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BIM TECHNOLOGY ACCEPTANCE AMONG REINFORCEMENT WORKERS – THE CASE OF OSLO AIRPORT'S TERMINAL 2

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SUMMARY: *Today's design teams deliver engineering models sophisticated enough to serve as blueprints for production and construction work. However, issues of adoption persist for the on-site use of building information modelling (BIM). It is known how delivery and placement of material such as reinforcing bars influences the productivity of the overall construction process. This article presents an early pilot case of BIM implementation for facilitating on-site placement of reinforcing bars. No traditional shop drawings were used throughout the fabrication and placement of the reinforcing bars. The research question asked is: Will BIM technology be accepted or rejected by concrete reinforcement ironworkers in carrying out their work? This question was considered worthwhile since whether or not individuals accept or resist using a new technology depends on whether they perceive it as beneficial or detrimental for doing their jobs. The technology acceptance model was used to structure the inquiry in this article. Data were collected based on a series of semi-structured interviews with reinforcement workers in Oslo's new airport terminal T2 project. The workers used a highly sophisticated virtual model indicating the position, type and dimension of reinforcement loops and bars. Findings are that even less IT-literate workers perceived the virtual models to provide them with a large relative advantage over paper workshop drawings. Thus, BIM systems, handheld devices, and apps can be considered sophisticated enough for replacing workshop drawings. A prerequisite is careful preparation work by structural and site engineers. Several issues hindering a more wide spread adoption could be identified: (1) information technology capability of structural engineers; (2) appropriate contracts, and (3) additional workload incurred by structural and site engineers. Our work indicates that substantial building process productivity improvements are possible when BIM adoption in reinforcing bar placement is introduced. However, there are costs which may outweigh some of the advantages. It was beyond the scope of our study to establish the added value of BIM for the reinforcement and the overall construction process.*

KEYWORDS: *BIM, reinforced concrete, on-site construction work, Technology Acceptance Model, Airport Terminal*

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1. INTRODUCTION

The Scandinavian region can be considered a global leader in Building Information Modelling (BIM) adoption and implementation (Smith, 2014). Statsbygg, Norway's largest governmental construction client, has demanded BIM in all projects since 2007 and they have required industry foundation class compliant BIM since 2010 (ibid.). Due to a long history of governmental clients embracing BIM, all large design and construction firms operating in Norway have hands-on experience from working on BIM projects. However, despite heavy investment in BIM technology, the Norwegian building industry is still missing out on many of the benefits that the technology has to offer (Larsen, 2008; Scheurer, 2010). This has to do with BIM not yet being fully diffused throughout the entire construction supply chain. While BIM has become the preferred tool in building design, its application for off- and on-site production and assembly is just in its infancy. In fact, sets of paper drawings continue to be the main information source for construction workers (Merschbrock, 2012). Or, as Davies and Harty (2013) put it: "issues of [BIM] adaptation persist, particularly for on-site use of BIM tools in the construction phase" (p. 15). It is not until recently that the digital building models have become sophisticated enough to facilitate on-site construction and assembly works (Merschbrock and Munkvold, 2015).

There are several pilot projects underway exploring how digital models displayed on handheld devices can best support on-site construction work (Davies and Harty, 2013). Thus, BIM gradually begins to affect organizational life in companies operating downstream in construction supply chains. Workers used to working based on paper drawings find themselves being exposed to novel modelling technology in their day-to-day work. This can be viewed as a 'technochange' situation similar to what has been suggested by Markus (2004). The term 'technochange' refers to situations where deploying new technology significantly affects organizational life. This is the case for on-site application of BIM since it is influenced by and influences the features of the industry, projects, and people involved (Linderoth et al. 2011). A risk involved in technochange is that people simply will not use the new technology and related processes. Scholars report that especially 'off-the-shelf' software, developed by technical teams not familiar with the characteristics of the organizational context, is likely to be resisted (Markus, 2004). Whether individuals accept or resist using a new technology depends on whether they perceive it to be beneficial or detrimental for doing their jobs. It is important that there exists a perceived relative advantage of using a new technology over the prevailing solution it replaces (Rogers, 2010).

In this article we focus on the technology acceptance of BIM by construction workers (Davis, 1989). More specifically we focus on the extent to which a group of ironworkers working in a Norwegian project, where BIM tools where applied in on-site construction, accepted the new technology. The software used was intended to enhance communication between structural engineers, reinforcing bar (rebar) fabricators, and site operations. The increasing complexity of today's structures makes placement and assembly of rebar based on paper drawings a challenging and error prone task. A prominent example of what can go wrong is the Harmon Hotel project in Las Vegas which was originally designed to be 49 stories high. The horizontal carrying reinforcement of the shear walls was positioned wrongly, the consequence being that the hotel had to be redesigned with its height reduced to 28 storeys (Way, 2011). The usefulness of ICT for supporting placement oriented design has long been advocated by construction researchers, and BIM has the potential to aid the clarity of expressing how rebars are to be assembled and placed (Aram et al. 2013, Bernold and Salim 1993). Scholars have worked with defining functional requirements for development of a BIM tool for cast-in-place reinforced concrete (Barak et al., 2009). Accordingly, restructuring the reinforcement supply chain by amongst others using more sophisticated information technology has received wide research attention in recent years (Aram et al. 2013; Polat et al, 2007; Tommelein and Ballard, 2005). Thus, embracing BIM deployment in reinforcement works is worthwhile. In this article we contribute to the discussion by exploring whether ironworkers (e.g. the users) find BIM technology useful and easy to use for placing and preparing reinforcement correctly. This work is important because using BIM on construction sites is virtually impossible without users accepting the technology (Owen et al, 2010). It is well established that many organizations remain skeptical about changing established work practices in response to new information systems (Guha et al, 2011). The research question asked in our article is: *Will BIM technology be accepted or rejected by concrete reinforcement ironworkers in carrying out their work?*

To answer the research question we conducted a case study in Oslo's ongoing airport terminal project where BIM was used to facilitate on-site reinforcement works. A series of semi-structured interviews with individual construction workers, structural engineers, and site engineers has been conducted to gain an understanding of how the technology has been accepted by the people using it. The theoretical approach supporting the analysis in this article is the so-called Technology Acceptance Model (TAM) (Davis et al., 1989). The intended contribution of this article is twofold: First we argue that applying a TAM perspective to understand on-site workers' acceptance of BIM adds to the understanding of the potential that lies within on-site BIM deployment. Second, construction managements' awareness that construction crews may or may not accept an on-site BIM implementation can be increased by this study. The article is structured as follows: first the Technology Acceptance Model (TAM) guiding our analysis is introduced. Second the 'Gardermoen – Terminal 2' project case and the research method are introduced. Third, the findings of the case study are presented based on TAM. Fourth, the discussion of the technology acceptance by reinforcement workers is presented. Last, we present the conclusions of our work and answer the research question.

2. THEORY

There exists a broad spectrum of theoretical models explaining technology adoption and acceptance in the information systems research community. Examples include the Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), Actor Network Theory (ANT), and Diffusion of Innovations (DOI). These theories also inform construction informatics and management research (Merschbrock and Munkvold, 2012). Hjelt and Bjork (2007) use UTAUT to study user attitudes towards electronic document management systems in construction. A combination of TAM and UTAUT has been deployed in a study on interorganizational information technology in the US construction industry (Adriaanese et al, 2010). DOI and ANT have both been deployed in the study of inter- organizational BIM adoption and use (Linderoth, 2010; Merschbrock et al, 2014). The technology acceptance model (TAM) has informed research on the user acceptance of building management systems as well as research on individual beliefs about the outcomes of BIM use (Davies and Harty, 2013; Lowry, 2002). A graphical depiction of TAM can be found in figure 1. The model depicted in figure 1 builds on the original TAM model introduced by Davis (1989) and the theoretical extensions (e.g. TAM2) suggested by Venkatesh and Davis (2000). Diverging from the original TAM and TAM2 models, the construct names 'intention to use' and 'usage behaviour' have been replaced with 'behavioural intention to use' and 'actual system use' respectively. This has been done in accordance with what has been proposed by Venkatesh et al. (2003).

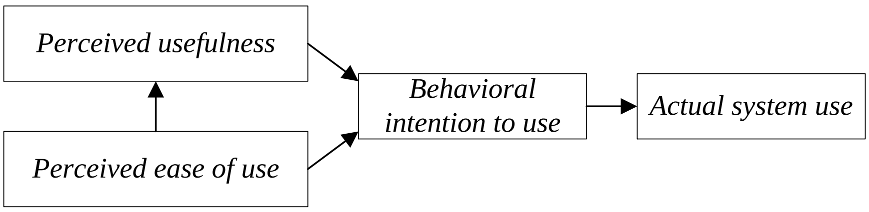

FIG 1. Technology acceptance model (Davis, 1989; Davis et al., 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003)

Positioning this article in line with other technology acceptance studies in building construction, this article is informed by the Technology Acceptance Model. TAM has proven its value for explaining how users come to accept and use new technology, making it a good fit for the study of how concrete reinforcement workers accept BIM systems. TAM posits that perceived usefulness and perceived ease of use will determine an individual's intention to use the technology. TAM places a strong emphasis on the users and places the construct behavioural 'intention to use' as a mediator of actual system use. Perceived usefulness is seen as being directly impacted by users' perceived ease of use. TAM can be viewed as an adaptation of the theory of reasoned action (TRA) to the field of information systems. TAM has emerged over the years and researchers have simplified the theory by removing the 'attitude' construct originating in TRA (Venkatesh et al, 2003). There have been multiple attempts to extend TAM by introducing new factors or examining antecedents and moderators for perceived usefulness and perceived ease of use (Wixom and Todd, 2005). A frequently voiced criticism of TAM is that its behavioural elements are relatively strong, assuming that if someone has an intention to act, they will be free to do so without limitation. This however would not be the case in practical settings where, for instance, organizational rules, codes, time or resources would prevent people from acting freely.

TABLE 1. Usefulness and ease of use of information systems (Hsu and Lin., 2008; Venkatesh et al., 2003)

Usefulness	*Ease of use*
• Enables task accomplishment more quickly • Improves ability to accomplish task • Increases productivity • Enhances effectiveness in task accomplishment • Makes it easier to do a task • Useful in task completion	• Learning to operate the system is easy • Easy to get the system to do what I want it to do • Interaction with the system clear and understandable. • The system is flexible to interact with • It is easy to become skillful at using the system • It is easy to use the system

The main constructs relevant in TAM theory are: (1) Perceived usefulness – "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis et al., 1989, p. 320); (2) Perceived ease of use - "the degree to which a person believes that using a particular system would be free of effort" (ibid, p. 320); (3) Behavioural intention to use - users intention of use of the system in the future (Venkatesh et al. 2003) (4) Actual system use - the users 'real' use of the system for performing work tasks (ibid). Users' perceptions of the usefulness and ease of use of a new system can be assessed based on the items listed in Table 1.

3. OSLO GARDERMOEN TERMINAL 2 CASE

The setting for our case study is the construction of Oslo Airport's Terminal 2, also known as Central Building 2, in Norway. The new terminal will increase the passenger handling capacity of the airport to 28 million travellers a year. The project construction works are 50% completed as of mid-2014 and the new terminal is scheduled to open in April 2017. The project is estimated to require an investment of up to €900 million and will cover an area of 120,000m². The new departures hall being built to the west of the existing terminal building will feature 36 new check-in counters, 12 new security checkpoints, food and drink outlets, duty-free and other shops, new centrally located toilets and a baby care room. The new 'North Pier' extends to the north of the existing terminal building and will cover a floor area of 63,000m². The project requires 10 000 tons of reinforcement steel to be placed. It was initially estimated that 50.000 paper drawings and documents would need to be issued to facilitate the construction works. Due to the inherent complexity of the project it was decided to use Building Information Modelling systems to facilitate reinforcement instead. The digital models were transferred by the main contractors' site engineers to the construction site reinforcement crew by using the cloud application Dropbox©. The software used to display the models was Tekla® BIMsight® and the hardware used were Apple iPads. Thus, this project represents an early implementation of on-site reinforcement BIM on a relatively large scale. Examples for the digital BIM models used can be found in figure 2. According to Building Smart Norway, it is probably the largest project in the world where BIM-based reinforcement models with open BIM based on industry foundation class (IFC) file exchange format are being used.

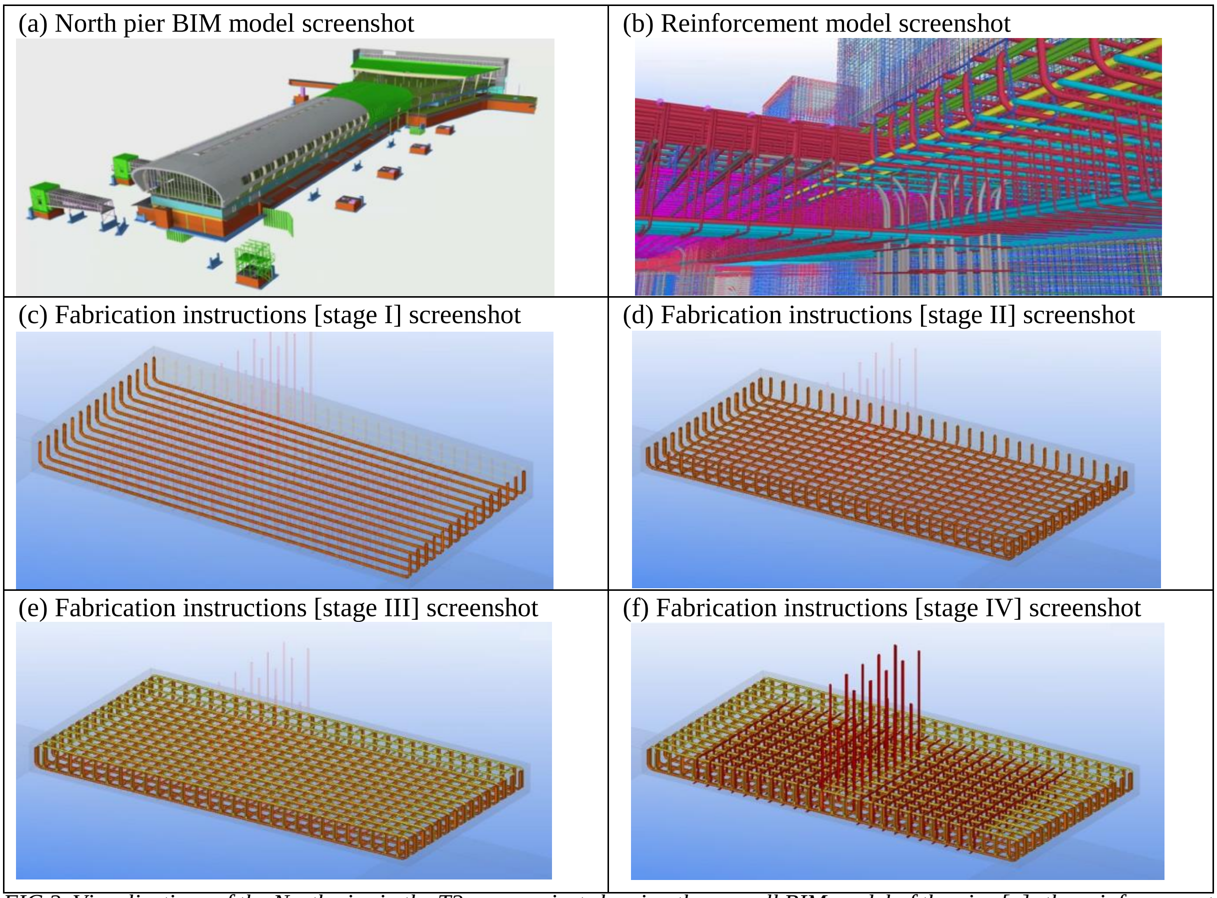

FIG 2. Visualizations of the North pier in the T2 case project showing the overall BIM model of the pier [a]; the reinforcement model [b];and fabrication drawings [c,d,e.f.] all courtesy of Øyvind Børstad, NCC Construction AS, Norway

4.METHODOLOGY

The case study approach has been chosen since it allows for exploring "sticky practice based problems where the experiences of the actors are important and the context of the action is critical" (Benbasat et al. 1987, p. 370). The on-site application of BIM is a practice based phenomenon and technology acceptance is closely related to actors' experiences. Moreover, a case study suits the investigation of relationships between people, organizations, and technology (Orlikowski and Baroudi, 1991). The strategy was 'extreme or atypical' case sampling where it was of the essence to find a case of sophisticated BIM use in reinforcement work (Miles and Huberman, 1999). The airport terminal case has been selected for this study due to the following reasons: first it represents an early and large scale implementation of construction site reinforcement BIM. Second the project was advanced to a stage where the BIM based design had been completed and the on-site assembly of reinforcement had been initiated.

The data were collected through a series of semi structured interviews with a group of reinforcement workers, the structural engineers preparing the model, and construction site engineers responsible for ensuring the quality of the concrete works. All interviewees had hands-on experience from working based on reinforcement BIM. They were either influential for creating the BIM model, the assembly of the reinforcement or in charge of the quality control. Interviewing these experts was sufficient for our study since it allowed for developing a solid understanding of the digital BIM works taking place in the project's concrete reinforcement supply chain. Interview guides were prepared based on the constructs important for understanding the system's ease of use, usefulness, behavioral intention to use, and actual use as shown in table 1 and figure 1. Informed consent was sought before the interviews were conducted. All interviews were voice recorded, transcribed, and coded by using the qualitative data analysis software NVivo10. The categories used in data analysis were the core concepts important in the Technology Acceptance Model as suggested by Davis et al. (1989). An overview of the interviewees is presented in table 2.

TABLE 2 Interviews conducted in the T2 Airport project (September 2014)

Structural engineer #1	Lead designer - structural concrete
Structural engineer #2	BIM manager – structural concrete
Contractor #1	Site manager – structural concrete
Contractor #2	Production manager – structural concrete
Ironworker #1, #2, #3, #4	Reinforcement workers

5. ANALYSIS

The analysis follows the structure suggested by the Technology Acceptance Model presented in chapter 2. First, the perceived usefulness of the BIM technology by ironworkers, site-engineers, and structural engineers for carrying out their work is discussed based on the items shown in table 1. Second, the perceived ease of use of the BIM software and hardware in the context of on-site construction work is presented (guided by the items shown in table 1). Third, the professionals' behavioral intention to continue using BIM for reinforcement works, as an indicator for actual system use in future projects, is depicted.

5.1 Perceived usefulness

The majority of the interviewed concrete reinforcement ironworkers stated that they found the new technology to be useful in task completion. A range of reasons for this view have been identified in the interviews. One frequently named advantage was a perceived increase in information quality attributed to using the new technology. Construction information displayed in models was perceived as being more complete and consistent when compared to paper drawings. A practical implication of this was that the iron bars and other materials needed for assemblies could be identified more readily by using a digital model. According to the workers this resulted in a reduction of the time spent on searching materials on the construction site. This indicates that BIM enhances effectiveness in task accomplishment by curbing unproductive downtime related to searching:

> "Using [paper] drawings is a real problem and I know that… For example when I use a plan view drawing to pick up the irons I need for a job and then later I look at a section drawing of the same situation then I find loads of information that has not been shown in the plan view. Then I start picking up more irons. Using the BIM model is just so much easier" (Ironworker #1).

Another upside of on-site reinforcement BIM was that workers escaped having to 'make sense' of various paper drawings showing the same detail from different viewpoints. Thus on-site reinforcement BIM improves the ironworkers' ability to accomplish their tasks in executing design solutions accurately. How the ironworkers found that they saved time by not having to discuss and interpret different information sources when using the digital model follows from the quote below:

> “I find working with paper drawings very difficult. We have to look at five different drawings before we begin to understand how a detail is built up. When using the 3D model we saw everything at once. Usually [when using drawings] we end up discussing a lot of things that would not have to be discussed if we had models” (Ironworker #1).

Moreover, working based on digital models displayed on handheld devices was considered to be more convenient than working based on paper drawings since all project data was stored in one single location. Thus, deploying on-site BIM makes it easier to do the task. Using sets of paper drawings frequently requires construction workers to search for the appropriate set of drawings by walking back and forth between the installation site and the construction site office. How the workers found using iPads with Tekla BIMsight more convenient follows from this quote: “I actually thought that using BIM was very nice. The best thing is that you have all the ‘drawings’ in one place on the iPad” (Ironworker #2).

Beyond being useful for speeding up the allocation of assembly material and project information retrieval, BIM was perceived to be useful for organizing the construction works. Productivity of the reinforcement work was increased by BIM providing a better foundation for deciding upon assembly sequences. Models provided a better foundation for discussing the practical details of the rebar installation work processes. The ironworkers found it easier to understand how to go about installing the iron bars. Thus, digital models were perceived as useful for organizing the on-site installation of concrete reinforcement bars: “Models are very helpful when you decide on a workflow for assembly. It is easier to visualize and find the right sequence for assembling the rebar” (Ironworker #3). Concrete reinforcement BIM models where perceived as particularly useful for complex installations such as elevator shafts. Here BIM’s zoom and turning functionalities provided a more intuitive understanding of the work that needed to be executed. How on-site reinforcement BIM was perceived as particularly useful for supporting complex assembly tasks follows from the quote below:

> “When we had to assemble the reinforcement for a complex elevator shaft then we just looked at the model, turned it around, and immediately understood how we had to do the job. Using drawings would have required us to take drawings on site, maybe write something down on them and we would not have had the same amount of information” (Ironworker #4).

A feature of BIM which reinforcement workers found particularly useful for supporting the organizing of on-site construction works was the functionality for displaying the rebar’s as color coded items. This allowed for attaining an easy overview of the types and diameters of irons to be placed: “It was easier to spot problems because ordinary 2D drawings are just black and white and the BIM models use a lot of colours. We were surprised at how easy it was to use Tekla. How foundations could be turned on their head, how you could turn the entire building around, look at the detail from the bottom, and how you could take the model apart piece by piece, how you could make a quick section through the building,…, that really helped us to solve many very difficult problems” (Ironworker #2).

However, while the workers found BIM to be helpful for facilitating complex work task it was not perceived as similarly important for easy industry standard type of assemblies. When for instance simple slabs were to be built, the usefulness of BIM diminished: “When we had complex work to do then it was great to see how the iron was to be placed. There were colour codes for different types of rebar which I think was really useful. However, if we have an easy job, then it is not really necessary to have BIM” (Ironworker #2). From the above it follows that most of the ironworkers found that using BIM for construction site operations was a good idea especially when complex installations needed to be accomplished. Nonetheless, there were some critical voices amongst ironworkers wanting to keep the existing way of working based on paper drawings intact. These people felt that using digital models would not significantly improve their job performance:

> “I see that some people felt it was unnecessary to learn something new to do a job they already knew how to do well. Then you meet a lot of challenges. It is difficult to convince a person about using a new technology when they believe the old one works fine even though BIM is without doubt the future way of working” (Ironworker #4).

The main contractor’s site engineers had the job of disseminating the assembly information to the reinforcement workers as well as quality insuring the finalized rebar installation ahead of pouring concrete. These professionals thus served as an ‘information hub’, distributing the digital reinforcement BIM models created by structural engineers to the on-site work crews. How it was a challenging task to control the digital models for completeness and correctness before uploading them to the iPads used by the reinforcement workers follows from the quote below:

> “Ensuring the quality of on-site reinforcement works is a really big and challenging task. Many errors can of course also be traced back to the structural engineers. If you deliver trash then you cannot expect anybody to use that. The reinforcement BIM model must be quality assured. […] However, we saw that the structural engineers had the skills to deliver models of proper quality. If you have such high quality then you can use models instead of drawings” (Contractor #1).

Like the reinforcement workers, the site engineers found that using reinforcement BIM models is worthwhile. They argued that there may be cost savings due to preventing faults and errors in installation and thereby BIM enhances effectiveness in task accomplishment*:* "I believe that we prevented many errors by using the model, which could also be viewed as a cost saving." (Contractor #2)

5.2 Perceived ease of use

Learning to operate the system was perceived as easy by the ironworkers: "Initially I thought BIM would be difficult to use since I was used to drawings, […] but then I was positively surprised when I understood what it [BIM] was. It was completely different, you do not have to think so much about how things should be done, you just see it" (Ironworker #1). When starting up the job the reinforcement workers kept a paper drawing set for 'safety' if the new technology would not work. However, these paper drawings were not used at all: "The drawings that I put in the shelf were not used. That indicates that working with BIM was easier" (Ironworker #1). That it was easy to become skillful in using the reinforcement BIM models and how easy it was to get the system to do what users wanted to do is indicated by the following statement made by a person not having much IT experience from before:

> "In the start we had drawings, we immediately put them away but just in case we had them available. We did not need them at all because we had all the information on the iPads which were very easy to use even for me. I am not at all an IT expert but it was just so simple to work with this" (Ironworker #4).

The crew of ironworkers had an average age of 30 with the youngest worker being 18 and the eldest 50 years of age. How the older workers had some initial 'start up problems' with BIM follows from the following statement: "I know that the oldest struggled a bit because they were not used to PCs but all of us found the technology very useful" (Ironworker #3). The statements above show how the ironworkers found the system easy to use and flexible to interact with. This can be partially explained by the site engineers preparing the digital information carefully before making it available for the ironworkers. The main contractors' site engineers subdivided the complete IFC model into sub-models just representing single work units or situations. The site engineers worked in the following way: they created a screenshot from the overall model indicating the position of the work 'unit' (foundation, wall, elevator shaft etc.); also they prepared an (IFC) file displaying the work 'unit'; both were uploaded to the Dropbox in the assembly sequence. This can be viewed as an effort to make the interaction with the system clear and understandable:

> "What we did was simple, we just made small IFC-files of various foundations, in different types and shapes. […] In addition, we created small screenshots structured by the sequence for how the building needed to be assembled. We put all necessary information into these screenshots (position, number, center distance, etc.). These we uploaded together to the Dropbox where they [ironworkers] could open them together to get the overview" (Contractor #1).

The site engineers worked together in their preparation with some of the ironworkers to control their work for buildability. How much 'manual' work was needed to prepare the digital modelling data in a way that construction workers could use straightforwardly, follows from the statement below:

> "This, how we did it, was a lot of manual labour, I prepared a document and then I took the shots which I found useful and arranged the sequence. I believe that it would be possible to program something that could do this automated. If you deliver the pictures out then there is no demand for teaching anybody. You just go to the Dropbox, click your way through and then you find the foundations or the other constructions you work with. Then you can go down and you find the sequence in which you should assemble the individual irons. That is so easy that you do not need to learn anything. That is much easier than to work with thirty drawings" (Ironworker, #1).

Thus, the perception of BIM being easy to use for construction site operation appears to hinge upon how well and skillfully the models are prepared for construction site usage. A process map of how the structural engineer, the site engineers, and ironworkers arranged the BIM data exchange in the project is depicted in figure 3. There were some concerns related to practical usage of handheld devices on the construction site. These had to do with the workers having to use protective gear such as gloves when assembling the iron. Moreover, especially in harsh weather conditions such as temperatures below -20°C, the devices were not easy to use on site. While not all protective gloves worked well, the workers managed to find gloves designed for working with tablet computers:

> "Gloves are not a real problem. You can find working gloves that are made for use with an iPad so I do not think there is a problem. I see a problem when we have low temperatures like minus 20 Celsius. That will not work in any case if you think about using iPads" (Ironworker #2).

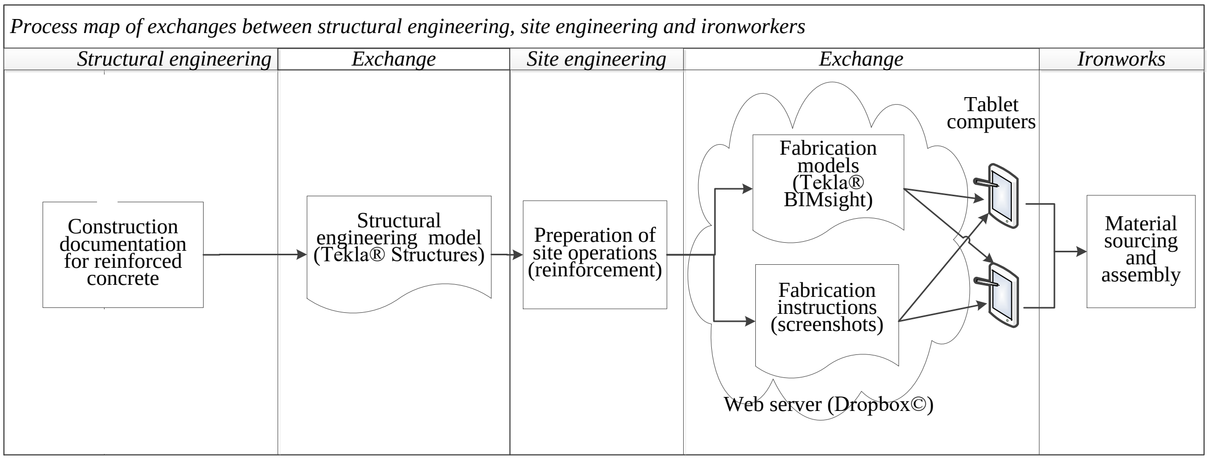

FIG 3. Concrete reinforcement model data exchange in the Oslo Terminal 2 case study

5.3 Behavioural intention to use

Given that the airport terminal 2 project was a pilot project in terms of advanced BIM technology use, the interviewees were asked whether they 'had the behavioral intention' to use the system again in other projects. Most users (e.g. ironworkers) were enthusiastic about the new technology and wanted to see it being used in other projects: "I want to use this in other projects! When I go to my next project then I will maybe ask for it. It was a very useful tool. It was incredibly fascinating to see the entire airport building. You could see how it was going to be" (Ironworker #4).

Using BIM appears to have altered the ironworkers' perception about the traditional way of working based on paper drawings: "I want to have something new [BIM]. I want to do things better, more effectively, because now I think that the drawings are so difficult to use" (Ironworker #3). Moreover they find that especially in projects with a tight schedule the use of BIM would be an effective means to curb construction time: "I think if you want to save time then you should use BIM. I believe you save a lot of time. It is the drawing revisions that are time consuming. If you have a revision of a workshop drawing then that can take days and not just the push of a button" (Ironworker #1). Some of the workers were so convinced about the usefulness and ease of use of the new technology that they even ask for it in projects where on-site reinforcement BIM is not being used: "I have asked for it several times already and I have missed it several times. I have asked them why did you not take this into use yet? But I never got a convincing answer for why not" (Ironworker #2). Moreover, even the more senior ironworkers who experienced initial 'start up issues' with the new technology were convinced about the usefulness of the technology and had the intention to continue using it: "New things can be scary and you distance yourself in the start. I did not expect anything from this BIM. I viewed it as something new and very strange. But once you learn it and you see its use then it is really good. I was positively surprised" (Ironworker #1).

The main contractor's site engineer stated that his firm was so convinced about the on-site use of BIM that they already submitted a new project tender based on a wide use of the technology: "Yes, we have just delivered an offer for a new project this month and we will focus on BIM implementation in construction work. The contract is written based on BIM and this will be the future" (Contractor #2). The second site engineer had similar views on BIM, and he felt that continuing with using the technology would be vital to develop both processes and capabilities: "You cannot stop this now, you just don't do that. The first time it's a bit strange but it keeps on getting better" (Contractor #1).

5.4 Actual system use

On-site BIM use is just in its infancy and, apart from a few pilot projects, not widespread. This is illustrated by the fact that none of the interviewees have used reinforcement BIM before or after the pilot project at Terminal 2. While the structural engineer was positive to using reinforcement BIM in other projects, he saw some constraints in the industrial context of the architecture, engineering and construction industry that would need to be overcome before the technology will succeed. There is, for example, a legacy of standardized contracts preventing innovative BIM technology use for on-site operations:

> "Today most of our contracts continue to tell us that we have to deliver drawings. This is what counts. The biggest step ahead now would be to define some standardized contracts explaining how to do this, and these need to regulate how to use BIM" (structural engineer #1).

Moreover, the structural engineer argued that at the moment there would be a shortage of engineers having IT capabilities strong enough to run similarly advanced BIM projects:

> "There is a shortage of people within my profession doing the job that I do (creating BIM reinforcement drawings). This is not a big job but there are horribly few structural engineers that understand BIM software programs, and even fewer understand freeware like Tekla BIMsight, Solibri etc." (Structural engineer #1).

What makes the "behavioral intention" by the ironworkers to keep on using BIM in other projects difficult to follow up, beyond contracts not being defined enough and missing IT capabilities with structural engineers, are the difficulties to understand BIM's business value. First, it appears challenging to find reliable figures on what the use of BIM costs: "You pay maybe 20-30.000 kroner for a new PC, but it costs a lot more to train people, to go from one working process to an entirely different process costs a lot more. This is a challenge for the entire industry" (Contractor #1). Moreover, not only is it difficult to determine what BIM costs; it appears also difficult to quantify what can be saved by using BIM: "If you can replace, let's say, 2500 drawings and if you calculate the cost of each drawing then I think you will be surprised. I believe here is a lot of cash" (Ironworker #3).

6. DISCUSSION

Streamlining the information flow in the reinforcement supply chain has been named a core issue for improving on-site performance in concrete work (Tommelein and Ballard, 2005). The case presented in this article confirms this and shows that an improved information flow can be achieved by extending BIM's application area to on-site operations. This finding is in line with earlier work exploring the promotion of on-site application of BIM technology for reinforced concrete works (Pheng and Chuan, 2001; Tommelein and Yi Li, 1999; Polat et al. 2009). Research has suggested software related workflows and business process models supporting on-site BIM usage for reinforcement work (Aram et al, 2013). The findings of this article show how ironworkers' perceptions of BIM's usefulness and ease of use depend upon clearly defined processes for model delivery by structural and site engineers. This confirms the necessity to define software related processes before embarking on deployment of 'on-site' BIM.

TABLE 3 'On-site' reinforcement BIM technology acceptance

TAM element	*Items in the Oslo Terminal 2 case study*
Percieved Usefulness	• Information quality improvement • Information storage in centralized repository • Increased speed of material identification • Increased speed of information flow • Better organized rebar assembly • Quick communication of revisions and changes • High accuracy and quality in reinforcement placing • Reduction of errors • Facilitates complex assemblies
Percieved ease of use	• Easy to learn for ironworkers • Easy and intuitive to use for ironworkers • Work-intensive for site- and structural engineers • iPads dysfunctional when colder than -20 Celsius
Behavorial intention to use	• Strong interest for continued use
Actual system use	• Few practical project implementations • Shortage of 'on-site BIM' capable structural engineers • Lack of contracts for 'on-site BIM' • No return on investment (ROI) figures for 'on-site BIM'

Going beyond this prior work, this paper inquired into how the new technology and processes would be accepted by a crew of reinforcement ironworkers. An overview of the core findings of the BIM technology acceptance by ironworkers can be found in table 3. The technology acceptance by the workers translated into a relatively strong interest to keep on using the technology in other projects. Nonetheless, BIM use for reinforcement work is still in its infancy and there are few cases of practical use in the industry (Concrete Industry's Strategic Development Council, 2009). This is mirrored by our findings indicating that, so far, only few structural engineers possess the capabilities for 'on-site' reinforcement BIM. This indicates that while the reinforcement ironworkers are ready for BIM the consulting engineers are not.

Applying the technology acceptance model helped to provide an understanding that BIM was well appreciated by the workers regardless of prior IT knowledge and age. This was a rather unexpected finding since research has identified a negative correlation between technology acceptance and age (Tams et al., 2014). Moreover, the reinforcement workers expressed a behavioral intention to continue using on-site BIM in other projects. This resulted from their perception of BIM as useful for accomplishing their work tasks. The new technology enabled prompt task accomplishment by providing centralized information storage and higher information quality. This enabled the workers to curb inefficient downtime such as trying to identify required materials based on several paper drawings or having to discuss and interpret contradictory information based on different paper drawings. Productivity of the reinforcement work was increased by BIM providing a better foundation for deciding upon assembly sequences. Overall, the ironworkers perceived BIM as making it easier to do their jobs and they found it useful for task completion. These findings are in line with earlier research suggesting that once project teams develop BIM capabilities for information creation, collaboration, and decision making, the performance of the reinforced concrete projects could be significantly improved (Aram et al, 2013).

Not only was the new technology perceived to be useful but it was also perceived as easy to use. Learning to operate the system was perceived as easy by the ironworkers. This can partially be attributed to the relatively intense preparatory work undertaken by the structural and site engineers. The data indicates that the model exchange and creation processes are crucial for technology acceptance. Delivering the modelling content 'portioned' in small sub-models in conjunction with the construction schedule provided the workers with the right information at the right time. The importance of getting the information flow 'just in time' for production has been stated in literature (ibid.).

The findings indicate that BIM was perceived as more useful for difficult and complicated assemblies (i.e. elevator shafts) than for industry standard work (i.e. slab). Parametric tools are useful and "extremely valuable" for defining complexity in construction projects (Scheurer, 2010; Merschbrock and Munkvold, 2014). Given that BIM-based reinforcement design is costly, as getting it 'right' requires a considerable amount of engineering hours, it could be an option for project teams to focus modelling activity in response to complexity. Thus, as opposed to creating reinforcement models for an entire structure, modelling efforts could be concentrated at complex details and assemblies. This would save engineering hours while still fulfilling the ironworkers' information needs, thus increasing the chance for future actual system use.

We developed our view on technology acceptance based on a single case project. While we argue that the concrete reinforcement supply chain studied is typical for projects in the architecture, engineering and construction industry with regards to the actors involved and the actors' modelling practices, our findings need to be validated beyond the project studied. Moreover, while we claim that our study provides a good indicator for how on-site BIM use may contribute to the productivity of the construction process, quantification of the added value lay beyond the scope of our study. Establishing how much the productivity of reinforcing bar assembly work can be improved by replacing paper based workshop drawings with BIM is an intriguing avenue for further research. Thus, we recommend further research analyzing BIM based construction reinforcement work in other projects using the TAM model. Moreover, this work could explore how business process models supporting on-site BIM usage should be built for maximizing technology acceptance.

7. CONCLUSION

This paper has presented a case study of a construction project in which a group of ironworkers worked based on digital modelling technology. The study represents an early application of 'on-site' BIM for reinforcement work. Based on the Technology Acceptance Model (TAM), this study set out to answer the following question: Will BIM technology be accepted or rejected by concrete reinforcement ironworkers in carrying out their work? In this study BIM was perceived as useful technology for improving reinforcement works, which is why the ironworkers accepted the technology. The acceptance had however to do with the way that the reinforcement models were prepared. Thus, the question can be answered as yes, BIM is likely to be accepted by ironworkers if the models are prepared well.

The degree to which structural engineers and site engineers succeed in preparing models well enough for on-site use appears to be a function of their IT capabilities and available resources. Practical implementations of on-site reinforcement BIM are rare and will continue to be rare unless the construction industry succeeds in increasing its IT capabilities and in building proper contracts for BIM use. Reinforcement BIM models are more useful for supporting complex assemblies than industry standard type of work. Thus, project teams could focus their limited IT capability and resources on modelling up complex details and assemblies rather than trying to create complete reinforcement models for entire buildings. The article is important for increasing project management's awareness about the potential that lies within on-site BIM use and that especially complex assemblies benefit from parametric modelling. Moreover, the article has, in line with earlier work, established that if BIM is to be used for site operations, the models need to be prepared carefully, requiring considerable engineering resources.

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