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USING BUILDING INFORMATION MODEL (BIM) DEVICES TO IMPROVE INFORMATION FLOW AND COLLABORATION ON CONSTRUCTION SITES

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EDITOR: Kumar B.

Fredrik Svalestuen, Ph.D. Candidate
Department of Civil and Transport Engineering,
NTNU - Norwegian University of Science and Technology, Trondheim, Norway
fredrik.svalestuen@ntnu.no

Vegard Knotten, Ph.D. Candidate
Department of Architectural Design and Management,
NTNU - Norwegian University of Science and Technology, Trondheim, Norway

Ola Lædre, Associate Professor, dr.ing,
Department of Civil and Transport Engineering,
NTNU - Norwegian University of Science and Technology, Trondheim, Norway

Frode Drevland, Assistant Professor
Department of Civil and Transport Engineering,
NTNU - Norwegian University of Science and Technology, Trondheim, Norway

Jardar Lohne, Research Scientist, dr.art,
Department of Civil and Transport Engineering,
NTNU - Norwegian University of Science and Technology, Trondheim, Norway

SUMMARY: *The AEC (Architectural Engineering and Construction) industry has been successfully using BIMs (Building Information Models) as a tool for improving the design process for some time now. Lately we have seen an increase in use of BIMs in the construction process with BIM devices like BIM stations and tablets. The research presented studied the advantages and challenges with BIM devices on a construction site and used communication theory to explain why these tools are more effective than traditional approaches. A survey with 82 respondents employed by a large Norwegian contractor revealed the most prominent challenges in the interface between design and construction to be both deficiencies and errors in the design. To further investigate these challenges and how BIM can help mitigate these challenges, mixed-method research plan with a case study approach was undertaken. In total, 24 semi-structured interviews with key actors from both the design and construction sides, a study of over 400 different documents from three cases implementing BIM devices, and a survey of craftsmen using BIM devices, with a total of 73 respondents, were carried out. The analyses indicate that reaping the full benefits of BIM devices demands insight in communication theory. The main finding is that BIMs used as a mediating artefact in synchronous communication provide far more effective communication than other types of synchronous communication. BIMs as a documentation option in the construction process are superior to all other media because it has a higher bandwidth and is self-documenting at the same time. Any new system or tool that is implemented will require some sort of training, and this study shows how proper training of all the involved practitioners will be necessary when implementing a BIM device. This study can help practitioners to focus on the right strategy when implementing BIMs and the use of BIM devices in AEC projects.*

KEYWORDS: *Tablets on site, BIM-stations, BIM on site, Design Management, Communication*

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1. INTRODUCTION

Over the last decade, studying the procedural and human aspects of realising projects within the Norwegian Architectural Engineering and Construction (AEC) industry has gained increased interest. This includes exploration of Building Information Models (BIMs) and other Information and Communications Technology (ICT) tools for enhancing on-site communication.

Even if BIMs and other ICT tools typically have been seen as most pertinent to the design phase, the technology equally represents a great potential during the construction phase. Over the last decade, BIMs have in fact gone from being a design tool to being an important part of the production process. Technological solutions such as so-called BIM stations render BIMs available for everyone, including all the workers onsite (Murvold et al., 2016).

A current trend in construction is that projects are getting more complex and require ever more detailed drawings. Van Berlo and Natrop (2015) question if the information presented by the drawings really constitutes all of the information needed on the construction site. They even claim that most drawings are not specific enough for specialised tasks. With BIMs, much more information is available than with traditional paper drawings. To develop the use of BIMs in the construction phase further – that is, to provide information with a quality high enough to enable such specialised tasks – it consequently seems desirable to move BIMs from the design office to the construction site, where the physical work is actually carried out; this introduction of BIMs to the workplace makes information available when and wherever it is needed (Van Berlo and Natrop, 2015).

BIMs, today, are mostly used inside the construction office. In this paper, we examine pathways to bringing them out to the construction site.

Norwegian AEC industry actors now commonly use ICT tools, such as project intranets and BIMs. Project intranets provide all team members immediate access to project information, thus speeding up information flows. Videoconferences make communication with other participants easier, even over long distances. Yet, the use of these tools can create problems; in some cases, they even reduce the overall comprehension of the project if not implemented adequately (Harstad et al., 2015). For example, when all participants have access to all information at any time, it is hard to control who receives what and when. In the worst cases reported, this resulted in actors making their own 'image' of the project, which sometimes was not in line with overall project objectives. In general, the potential of such tools does not seem to be used to its full degree.

It is in fact essential to acknowledge that in contemporary construction projects, actors interact in an environment in which different barriers combine to prevent straightforward production of the physical artefact. On the basis of this insight, one general lesson stemming from experiences within the Norwegian context is that it seems important to proceed with informed attention when adopting new methods and technologies. This proves particularly true if the advantages that these entail for the project team are not immediately clear. As can be learnt from Norwegian industry, an uncritical implementation of such tools can, in the worst cases, reduce the overall performance of project teams.

Internationally, the implementation of BIMs on worksites through specific methodologies have been examined by several authors, e.g. Sacks et al. (2013), Ruwanpura et al. (2012). The ambition of this paper is to explore what we consider usages of ICT solutions that are in the forefront of AEC practice within the Norwegian context today, from a communication perspective. More specifically, we examine the use of so-called BIM stations and tablets onsite with the ambition of improving the two-way communication between design and construction.

To address this general concern, we in this paper address the following research questions:

- How can BIM enhance communication between design and construction practitioners?
- What are the advantages and challenges of using BIM to communicate between design and construction practitioners on site?
- What practical measures can lead to BIM enhancing communication between design and construction practitioners?

The first question will be addressed in the theoretical framework section. The second question is presented in the findings section and is mainly empirical based. The last question will be addressed in the discussion section.

2. THEORETICAL FRAMEWORK

In the following, we describe why it is important to study further the information flow between design and construction, and how BIM devices like tablets and BIM stations can help improve information flow.

2.1 Information flow at the construction site

A study carried out by Tenah (1986) shows that a manager or supervisor cannot perform his or her functions efficiently without accurate, timely and relevant information on which to base decisions. The flow of information significantly affects all other resource flows, and is therefore important to manage (Dave et al., 2010; Sacks et al., 2010). The control of information is viewed as a source of power and therefore poses a challenge to management processes (Knotten et al., 2015b)

Waste in construction includes delays, quality costs, rework, unnecessary transportation trips, long distances, improper choice of management, methods or equipment, and poor constructability (Koskela, 1992; Alarcon, 1997). Studies show that waste often occurs due to poor information management. The research of Love and Li (2000) demonstrates that during construction, rework often arises out of incomplete and incorrect information. Their work indicates that rework results in inactivity and inefficiency in several activities at the construction site.

To solve site problems, production management personnel typically have to run back and forth between the construction site and their computers at the site office. According to Lofgren (2007), documentation of building activities, production meetings and various inspections often have to be carried out twice; once when they are actually occurring and then once again in a computer document. This leads to inefficient use of managerial resources due to unnecessary transportation and a production management team that is occupied with their computers for a large part of their working hours. Samuelson (2003) claims that the fact that information needs and communication behaviours at construction sites are not adequately met explains the low productivity figures in the construction industry.

According to Lofgren (2007), the quantity of information that is passed to the construction site can be overwhelming, and it often generates a poor quality of information in the field. As a result, construction personnel are forced to deal with slow problem solving and construction rework.

2.2 Richness and effectiveness of communication

The notion that communication can have different degrees of richness is based on how much understanding different types of communicated information provide. Daft and Lengel (1983) explain that rich information provides substantial new understanding; information with low richness, on the other hand, provides little new understanding. Furthermore, the different types of channel/media used for communication will have a direct effect on its richness. Lengel and Daft (1989) acknowledge that communication media differ in their capacity to convey information; they consider that the more information that can be ‘pumped through a media, the richer the media is. Furthermore, they define three important characteristics for a rich communication medium, notably 1) the ability to handle multiple information cues simultaneously, 2) the ability to facilitate rapid feedback and 3) the ability to establish a personal focus. Based on an analysis of the different types of media usually available to a manager, Lengel and Daft (1989) classified the different types hierarchically on a ‘richness scale’, shown in Figure 1.

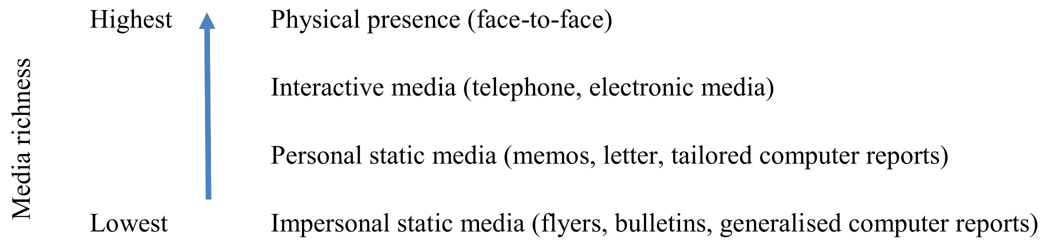

Figure 1: Different types of media and their richness (Lengel and Daft, 1989).

Lengel and Daft (1989) also examined the different types of communication that take place in an organisation and categorised them into routine and non-routine communication. The routine communications within this categorisation typically include straightforward day-to-day messages, with an established common frame of reference and with high degree of objectivity (e.g. a work order from management). The non-routine communications on the other hand typically concern communication novelties, which are events with no common framework between sender and receiver. Feelings and subjective beliefs may influence the non-routine communication. For such reasons, a communication media with higher richness is therefore preferred in such circumstances.

Table 1 shows the different types of communication media Reinertsen (1997) studied (which he called systems), and what types of attributes they were characterised by.

Table 1: Different type of communication media and their attributes (Reinertsen, 1997).

System	Real time	Self -documenting	Leveraged	High bandwidth
Meetings	X			X
Telephone	X			
Voice Mail		X	X	
E-mail		X	X	
Paper Documents		X	X	
Web sites		X	X	
Video tapes		X	X	X
Video conference	X			X
Chance Encounters	X			X

Real-time are communication media that can send and receive information in real time. *Self-documenting* are communication media that can store the sent information without requiring a second source for storage (e.g. information from a face-to-face meeting could be stored with a recording device). *Leverage* is the relative time spent by sender to encode the information vs. the receivers to decode the information (e.g. it takes just seconds to send an e-mail with a link to a 100-page document, which of course takes longer time to read). *Bandwidth* refers to how much information the communication media can convey at a given time (e.g., a face-to-face meeting can communicate both facial expression, vocal tone and the message at the same time, furthermore the receiver can ask questions in real-time. This is opposed to communication based on paper documents, which take a long time to read and reply to).

Cockburn (2006) made a visual presentation of different communication media and how they relate to richness and effectiveness. As shown in Figure 2, the richer the communication media, the more effective it is.

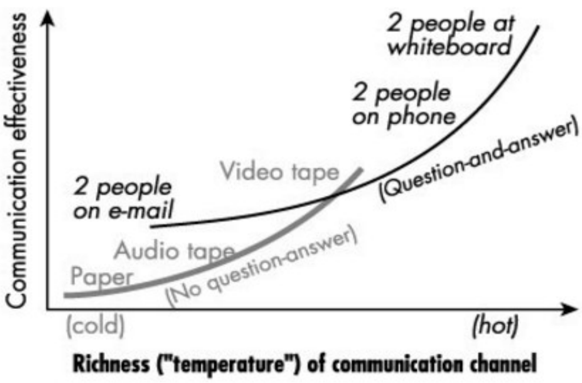

Figure 2: Illustration of richness and effectiveness of different communication channels (from Cockburn, 2002; 2006).

Cockburn (2006) also divided the different media into two categories, “question-and-answer” and “no question-answer”, based on the media’s capability to handle direct two-way communication. The question-and-answer category consists of all two-way, real-time media. An exception from this is the use of e-mails, which is clearly capable of a two-way communication but lacking the real-time attribute that Reinertsen (1997) identified. The no question-answer category consists of all media that do not allow the receiver to answer the sender without using another of the same or other type of media.

Ambler (2002) and added some new media to Cockburn’s figure, such as face-to-face without whiteboard and video conversation (Figure 3).

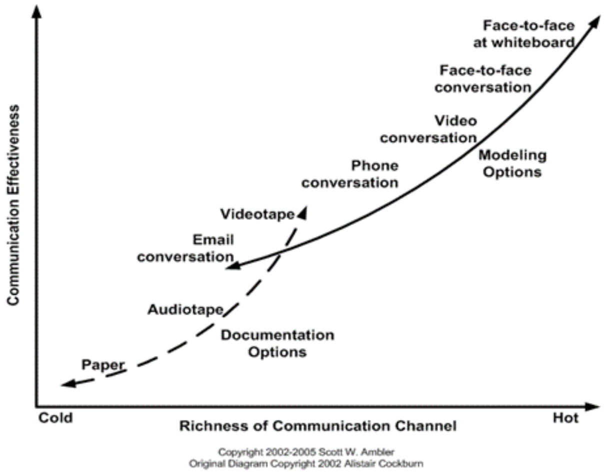

Figure 3: Illustration of richness and effectiveness of different communication channels (from Ambler, 2002; after Cockburn, 2006)

Ambler (2002) has not significantly modified the Cockburn (2006) model, other than add some new communication media and rename the categorisation of different communication media. The new categories *modelling options* and *documentation options* seem to be the same as those used by Cockburn (2006), without giving any explanation other than it seems to better fit the theme of his book.

Otter and Emmitt (2008) describe two ways of communicating, asynchronous and synchronous. Synchronous communication is described as information flow between two or more persons directly, using hearing, sight and speech (e.g. meetings, telephone etc.) Asynchronous communication is a remote flow of information, which is not directly in time (e.g. emails, drawings, models). The more complex the processes, the higher the need for synchronous communication (Bell and Kozolowski, 2002; Knotten et al., 2015a). Emmitt (2009) states that it is vital for a building design team to use synchronous communication when the team task complexity is high.

Communication can typically be divided into three categories, verbal, non-verbal and symbolic (Granér, 2003). Verbal communication is spoken or written words. Written words do not contain any more meaning than the literal one. Oral communications on the other hand, can have different emotional value to the receiver, as it allows the sender to use feeling in the spoken words (e.g. screaming a message will have a different meaning than whispering it). Non-verbal communication includes using body language and gestures, which can further help enhance the communication. Symbolic communication is the use of different objects like drawings and models, and even the clothes you wear to a meeting will have a symbolic meaning (Granér, 2003).

Communication media that can transmit information that is verbal, non-verbal and symbolic will always be richer and more effective. For instance, a phone call can transmit just verbal communications, but a videoconference where the sender and receiver can see each other can transmit both verbally and non-verbally. Using a whiteboard in the conversation as well can further enhance communication and work as a common ground for the sender and receiver. Koskela et al. (2016) define such tools to be *mediating artefacts* that, among other things, allow for exploration of sematic differences and help the joint transformation of knowledge between actors from different practices (architects, structural engineers, project managers etc.). In fact, the cognitive process may involve distributed cognition states, where a cognitive process can be shared among members of a group, and external processes like materials or the environment. Furthermore, the process may be distributed through time, allowing previous experience to transform later events (Hollan et al., 2000). This means that a group of people using a mediating artefact will be able to share the cognitive process across the group members. Busby (2001) studied errors and distributed cognitions in design work, and found that the design team could benefit from thinking of their task in terms of distributed cognition.

3. THE USE OF BIM ON SITE

Over the last years, different methods have been developed to bring BIMs to the workers on site, enabling access to the model wherever they are. With BIMs on site, it is possible to find and solve problems early. This is a relatively new approach to on-site production control for contractors. Van Berlo and Natrop (2015) state that paper drawings typically dominate information in the workplace. Furthermore, they claim that BIMs on site can realise a great potential during the construction phase and that construction workers get the benefit of visualising when communicating using a BIM on site. The different tools that are being used can be divided into three categories. 1) Computer terminals on site (hereafter called BIM stations), 2) mobile devices such as tablets and 3) specialised environments (e.g., BIM caves).

Hewage and Ruwanpura (2006) found that there was a need for a mobile, real-time information source on site. Workers wanted an opportunity to view 3D and 4D (3D with timeline) drawings, technical information, safety information, weather updates, and other information related to the project. Following this research, Ruwanpura et al. (2012) developed an information booth to give workers onsite access to material management, work demonstrations and updated drawings. This led to positive results in productivity, efficiency and worker satisfaction.

Davies and Harty (2013) found that there was only limited research on how BIM has been used on site. They studied the implementation process of “Site-BIM” in a case study of a large hospital project in the UK. Mobile tablets were used to access the project’s BIMs. Tablets onsite combined with in-house document management systems resulted in positive effects, like waste reduction and a lower than usual cost growth for service installations. Harstad et al. (2015) have also documented positive effects from their research on tablets on the construction site. Based on research carried out, we can maintain that tablets provide easy access to information, are easy to carry around, and can increase the understanding of the project while creating a new line of communication.

The contractor Skanska developed a prototype in 2014 of what they called a “BIM computer kiosk” (Bråthen and Moum, 2015). They placed a computer connected to a 50-inch TV-screen on each floor of the building site. These computer kiosks allowed workers to access the 3D-model on site. The equipment was placed inside a protective wooden cabinet with an internet connection (Bråthen and Moum, 2015). The BIM kiosks were widely used on the project and resulted in better productivity, especially for MEP (Mechanical, Electrical and Plumbing) workers. Vestermo et al. (2016) showed that a device like a BIM-station could help reduce the volume of non–value-adding activities on a project and that the use of BIM-stations in a production phase could enhance lean outcomes.

Van Berlo and Natrop (2015) analysed a concept using BIMs to generate drawings adapted to the task of workers onsite. The idea behind this was to “[...] provide site workers with all the information they need for the task, but nothing more”. They found that this approach created a very good communication tool between the site office management and construction workers. According to Chen and Kamara (2008), the most effective way for workers to acquire information onsite is to collect or capture information at the point where they are, when they need it.

Sacks et al. (2013) have developed a system for workflow control on site, called KanBIM™. The system visualises the workflow of both process- and product information on a ‘live’ BIM to the workers on site. A field test of the system revealed two desired results: 1) a reduction of time spent ‘looking for work’ and 2) the system could potentially enable site superintendents to double the scope of work they could supervise.

BIMs can result in a leaner construction process with a greater degree of utilisation of prefabrication, improved workflow stability, reduced inventories and enhanced teamwork (Alarcon et al., 2013). When BIMs are implemented in the design phase, there could be some challenges to carry it forward to the construction phase. Some of the most common barriers are: software and hardware issues, cultural barriers, contractual and legal aspects, lack of commitment, lack of training and lack of a client request for it (Alarcon et al., 2013). Compared to the positive aspects of implementing BIMs in the construction phase, however, the challenges must be said to be of a relatively limited nature.

4. METHODOLOGY

The research questions addressed in this paper cover a wide spectrum of interrogation. This approach has been chosen to include as large a variety of elements in the analysis as possible, through triangulation of different research methodologies. In order to respond to challenges possibly entailing from this methodological approach, data collection has been done according to the recommendations of Creswell (2009) about using mixed-methods approaches. The different approaches used are explained in the following.

The starting point for this study was a literature study, following the five basic steps described by Blumberg et al. (2011). Relevant literature was identified and collected. Then this literature was reviewed and analysed. After synthesising the literature, the theoretical framework presented in this paper was developed.

Next, a survey was sent to 602 potential respondents working for the largest contractor in Norway in order to map the challenges between design and construction and their general experiences with BIM devices such as tablets and BIM-kiosks on construction sites. Out of these, 82 answered the survey. The results are reported in Section 5.1.

In order to find out how tablets influence communication – that is, what advantages and disadvantages follow their use, and what measures can lead to tablets enhancing communication – nine semi-structured interviews with both design and construction personnel were conducted. The respondents were mainly project managers and foremen from contractors and design consultants working close to construction sites. One representative from an application developer was interviewed in order to reveal aspects of interest related to using tablets to communicate BIMs. The nine initial interviews were followed by interviews with five persons holding key positions in some of the largest contractor firms in Norway. These five contractors have adopted, to a varying degree, tablets in their projects. All fourteen respondents answered on a general basis, i.e. they didn't use case-specific experiences. A general study of documents from different, randomly selected projects where tablets were used to communicate the BIMs supplemented the findings from the interviews.

In order to find out how BIM stations influence communication, three different cases were then selected in order to collect experiences from practitioners. These cases were selected based on criteria suggested by Yin (2013). Attention was paid to find out how BIM stations influence communication, that is, identifying what disadvantages follow their use and what measures lead to them enhancing communication. Ten case-specific interviews with contractor representatives – seven BIM specialists and three project managers – were carried out. A study of more than 400 different documents from the three cases was carried out in order to supplement the case-specific interviews, following the general prescriptions of Krippendorf (2013). A second survey asking about the specific experiences from each of the three cases was carried out with 48, 15 and 10 respondents, respectively. The purpose of the case-specific survey was to map the use of the BIM stations in addition to user attitudes and behaviour. The questions were both multiple choice and open-ended questions. Multiple choice responses gave the ability to compare the answers and obtain a statistical representation. These results are reported in Section 5.2.

Both the general and the case-specific interviews were based on interview guides structured after this paper's three research questions. The respondents answered – almost word-for-word (small adaptions were made) – the same questions. The document study followed the guidelines proposed by Krippendorf (2013). The surveys, both the general and the case-specific ones, were inspired by the informative how-to-do description proposed by Fink (2013).

5. FINDINGS

The findings chapter is divided into two parts. The first part, Section 5.1, presents findings from the general survey undertaken of employees of a large Norwegian contractor. The survey presents the AEC professional view of the industry's major challenges. The second part, presented in Section 5.2, is based on a case-study approach, using interviews, study of documents and case-specific surveys. The case studies present the advantages and challenges with using BIM devices in construction projects, mainly from a practitioner perspective.

5.1 Challenges between design and construction

Figure 4 shows the general challenges found in the interface between design and construction. Major findings here are a lack of design in a particular area and errors in design, collisions between the different trades, delayed drawings and poor communication.

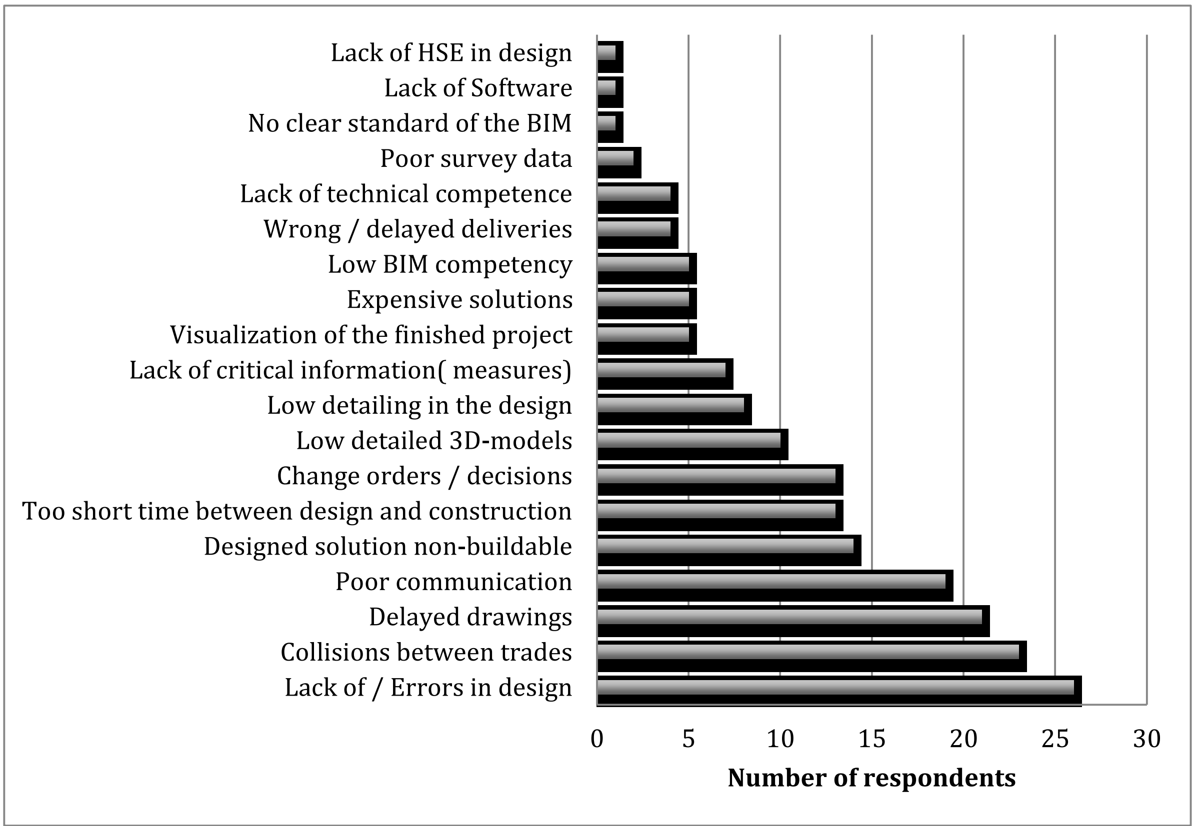

Figure 4: general challenges found in the interface between design and construction.

The survey also posted a question of which challenges the use of BIMs on construction projects can help solve. All respondent agreed that the use of BIMs could mitigate some of the challenges between design and construction. The main answers were:

- Fewer change orders and faster decisions
- Details of the project more visible and increases client knowledge of the final product
- Collision between trades can be mitigated by using collision control tools in BIM viewers like Solibri.
- A model can easier show the proposed solutions and simulate the construction process to increase knowledge of constructability.
- Better coordination among trades.
- Better control of quantities, can reduce the time spent on quantity take off in the construction process.
- The use of BIMs forces the design ahead and deficiencies are more obvious.
- A good tool to assess constructability of the designed solutions before drawings arrive at the construction site.

5.2 Experiences with the use of BIM devices on the construction site

The BIM devices discussed here are BIM stations and BIM tablets. BIM stations are computers with large screens made available for the workers at site. The BIM station, as its name implicates, includes software for using BIM.

However, there could be several other functions linked to the BIM station as well, such as progress plans, information from management, QA systems etc.

Tablets are small mobile personal computers with a touch screen, including software for using BIMs, CAD and other Project manager tools. Primarily a tablet is used by people with typical control responsibilities, like project managers, construction managers, superintendents and foremen. Design consultants and client representatives also use them. Most of the respondents primarily use tablets as a tool to obtain information in design meetings, site meetings and out in the field. However, there are a number of other applications related to the use of tablets.

First, we present the advantages of a BIM devices. Second, we present some challenges and improvements to increase the benefit of BIM devices. The findings presented here are based on the cases studied.

5.2.1 Advantages with BIM devices

It is not only the use of BIMs that contribute to more effective construction projects. Equally important is the fact that it is a tool with continuously updated production descriptions (drawings, models, descriptions, plans etc.) onsite. Furthermore, the tool can contribute to increased collaboration between the different trades. As shown in

Table 2, there are some advantages that are common for both BIM stations and tablets; advantages that are more specific either to BIM stations or tablets are shown at the bottom of the table.

Table 2: Advantages with BIM devices as reported by the interviewees and identified through the case-specific survey.

<table>
<tr><th colspan="2">Advantages of BIM devices</th></tr>
<tr><th colspan="2">Common</th></tr>
<tr><td colspan="2">• Helps the workers get a better understanding of the project through the 3D visualisation
• Helps to provide updated production information (drawings, specifications BIMs, progress plans) at the site at all times
• Can provide quantitative take-off on-site for the workers
• Can provide tools for the reporting of task completion, quality control and errors to the designers.
• Obtaining direct measurements from the blueprints and BIMs onsite.
• Live communication through video chat between site and office
• Reduce the risk of errors due to old drawings
• Less printing and distributing drawings</td></tr>
<tr><th>BIM Stations</th><th>Tablets</th></tr>
<tr><td>• Provide a meeting place and the BIM is a great communication enhancer</td><td>• Access to BIM and drawings (Pdf/dwg) everywhere
• Operation and maintenance management</td></tr>
</table>

The primary function of the BIM station is to present an updated version of the BIMs to the workers onsite. The BIMs give the workers a better understanding of the project, sequence of trades, details etc. The BIM station creates an artefact for better communication between the trades on site.

As for the positive effects of BIM stations on the project, opinions were divided in the first survey. Some of the carpenters considered the BIM stations an unnecessary cost, with no positive effects whatsoever. However, this was not the general opinion. A large percentage of workers experienced saving time with BIM-stations. They reported higher productivity due to having the necessary information available at all times. The overall impression from both the survey and interviews is unanimity that the MEP workers had the greatest benefit of the BIM-stations. This is also reflected in the answers for the last question the workers were asked: we wanted to know if

BIM stations were something the workers would like to have access to on their next projects. A total of 96% of the MEP workers wanted this, while only 50% of the carpenters did.

A reason as to why some of the carpenters thought that the BIM station was an unnecessary cost for the project was that the information they could get from the BIMs was too vague. The model lacked information they needed to do their work, e.g. measurements of the door openings relative to the axis system of the building. Consequently, the carpenters had to check the drawings to get that kind of information. The superintendent on one of the projects did also comment that a lack of excitement about the BIMs among some of the carpenters could be because they lacked the proper tutoring and training in the use of the BIM station.

As shown in

Table 2, one specific advantage of having a BIM station is that it provides a good arena for meeting on the construction site. All the interviewed workers had an impression that it gave them more insight into the weekly production plan and how their work was related to others. The BIM model was a great tool for showing the workflow of different areas in the building and how the work of different crews were interrelated. Furthermore, the crew leaders felt that members of their work team was more involved in the planning when they had a meeting around the BIM station as opposed to the normal meeting without the BIM station.

Tablets provide easy access to up-to-date PDF/DWG drawings and BIMs at meetings, in the office and out on the construction site. This reduces the risk of errors and rework due to old drawings. As one of the interviewed superintendents said: ‘we spend less time on controlling that drawings on site are up to date since tablets and BIM-stations provide workers with an up-to-date drawing’.

Less time is consumed obtaining necessary information like heights and measurements in the field through drawings and BIMs on the tablet, instead of walking back to the site office and searching through stacks of paper to find the required information. Tablets also provide access to information about the progression of tasks and distribution of responsibilities. Much time is spent on delegating, follow up and ensuring that things have been done. Through tablets, the workers at the site can receive personal tasks and responsibilities, which they mark as finished when the task is done. This is an easy way to keep track of progress and reduce time spent on monitoring tasks and responsibilities. Furthermore, using tablets for quality control in the handover phase gives the client a better way to point out where the quality is not up to the given standards. With the tablet, he can just take a picture of it and link it up to the model with a short description of errors. This makes it easier for the workers to find the specific quality error and correct it. When it is corrected the workers can use the tablet to take a picture of the corrected error and check it off on the tablet as completed.

5.2.2 Challenges of using BIM devices

Even though the BIM devices had a lot of positive advantages and contributed to mitigating some of the challenges presented by the professionals in Figure 4, some additional challenges were also revealed in this study. The challenges are presented in Table 3.

The results stem from three different case studies, yet they bear similarities and sum up the same challenges; mistrust of this new tool, scepticism towards protecting the devices against harsh environment (dust, moisture, etc.) and lack of tutoring to access all the benefits of the device.

Table 3: Challenges with BIM devices onsite as reported by the interviewees and identified through the case-specific survey.

Challenges of using Tablets on site	Challenges of using BIM stations
• Cost/benefit ratio	• If the distance to the BIM station is far from the work site, there is a lot of lost time
• Poor motivation amongst craftsmen	• Training of the workers to use the BIM station efficiently
• Poor usability of the BIM	• Knowledge of the BIM stations' potential
• Lack of trust in the BIM	• Obtaining sufficient resilience in the hardware to cope with tough conditions.

• Dependent on network	• Needs stable internet access to remain updated.
• Reduced data security	
• Vulnerable to moisture and dust	
• Lack of support of operating systems	

The cost/benefit ratio was a challenge that some of the respondent on the survey voiced as an important challenge. However, the cases studied that used tablets did not see the huge cost in procuring tablets for those who needed it, the benefits where superior to the cost. The other challenges that is presented in Table 3 will be further discussed in Section 6.1.

5.2.3 Initiatives to better utilise BIM devices

Initiatives to better utilise the devices were discussed with practitioners in the three studied cases are presented in Table 4. An important factor was the need for better tutoring and training to use the devices. More than 60% of the workers highlighted more training as the most important factor to increase the benefit of BIMs on site. Furthermore, one of the cases had just one BIM station placed rather close to the construction office, so the walking distance from the work site was just about the same. The workers would like to have more stations and the ability to move the stations closer to their work if needed. Another initiative to improve the use of both tablets and BIM stations was to have applications that could handle more than one function. When the workers needed specific measurements, they used one application, for progress reports they used another and a third one for viewing the 3D model. The workers felt like this was unnecessary and required training in more than one application.

Table 4: Initiatives to better use BIM devices as reported by the interviewees and identified through the case-specific surveys.

Initiatives which can lead to better utilisation of BIM devices	
• Better training in use of the devices	• Promote success stories
• More details in the BIMs	• Pilot projects
• Change the attitude of users	• WLAN at the site
• Better location of BIM stations	• Assess usability throughout the development of the BIM
• Better protected devices	• Several functions in one application

6. DISCUSSION

Figure 4 shows the general challenges in the interface between design and construction on AEC projects. The four most prominent challenges are quite typical for a fragmented industry like the AEC industry. Especially, the challenges with collisions between trades are directly caused by the fragmentation between the trades.

The fragmentation of the industry is hard to change as it stems from many factors, like contract models and tendering processes. Such deep structures are inherently challenging to alter significantly. A more practical solution to the challenges the industry faces is richer and more effective communication between the trades on a construction project. BIMs could be a good tool for increased understanding of the information communicated between the trades, as the model itself works as a mediating artefact, increasing knowledge transfer between the trades, as Koskela et al. (2016) described. A BIM could work well (and even better than a drawing) as a mediating artefact. For instance, using BIMs on screen in a meeting will allow the different trades to visualise the whole project in several dimensions at the same time. Like the use of drawings between persons without a common language, the BIM can enable trades to understand each other, by moulding different jargons into a common form so they can see their respective interpretations of the model.

As the findings show, most of the challenges presented in Figure 4 can be mitigated with BIM. However, implementing IT-tools like BIMs poses new challenges, like the need for proper training in the use of the tool. The advantages and the challenges of using BIMs are further discussed in the next section.

6.1 Advantages and challenges of using BIMs to communicate between design and construction practitioners on site

There are many advantages with using BIMs on a construction site, as opposed to the traditional way of using drawings and written descriptions. BIMs can solve some of the general challenges in the interface between design and construction. The findings chapter presents some of the advantages with using BIM devices like BIM stations or BIM on tablets in the construction phase. One of the common advantages was better understanding of the project through 3D visualisation. The visualisation of the project helps the workers understand the whole project and the design of certain elements in the building. As Wileman (1993) describes, visual communication can be more effective than verbal communication. A BIM device also has the possibility to further increase the effectiveness of the communication, as the workers are able to interact with the model. Furthermore, the BIM devices used on construction sites have the possibility for two-way communication. Such two-way communication channels enable the easy reporting by the workers of errors, progress, etc., directly to the design team. Two-way communication is, as described in the theory section above, more effective than a simple one-way communication media such as a drawing.

Having a BIM device onsite opens up another communication channel between design and construction. This permits the addressing of problems involving, for instance, poor communication and delayed drawings. Traditionally, phone calls, e-mails, drawing and meetings between superintendents and design managers have been the commonly used communication channels. These are not, however, very efficient means for communicating concerning progress, error, etc. as the information has a long route before it reaches its destination (e.g. a construction worker reports an error to the superintendent who then talks to the design manager who then informs the proper designer). In such long chains of communication, errors and misunderstandings typically occur, making it even harder to address the experienced challenges. With a BIM device, the workers can easily mark up an error on the BIM and send a direct error report to the design team. To make the information even richer, workers can take a photo of the building site with the tablet and attach it to the error report, so the designers can see exactly what the problem might be. Such direct communication between construction workers and designers could evidently decrease the perceived need for control and traceability of all information for a manager. In the view of the authors, such challenges ought not to be overestimated. A BIM device is a documentation option, meaning all the information that is sent from such a device is stored in a database accessible to a manager. Furthermore, using a system like KanBIM™, process information and product information can be traced through the project (Sacks et al., 2013).

Traditionally, the means of communicating a design to a construction site has been drawings and descriptions. When there is a revision of those drawings, the designer will print out new ones and send them to the construction site. This creates the need for on-site control of those drawings, to secure that every worker uses the newest revision. With a BIM device, a printed drawing is rendered obsolete, as the workers have access to all drawings, descriptions and models on the device. Furthermore, connecting the device to a wireless network, will secure an automatic upload of the newest revisions. In addition, it will reduce the risk of errors due to workers using old drawings.

Having access to 3D models with a 4D presentation of the workflow enables the workers to better understand project information and the workflow of the project. This can lead to a positive effect on the productivity and efficiency of the workers. Ruwanpura et al. (2012) demonstrated the same result with the use of an information booth, which is essentially the same as BIM station.

There are some challenges with the implementation of BIM devices on a construction site. For instance, there is the cost of buying the equipment, like tablets and computers, for use on site. Buying the equipment could be a substantial cost for a small project and something that could be difficult to defend in a project budget. However, the benefit of using BIM devices in most cases should exceed the cost. As has been previously discussed, the traditional way of communicating is ineffective and the cost of rebuilding because workers accidentally use old drawings could easily exceed the one-time cost of BIM devices.

Another challenge discovered is that workers do not know how to use BIM devices and therefore do not see the benefit of using them. However, this is not unique to BIM devices. Every implementation of a new system, tool, method, etc. will be met with scepticism if the workers do not get the proper training to use the tool. In fact, the tool will not provide any benefit at all if the workers do not know how to use it.

A more specific challenge that arose under the implementation of BIM devices was hardware and network connectivity. On a construction site, there is a lot of dust and moisture, so the hardware used must be resistant enough to withstand such a tough environment. Today such devices exist so it is not a challenge, but it is important not to buy the cheapest equipment and also to know what kind of environment the equipment can tolerate. The construction site also needs to have a good and stable internet connection to get the full benefit of BIM devices. This is not a huge challenge either; it is more a question of investing in enough wireless access points around the construction site.

Of course, open access to documents and having wireless access on the construction site can become a security risk. If for instance, someone loses the tablet without having a good password protection it could give someone unauthorised access. However, this is easily solvable by having good security routines and using a protected network on site. Furthermore, the access to the documentation database could be restricted with a virtual private network (VPN) using a secure ID for logging.

Finally, the findings showed that there is some operating software (OS) out there that does not support all the different BIM software. However, the software industry is continuously developing and it is not a question of if it is supported, but rather when it will be supported. Nevertheless, it is something that should be taken into consideration before investing in the equipment – check what type of OS supports the BIM software used on the project and invest in that.

6.2 What practical measures can lead to BIMs providing better communication between design and construction practitioners?

There are several practical measures to better utilise BIM devices. An important step is to set up a training program for users, so they learn how to use the new tool. Although it is important to know how to use a new tool, there is not a direct link between knowing how to use it and seeing the benefit of using it. Therefore, it could be beneficial to have a good implementation strategy with clear goals for the implementation, perhaps also running a pilot project that gets extra attention to secure a success. To get people to see the benefit in implementing new tools like BIM devices, it is important to promote success stories among co-workers. Most people want to be the best or do their best, if they see that one project has a tool that makes them more efficient, it is normal that other people want to try out the same tool.

6.3 How can BIMs enhance the communication between design and construction practitioners?

Based on the insight from the analysis presented in the theoretical framework section, and experience from the case studies, the theoretical model found in the literature lacks the new communication channels that BIM has introduced.

Coming back to the Ambler (2002) model and the relative effectiveness of communication channels, it is clear that the most effective form of communication will be face-to-face at a whiteboard. Everything else being equal, a BIM device is clearly a much richer artefact than a whiteboard, thus better enabling communication.

If we consider BIM as a documentation option, the situation becomes a bit fuzzier. Although a BIM will normally be far superior in information richness and ease of retrieval, it cannot serve as a carrier of non-verbal information the same way audio and video documentation options can. We would say, however, in the communication context that we are considering, the value of this information is negligible; e.g., knowing that the architect is happy with the building he drew is normally not pertinent to executing the construction correctly.

Another potential weakness of BIM compared to other documentation options is the possibility of 'false' information. When modelling, software packages will supply, in many cases, default values for attributes like ceiling height or wall thickness if the user does not specify them. This could lead to a communication error down the line if people who access the model assume that the designers have actually decided upon these values.

In practice, the solution to this is to have an Information Delivery Manual (IDM) that specifies what information is supposed to be in the model at different stages of a project. Thus, the designers will know what information they have to put in, and builders and others that access the model will know what information can be expected to be relied upon and what is just 'placeholder' information.

Although using BIM as a documentation option has some issues, we consider BIM to be a documentation option far superior to other options, if it is used correctly.

Figure 5 shows how BIM and BIM devices fit in to Ambler's model. In addition, we have added Emmitt's definition of communication as either asynchronous or synchronous. This makes the model richer as it gives a clearer picture into what kind of communication channel has the capabilities for real-time communication.

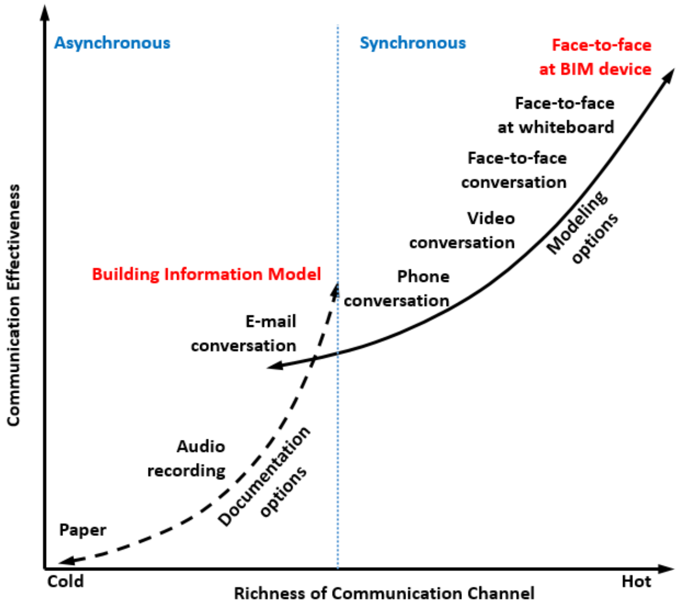

Figure 5: different types of communication channels and how rich and effective they are compare to each other (after Ambler, 2002; Cockburn, 2006).

Knowing when to use synchronous and when to use asynchronous communication is important on a construction project with a high degree of complexity. Clearly, it is not efficient to use synchronous communication on topics that Lengel et al. (1989) call routine, e.g. calling into a meeting just to say when the materials will arrive on site is not very effective. Synchronous communication should only be used on non-routine topics, where the outcome is unknown and requires collaboration.

7. CONCLUSIONS

This article has studied the advantages and challenges with the use of BIM devices on a construction site and has explained with communication theory why these tools are more effective than the traditional approach. Most of the advantages and challenges presented here have been presented earlier in previous studies by the authors themselves and by others. However, to the best knowledge of the authors, there is no study that has used communication theory to explain why it is an advantage to use BIM devices on a construction project.

Reaping the full benefits of its potential demands insight into communication theory. The main finding is that BIMs, used as a mediating artefact in a synchronous communication option, provide far more effective communication than other types of synchronous communication. BIMs as a documentation option are superior to all other media, because they have a higher bandwidth and are self-documenting at the same time. We have found some challenges with communication in general and more specifically with BIM devices. The most prominent challenges with BIM devices are connected with the implementation process and are not necessarily unique to them. Any new system or tool that is implemented will require some sort of training, and proper training of all the involved practitioners will be necessary before implementing a BIM device.

This study also shows that it is important to know when to use asynchronous and when to use synchronous communication. Although the latter is far superior in effectiveness, using synchronous communication on routine topics will be counterproductive.

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