaboration and communication between partners in a construction project.

Another example of contextual influence is in establishing the infrastructure required for operating BIM. Effective interoperability among infrastructures within and between organizations is a necessary precondition for industry-wide adoption and use of BIM. However, several interoperability problems have been observed. Difficulties in handling huge amounts and loss of data through interoperability problems were the most frequently mentioned problem by BIM users. Industry-wide open standards are still not fully implemented, although some components are available. The lack of an industry-wide digital standards impacts the use of BIM.

VR/MAR applications

Physical influence

The physical influence of current VR applications simulating construction sites is that it make users feel that they are there, within the created reality of a building or construction site. The use of the Head Mounted Displays (HMDs) in the VR-based learning environment studied allows a realistic interaction between user and the virtual construction site. Users mentioned that they become, after a certain period of adaptation, focused on the work to be done in the simulated context. The VR scenes based on realistic or actual data enables an immersion in these scenes. Further, the use of HMDs, haptic sensors, and joysticks allows a deeper and wider interaction with the VR scenes.

Cognitive influence

MAR applications, such a Google Glass and HMDs, influence human decision-making by providing virtual instructions that are visualized during onsite construction activities. Users do not have to rely only on their cognitive capabilities because context-aware instructions are provided through MAR devices. MAR are related to objects external to the augmentation, i.e. the elements to be assembled. Several members of the assembly crew commented that this MAR device gives them a comforting feeling to know that they can rely on this technology, without having to make uncertain decisions. The city engineers concluded that the MAR device to visualize existing on-site subsurface infrastructure allows them to better estimate design and construction workspaces. Another example of such a cognitive influence in construction practice are VR simulators exposing users to a scene through a set of screens. These simulators focus on how to use the VR technology as such. They stimulate users to interact with the technology itself.

Contextual influence

The decisions and choices made when designing VR/MAR applications are an example of a contextual influence or impact of the technological environment. Here, design decisions determine the possible human–computer interactions in the context–user interaction phase. The design of the MAR application to visualize and augment existing on-site subsurface infrastructure is based on an existing conceptual utility model determining possible interactions. Another example is particular uses of a VR-based learning environment determined by the training instructors. These instructors make choices based on the learning objectives of a particular training exercise and the skill level of the trainees. Instructors identify the scope and learning objectives of the training program. In this way, the possibilities of a VR training tool for a particular user or trainee are determined by the instructors within the VR technology.

RFID

Physical influence

The physical influence of RFID is the experience of portable or mobile handheld RFID readers as natural extensions of the body. Through this physical influence, handheld tools, e.g. iPads and smartphones that include RFID functionalities, change routine behaviors in construction project management. Where mobile digital technologies are integrated in construction project practice, information can be collected, updated, and accessed automatically by the users where and when needed.

Cognitive influence

In several projects, RFID applications impact decision-making by automatically identifying which products had been delivered, and where these were stored on site. By providing the exact path that a shipment has followed, RFID invites users to take actions to optimize the delivery process. Once the logistic flows of products become visible, one can optimize these flows by combining shipments and reduce the distance driven by suppliers or optimize the delivery schedule. Knowing the time spent on locating and tracking tools and equipment, could suggest a different construction site layout. Insights through RFID into the realized planning or the actual quality of materials used could invite corrective actions.

According to the interviewees, using RFID also increases workers' awareness of safety. Here, an RFID system can prevent accidents on the construction site by warning workers of hazardous materials, fall risks, fires, and proximity to operating heavy equipment using different types of signals. Also, by providing insights into the location of stored products, RFID may prevent unsafe actions and situations arising at the construction site. With RFID, the technology can be used to give people access to restricted areas of a building in the event of an emergency. Here, RFID will influence users or direct people in certain directions.

Contextual influence

The impact of RFID as part of the technological environment can be seen for maintenance and use of buildings. RFID has a particular impact contextual influence when it comes to a building's efficiency in terms of maintenance and use. Interviewees in the RFID projects mentioned that real-time information about the performance of installations and building occupancy, gathered through RFID, could optimize the technical lifetime and increase and influence building utilization by its users Table 3.

Table 3. Influences of digital technologies in construction practice.

	Digital technologies		
Influences	BIM	MAR/VR	RFID
Physical	• acquiring new BIM skills and routines • interactive learning effects through BIM	• deeper immersion in a VR scene through HMDs	• handheld RFID tools changing routines on site
Cognitive	• external pressures to use BIM through requesting actors, protocols and contracts • incentives to exchange data through BIM • creating innovative image through BIM	• MAR applications in HMDs instructing users on site • VR training tools guiding users through different screens	• RFID optimizing materials management off and on-site • RFID in safety management warning workers • RFID directing people in case of emergency
Contextual	• changing behaviors through BIM • BIM interoperability among infrastructures impacting use	• MAR/VR user possibilities determined by design choices	• RFID impacting building' utilization by its users

Analysis of the types of influences

Four *types* of the various influences of BIM, RFID and VR/AR are analyzed using the terms of Tromp et al. (2011): the force of the influence (weak versus strong) and its visibility (hidden versus explicit).

Apparent and strong influences

In case of a strong and apparent influence, users are aware of this influence and experience it as a strong external force (Tromp et al., 2011). It is found that these influences may have a physical or a cognitive character.

Examples found of apparent and strong *physical* influences relate to the embodiment of digital technologies through learning processes, technologies as natural extensions of the body, and users being immersed in a virtual environment. Learning new BIM software and skills are the first example of an apparent and strong influence with a physical locus. A second example of this influence is the experience of portable or mobile handheld RFID readers as natural extensions of the body changing routine behaviors. A third example is users being immersed in a virtual environment using VR applications.

Examples found of apparent and strong *cognitive* influences in a construction project relate to a strong external force to use certain technologies, or to be directed by certain technologies. Certain MAR applications, such a Google Glass and HMDs, steer decision-making processes by providing virtual instructions onsite. In the event of an emergency, RFID steers users or directs people in certain directions by giving them access to restricted areas of a building. Another example of an apparent and strong cognitive influences is that some parties within a project may only adopt BIM because external organizations, such as public clients, requires them to use it through contracts and protocols.

Apparent and weak influences

In the case of apparent and weak influences, technologies can explicitly encourage people to change their behavior, but these influences can easily be ignored. It is found that these influences primarily have a cognitive character through guidance and persuasion.

RFID applications in safety management and conventional VR simulators are examples of apparent and weak *cognitive* influences of digital technologies guiding their users. RFID systems in safety management can prevent accidents on the construction site by warning their users when working on the construction site. Conventional VR simulators guide their users on how to use these technologies.

BIM incentives and certain RFID applications are examples of apparent and weak *cognitive* influences of digital technologies persuading their users. Incentives created by BIM persuade project partners to exchange data through this technology. By providing certain data, RFID applications in materials management and construction site monitoring invite users to optimize the delivery process or to take corrective actions.

Hidden and weak influences

In the case of weak and implicit influences, people are unaware of these influences and experience their behavior as internally motivated (Tromp et al., 2011). It is found that these influences may have a physical, cognitive or contextual character.

A hidden and weak *physical* influence found is unconscious learning processes on the organizational and project levels. Maradza, Whyte, and Larsen (2014) suggests that BIM unconsciously shapes a firm's internal and external interactive learning processes, amounting to an embodiment effect. An example of a hidden and weak *cognitive* influence is when BIM is used to establish or improve an innovative corporate image. An example of a hidden and weak *contextual* influence is when BIM is creating suspicious behavior when it comes to sharing data with other parties in a project or, the opposite, the optimistic belief that BIM creates an open collaborative working environment. This hidden and weak contextual influence is an example of technical determinism where technical developments may create or transform human values and needs. This contextual influence can also be interpreted as a side effect: through sharing data BIM creates transparency but this advantage may be undone when this technology creates suspicious behavior too.

Hidden and strong influences

In the case of strong but implicit influences, people experience their behavior as externally regulated, but do not see this as a deliberate influence by the designer of the technology (Tromp et al., 2011). It is found that these influences all have a contextual character.

An example of hidden and strong influences of digital technologies in terms of background conditions is the interoperability among infrastructures within and between organizations necessary for utilizing BIM. Another example of a hidden and strong influence is the use of RFID for maintenance and use of buildings. Real-time information about building occupancy, gathered through RFID, could increase and influence building utilization by its users. Also the decisions and choices made when designing a VR-based learning environment is an example of this contextual influence. In all these examples, users are influenced by the technological environment Table 4.

Table 4. Loci and types of mediation of digital technologies in construction practice.

	Hidden	Apparent
Strong	Contextual *background conditions*: 1. BIM and interoperability among infrastructures 2. RFID in maintenance and use of buildings 3. VR user possibilities' determined by design	Physical *embodiment*: 1. learning BIM skills and routines 2. RFID/MAR as extension of the body 3. immersion through HMDs Cognitive *guidance*: 4. MAR applications on HMDs 5. RFID in case of emergency 6. BIM protocols and contracts
Weak	Physical *embodiment*: 1. unconsciously interactive learning effects Cognitive *image*: 2. innovative image through BIM Contextual *technical determinism* or *side effect:* 3. changing behaviors through BIM	Cognitive *guidance*: 1. RFID in safety management 2. VR training tools guiding users Cognitive *persuasion*: 3. incentives through BIM 4. RFID in materials management and construction site monitoring

Discussion

The theoretical contribution, the contribution to knowledge and practice and limitations of this study are discussed in this section.

Different 'actant' roles

The theoretical contribution of this study is that it shows that digital technologies in construction may play different 'actant' roles in actor networks of technologies and their users (Latour, 1992). Analysing and categorizing the force and visibility of these actant roles also adds a new theoretical perspective on the interaction between users and digital technologies in construction.

The first 'actant' role is that digital technologies in construction practice become natural extensions of the body (Dias, 2006). In first instance, this actant role is apparent and strong and can be related to the embodiment of technologies in construction practice (Ihde, 1990). Once users have gained the skills and expertise necessary to work with it automatically in an unreflective way, digital technology becomes embodied in construction practices (Dreyfus & Dreyfus, 1996; Riemer & Johnston, 2014; Voordijk & Sloot, 2019). In this situation, the technology has become familiar to the user and almost 'disappears' in its use: it is not consciously noticed anymore by the user.

The second 'actant' role is that digital technologies in construction practice are perceived as 'quasi-others' having their own agency: users obey intelligent directions verbalized by these technologies (Hogan & Hornecker, 2011). Digital technologies as 'quasi-other' guide users in a certain direction (Latour, 1992). Where digital technologies in construction practice have apparent, weak or strong, cognitive influences, these technologies function as 'quasi-others'. They invite users to act in a certain way while inhibiting acting in other ways (Ihde, 1990). Interacting with digital technologies gives the user a sense of interacting with something 'other' than either themselves or reality.

The third 'actant' role is that digital technologies in construction practice play a role in the background: they shape the context in which humans act. The background role relates to hidden and strong contextual influences of digital technologies. The term *affordance* is appropriate here. Affordances refer to what the physical environment, in terms of properties, offer to human beings (Gibson, 1986). Affordances refer here to the properties of a digital technology and its meaning for its user (Voordijk & Vahdatikhaki, 2020). Affordances of a digital technology are the set of all possible uses this artifact could potentially have, and these are determined by decisions taken in the development and design process of a technology.

Practical implications and limitations

The contribution to knowledge and practice are insights in the relation between different types of user-technology interaction and different preconditions for successful implementing and using digital technologies in construction.

Physical influence can be a coercive intervention when implementing and using digital technology in construction practice. This type of intervention can be experienced as conflicting with users' individual freedom (Tromp et al., 2011). Such a coercive intervention can therefore only be successful if users almost unanimously agreed upon this. Users have to learn to use new technologies. Through this coercive intervention, digital technologies apparently change routine behaviors in construction practice.

Cognitive influences can be related to persuasive interventions when using digital technologies in construction. In this case, the use of digital technologies is most successful when interaction with them occurs on a voluntary basis. In particular persuasive interventions related to safety and emergency issues are easily accepted by individuals, e.g. RFID applications inviting users to act in a certain way. Persuasive interventions are also best applied when collective interests are in line with individual interests, e.g. BIM creating incentives for parties to deliver the data required.

Contextual influence can be related to 'decisive' designs of technologies that determine possible human–technology interactions when using them. The system interoperability of BIM (Farghaly, Abanda, Vidalakis, & Wood, 2018), the choices made when developing VR/MAR applications or particular uses of a VR-based learning environment determined by the training instructors are typical examples of decisive designs determining possible interactions.

This study started with the question: where and how do digital technologies in construction interact with their users, and what is their effect? It is shown that digital technologies can become natural extensions of the body, perceived as 'quasi-others' having their own agency or shape the context in which humans act. Implementation of these technologies are related to respectively coercive and persuasive interventions and 'decisive' designs.

This study also has its limitations. First, the findings and its analysis are both based on a limited number of use-cases of BIM, VR/MAR and RFID in the construction domain. As such, further cases of these and other digital technologies are required to establish the external validity of the developed typology of the loci and types of mediations of digital technologies in construction. Also, more detailed information on the exact scope, use and change of digital technologies used in construction practice is required to get deeper insights in the user-technology interactions and their developments over time.

Conclusions

In this research, the mediation approach was used to study the influence of human-technology interactions on users' behavior of digital technologies that are now regularly used in construction practice such as BIM, RFID, and AR and VR applications. It has been possible to trace the mediating effects of these digital technologies in terms of locus and type (Verbeek, 2013). The theoretical contribution of this study is that it shows that digital technologies in construction practice may play different 'actant' roles by influencing or directing users in certain directions. The contribution to knowledge and practice are insights in the relation between these actant roles and different preconditions for successful implementing and using digital technologies.

Physical influences in construction practice of digital technologies relate to the *embodiment* of technologies (Ihde, 1990): the conscious and unconscious learning effects when trying to use BIM and RFID in construction practice or when users become immersed in a VR/AR virtual environment. Digital technologies in construction practice become natural extensions of the body. In first instance, this actant role is apparent and strong but almost 'disappears' in its use. Implementation of such a digital technology is a coercive intervention and can therefore only be successful if users almost unanimously agreed upon this.

Apparent cognitive influences of digital technologies in construction practice relate to their actant role as 'quasi-others'. Digital technologies have their own agency and invite users to act in a certain way. RFID and VR/MAR applications function as 'quasi-others' to which users relate by obeying virtual instructions. On a project level, BIM creates incentives or requests to exchange information in a specific way. Users sense they are interacting with something 'other'. The use of this category digital technologies is based on persuasive interventions and most successful when interaction with them occurs on a voluntary basis.

Contextual influences of digital technologies in construction practice can be related to 'decisive' designs of technologies that determine possible human–technology interactions when using them. Decisive designs shape the context in which humans act and are related to hidden and strong contextual influences of digital technologies. The BIM infrastructure and its system interoperability and the choices made when developing VR/MAR applications are examples of decisive designs. A decisive design of a technology is related to the affordances of digital technologies which are determined by decisions taken by designers in the development process.

The outcomes of this study can serve as useful input for future empirical research on specific applications of digital technologies in construction practice. For example, it could be investigated why organizations choose to use certain applications in their projects, and what the perceived benefits, and disadvantages, of these applications are that influence an organization's intention to adopt a technology. Future implementations of digital technologies could benefit from an initial assessment that seeks to balance the various mediating effects.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are available from the corresponding author, H. Voordijk, upon reasonable request.

References

Akrich, M. (1992). The de-scription of technical objects. In W. E. Bijker, & J. Law (Eds.), *Shaping technology/building society: Studies in sociotechnical change* (pp. 205–224). Cambridge: MIT Press.

Alin, P., Iorio, J., & Taylor, J. E. (2013). Digital boundary objects as negotiation facilitators: Spanning boundaries in virtual engineering project networks. *Project Management Journal*, *44*(3), 48–63. doi:10.1002/pmj.21339

Azzouz, A., & Papadonikolaki, E. (2020). Boundary-spanning for managing digital innovation in the AEC sector. *Architectural Engineering and Design Management*, *16*(5), 356–373. doi:10.1080/17452007.2020.1735293

Bank, J., Pachano, M., Thompson, L., & Hanny, D. (2007). *RFID applied*. Hoboken, NJ: John Wiley & Son Inc.

Cao, D., Li, H., Wang, G., & Huang, T. (2017). Identifying and contextualising the motivations for BIM implementation in construction projects: An empirical study in China. *International Journal of Project Management*, *35*(4), 658–669. doi:10.1016/j.ijproman.2016.02.002

Dias, W. (2006). Heidegger's resonance with engineering: The primacy of practice. *Science and Engineering Ethics*, *12*(3), 523–532. doi:10.1007/s11948-006-0050-7

Dorrestijn, S. (2012a). *The design of our own lives: Technical mediation and subjectivation after Foucault*. Enschede: Universiteit Twente.

Dorrestijn, S. (2012b). Technical mediation and subjectivation: Tracing and extending Foucault's philosophy of technology. *Philosophy & Technology*, *25*(2), 221–241. doi:10.1007/s13347-011-0057-0

Dorrestijn, S. (2017). The product impact tool: The case of the Dutch public transport chip card. In K. Niedderer, S. Clune, & G. Ludden (Eds.), *Design for behaviour change: Theories and practices of designing for change* (pp. 26–39). Abingdon & New York: Routledge.

Dreyfus, H. L., & Dreyfus, S. E. (1996). The relationship of theory and practice in the acquisition of skill. In P. Benner, C. Tanner, & C. Chesla (Eds.), *Expertise in nursing practice: Caring, clinical judgment, and ethics* (pp. 29–47). New York: Springer.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors*. Hoboken, NJ: John Wiley & Sons, Inc.

Farghaly, K., Abanda, F. H., Vidalakis, C., & Wood, G. (2018). Taxonomy for BIM and asset management semantic interoperability. *Journal of Management in Engineering*, *34*(4), 04018012. doi:10.1061/(ASCE)ME.1943-5479.0000610

Fogg, B. J. (2002). *Persuasive technology: Using computers to change what we think and do*. San Franciso: Morgan Kaufmann Publishers.

Gerbert, P., Castagnino, S., Rothballer, C., Renz, A., & Filitz, R. (2016). *Digital in engineering and construction: The transformative power of building information modeling*. Boston: The Boston Consulting Group Inc.

Gibson, J. J. (1986). *The ecological approach to visual perception*. Hills-dale, NJ: Lawrence.

Harty, C. (2005). Innovation in construction: A sociology of technology approach. *Building Research & Information*, *33*(6), 512–522. doi:10.1080/09613210500288605

Hasan, A. N., & Rasheed, S. M. (2019). The benefits of and challenges to implement 5D BIM in construction industry. *Civil Engineering Journal*, *5*(2), 412. doi:10.28991/cej-2019-03091255

Hogan, T., & Hornecker, E. (2011). *Human-data relations and the lifeworld. Proc 5th Irish human computer interaction conference*. Cork, Ireland.

Ihde, D. (1990). *Technology and the lifeworld: From garden to earth*. Bloomington: Indiana University Press.

Latiffi, A. A., Brahim, J., & Fathi, M. S. (2015). Roles and responsibilities of construction players in projects using building information modeling (BIM). In A. Bouras, B. Eynard, S. Foufou, & K.-D. Thoben (Eds.), *Product lifecycle management in the area of Internet of things* (pp. 173–182). Cham: Springer.

Latour, B. (1992). Where are the missing masses? The sociology of a FewMundane artifacts. In W. E. Bijker, & J. Law (Eds.), *Shaping technology/building society: Studies in sociotechnical change* (pp. 225–258). Cambridge: Mass.: MIT Press.

Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R., & Le, Y. (2015). Information and communication technology applications in architecture, engineering, and construction organizations: A 15-year review. *Journal of Management in Engineering*, *31*(1), A4014010. doi:10.1061/(ASCE)ME.1943-5479.0000319

Maradza, E., Whyte, J., & Larsen, G. D. (2014). Interactive learning in UK construction practice: Examining the role of BIM process standards. *Proc 30th Annual ARCOM Conference*, 1-3. Portsmouth: Association of Researchers in Construction Management.

Miller, D. (2010). *Stuff*. Malden, MA: Polity Press.

National Institute of Building Sciences. (2007). *National building information modelling standard Part-1: Overview, principles and methodologies*. Washington, DC: NIBS.

Papadonikolaki, E., Van Oel, C., & Kagioglou, M. (2019). Organising and managing boundaries: A structurational view of collaboration with Building Information Modelling (BIM). *International Journal of Project Management*, *37*(3), 378–394. doi:10.1016/j.ijproman.2019.01.010

Papadonikolaki, E., Vrijhoef, R., & Wamelink, H. (2016). The interdependences of BIM and supply chain partnering: Empirical explorations. *Architectural Engineering and Design Management*, *12*(6), 476–494. doi:10.1080/17452007.2016.1212693

Riazi, S. R. M., Zainuddin, M. F., Nawi, M. N. M., Musa, S., & Lee, A. (2020). A critical review of fragmentation issues in the construction industry. *Journal of Talent Development and Excellence*, *12*(2), 1510–1521. htttp://iratde.com/index.php/jtde/article/view/545

Riemer, K., & Johnston, R. B. (2014). Rethinking the place of the artefact in IS using Heidegger's analysis of equipment. *European Journal of Information Systems*, *23*(3), 273–288. doi:10.1057/ejis.2013.5

Saini, M., Arif, M., & Kulonda, D. J. (2019). Challenges to transferring and sharing of tacit knowledge within a construction supply chain. *Construction Innovation*, *19*(1), 15–33. doi:10.1108/CI-03-2018-0015

Tromp, N., Hekkert, P., & Verbeek, P.-P. (2011). Design for socially responsible behavior: A classification of influence based on intended user experience. *Design Issues*, *27*(3), 3–19. doi:10.1162/DESI_a_00087

Verbeek, P.-P. (2005). *What things do: Philosophical reflections on technology, agency, and design*. University Park, PA: Pennsylvania State University Press.

Verbeek, P.-P. (2013). Technology design as experimental ethics. In S. van den Burg (Ed.), *Tsj. Swierstra. Ethics on the laboratory floor* (pp. 83–100). Basingstoke: Palgrave Macmillan.

Verbeek, P.-P. (2015a).. Beyond interaction: A short introduction to mediation theory. *Interactions*, *22*(3), 26–31. doi:10.1145/2751314

Verbeek, P.-P. (2015b). Designing the public sphere: Information technologies and the politics of mediation. In L. Floridi (Ed.), *The onlife manifesto* (pp. 217–227). Springer. doi:10.1007/978-3-319-04093-6_21

Voordijk, H. (2019a). Building information modeling and its impact on users in the lifeworld: A mediation perspective. *Frontiers of Engineering Management*, *6*(2), 193–206. doi:10.1007/s42524-019-0013-8

Voordijk, J. T. (2019b). Technological mediation in construction: Postphenomenological inquiry into digital technologies. *Journal of Construction Engineering and Management*, *145*(12), 04019084. doi:10.1061/(ASCE)CO.1943-7862.0001719

Voordijk, H., & Sloot, R. (2019). BIM mediation and users' behavior. *International Journal of Managing Projects in Business*. doi:10.1108/IJMPB-11-2018-0255

Voordijk, H., & Vahdatikhaki, F. (2020). Virtual Reality learning environments and technological mediation in construction practice. *European Journal of Engineering Education*, 1–15. doi:10.1080/03043797.2020.1795085

Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International Journal of Environmental Research and Public Health*, *15*(6), 1204. doi:10.3390/ijerph15061204

Williams, G., Gheisari, M., Chen, P.-J., & Irizarry, J. (2015). BIM2MAR: an efficient BIM translation to mobile augmented reality applications. *Journal of Management in Engineering*, *31*(1), A4014009. doi:10.1061/(ASCE)ME.1943-5479.0000315