A qualitative approach to examining how digital twins impact users' mental models

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Abstract

Digitalisation has led several industries to introduce new technology, with the intention of increasing safety and efficiency. The current study aims to identify how the implementation of a digital twin impact users' mental models in a high reliability organisation (HRO). To collect data, nine semi-structured in-depth interviews were conducted with personnel from the energy industry, who had experience with using a digital twin. Using a template analysis, four reoccurring themes were identified: (1) the influence of digital twins on the users' work, (2) reliability of the tool and the users' trust in their own abilities, (3) how users' test their internal representations, and (4) how the digital twin aids in creating shared understandings. The data suggests that the implementation of a digital twin has aided users' formation of mental models. Easier access to information has led to more effective decision-making. However, when encountering complex problems, the implementation of the digital twin has led users to compare and question their mental models. A HRO requires a high degree of safety. This entails new technological tools to be thoughtfully designed and implemented, in order to maintain safety and efficiency.

Keywords: Mental models, digital twin, human-computer interaction, qualitative study

Sammendrag

Digitalisering har ført til at flere industrier introduserer ny teknologi på arbeidsplassen, med intensjon om å øke sikkerhet og effektivitet. Hensikten med denne studien var å identifisere hvordan implementeringen av en digital tvilling påvirker brukernes mentale modeller i en høyreliabilitetsorganisasjon (HRO). Ni semistrukturerte dybdeintervjuer ble gjennomført med personell fra energiindustrien som hadde erfaring med bruk av digital tvilling. Ved hjelp av en templateanalyse ble fire gjengående temaer identifisert: (1) påvirkning av den digitale tvillingen på brukernes arbeid, (2) verktøyets reliabilitet og brukerens tillit til egne evner, (3) hvordan brukerne tester sine indre forestillinger, og (4) hvordan den digitale tvillingen bidrar til felles forståelse. Dataene tyder på at implementeringen av en digital tvilling bidrar i dannelsen av brukernes mentale modeller. Lettere tilgjengelig informasjon har ført til mer effektiv beslutningstaking. Implementering av en digital tvilling, har likevel ført til at brukere sammenligner og stiller spørsmål ved sine egne mentale modeller, særlig i møte med komplekse problemer. En HRO krever et høyt sikkerhetsnivå. For å sikre at sikkerhet og effektivitet blir ivaretatt, er det en forutsetning at designet og implementeringen av det nye teknologiske verktøy er nøye gjennomtenkt.

Nøkkelord: Mentale modeller, digital tvilling, menneske-maskin interaksjon, kvalitativ studie

Acknowledgements

Over the course of our studies, we have developed a special interest in human factors and digitalisation. We, therefore, chose to study the impact digital twins has on the users' mental models. This masters project has proved to be a demanding process requiring a steep learning curve, but also highly rewarding. Through this work, we have acquired valuable insights about the role as researchers, with its ups and down, and have been able to find joy in doing research.

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Sandefjord and Os, 28.05.2020

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Digitalisation has been identified as one of the most important trends in today's society (Gressgård, Melberg, Risdal, Selvik, & Skotnes, 2019). The term *digitalisation* is used to refer to converting analog data to digital data (Osmundsen, Iden, & Bygstad, 2018), but also to the implementation of digital technology which changes socio-technical structures (Brennen & Kreiss, 2016). The digital transformation happening to industry and society is known as *the fourth industrial revolution*, or *industry 4.0* (Schwab, 2017). Within the petroleum industry, this has meant an increased focus on work methods where technological solutions and real-time information create the foundation for collaboration across technical disciplines, organisations, and geographical locations (Gressgård et al., 2019). There are several reasons why digitisation is important within the oil and gas field. Operators within the oil and gas field have named improvement of efficiency as a governing factor in the development of digital solutions, whilst safety has been highlighted as a prerequisite for the implementation of new technology (Ellingsen, Håland, & Kadal, 2019). As errors in this field can lead to catastrophic consequences, offshore petroleum operations are considered high reliability organisations (HROs) that operate in safety-critical situations (Klein, Bigley, & Roberts, 1995). They are obliged to follow strict safety standards to prevent major accidents and reduce the ramifications of such an accident if one should occur.

In order to increase safety and efficiency, several industries have begun implementing digital twins to aid workers and ensure information-based decision-making. A digital twin is, in simple terms, a virtual copy of the physical world. However, a digital twin can be more accurately described as a comprehensive physical and functional description of a component, product, or system which includes information that could be useful in both current and future system states (Boschert & Rosen, 2016). Digital twins often consist of several different conceptual models, including interactive three-dimensional (3D) models, two-dimensional (2D) drawings and documentation, and live data. Introducing tools such as digital twins is intended to have positive effects on safety; however, it has been suggested that it could also lead to unintended detrimental effects (Ellingsen et al., 2019).

In light of this, the role of research should be to observe how technological changes transform cognitive activities and demands, and how people in turn adapt to those changes (Woods & Dekker, 2000). Our study seeks to understand how the implementation of digital twins impacts users' mental models of their work. In the next section, we outline how factors such as trust and reliability affect the implementation of new technology. Mental models are used as a framework for understanding how users describe, explain, and interact with their surroundings. We examine how conceptual models present information in different ways and what consequences this has for the users of digital twins. Finally, we explore the impact different models have on each other and how this affects users' understanding of their surroundings in a safety-critical environment.

Impact of new technology

More and more organisations are introducing new technological tools, such as digital twins, with complex displays that make more information available and retrievable. The displays are mobile, sometimes even wearable, allowing users to access information from any location (Rowen, Grabowski, Rancy, & Crane, 2019). The introduction of these types of tools has led to the idea that the human operator and the digital tool form a human-computer *team* as they rely on each other (Dzindolet, Beck, Pierce, & Dawe, 2001). This human-computer team is more productive than the technological tool or the human operator working alone (Dzindolet, Peterson, Pomranky, Pierce, & Beck, 2003). However, that does not mean that the human-computer team always functions optimally (Dzindolet et al., 2003). It is therefore important to study factors which influence human-computer interactions.

Parasuraman and Riley (1997) examine trust as an important factor associated with human use of automation. This is believe to be transferable to technological tools in general.

According to Dzindolet, Beck, & Pierce (2006), trust is determined based on a comparison process between the perceived reliability of the technology and the perceived reliability of manual control. The outcome of this process leads to a decision regarding the perceived utility of the tool. If the perceived reliability of the tool is greater than the perceived reliability of the user's own abilities, the perceived utility of the tool will be high, and vice versa. Trust can lead to human operators under- or overutilising technological tools, which in turn can impact their performance and compromise the safety of operations (Parasuraman & Riley, 1997). When individuals overestimate the perceived utility of a tool, they rely on the tool in circumstances where it would be more beneficial to rely on their own abilities (Dzindolet et al., 2006).

Trust is acknowledged by several researchers as an important factor when people are deciding whether to rely on a new technology (Lee & Moray, 1992; Liu & Hwang, 2000; Rovira, McGarry, & Parasuraman, 2007). New technologies rarely gain instant acceptance in the workplace. Operators may dislike or mistrust them in the beginning. However, as operators gain experience with a tool, they are more likely to perceive it as reliable and accurate (Parasuraman & Riley, 1997). When new technology is introduced into a workplace, it is not a given that all users start out with the same level of technical understanding. With several inexperienced users making decisions, mistrust in a tool becomes a risk that can lead to hazardous situations (Janssen, Donker, Brumby, & Kun, 2019). Thus, training and instruction are important, especially for inexperienced users (Janssen et al., 2019). This training can provide them the competence needed to cope with system failures, accurately estimate risks, and appropriately place their trust (Janssen et al., 2019; Parasuraman & Riley, 1997).

New mobile displays, such as tablets, can also change when, how, and where tasks are performed, which presents operators with an even more complex adjustment (Janssen et al., 2019). Though designed to increase productivity and support decision-making, this adjustment can lead to faulty cognitive processing. In order to implement a new tool effectively, it is important that the users receive training and instruction in how to use the tool. Furthermore, it is essential that the designers of technological tools be mindful of the end-users when developing their tools. How a tool presents information impacts how well it aids in the development of mental models that represents the system (McDougall, Curry, & Bruijn, 2001).

Mental models

The theory of mental models is founded on the idea that humans construct working models in their minds to understand the world they live in (Johnson-Laird, 1983). As early as the 1940s, Craik (1943) suggested that assessing situations, making correct judgements, and acting before problems arise can be made possible by internalising a *small-scale model* of external reality and of one's own potential actions. Little research was done on this subject until the idea was revived in the 1970s by cognitive psychologists and ergonomists involved in the field of human factors (Johnson-Laird, 2004). Today, the premise that humans develop and use internal mental representations of external reality is widely accepted in cognitive science and psychology (Jones, Ross, Lynam, Perez, & Leitch, 2011).

Mental models are an interdisciplinary concept, which has led to some confusion about how to define it (Moray, 1996; Wilson & Rutherford, 1989), as the different disciplines put emphasis on separate aspects. In the field of ergonomics, employing a system-oriented definition makes sense, while the cognitive psychology tradition favours a behaviour-oriented understanding. Rouse and Morris (1986) evade this problem by proposing a functional definition of mental models that takes both system and behaviour into account, stating, "mental models are mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (p. 7). This definition emphasises three crucial aspects of mental models' functions: to help individuals describe, explain, and predict.

Being able to describe a system, explain how it works, and predict how it will react in the future are central to human functioning, as it allows an individual to understand and interact with their environment (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). In a safety-critical situation, individuals' responses depend upon the mental models they have of the system. Having satisfactory mental models of a system positively influences the way they conduct their work and the results they provide. These mental models are not only important for the individual, but also have extended effects that have significant implications in a safety-critical environment.

Characteristics of mental models. The concept of mental models can be distinguished from knowledge in general in that mental models are frameworks that encompass special types of knowledge (Rouse & Morris, 1986). Mental models have been linked to schemas, another cognitive structure related to storing and processing information (Wilson & Rutherford, 1989). There is an agreement amongst cognitive psychologists, that cognitive schemas constitute the fundamental basis for the construction of mental models (Al-Diban, 2012). However, several opposing characteristics can be used to differentiate between mental models and schemas. Whereas schemas tend to contain generic or prototypical knowledge, mental models represent knowledge that is more specific (Wilson & Rutherford, 1989). Schemas are often seen as absent, insufficient, or inadequate for solving a novel task or problem, whilst mental models involve a restructuring of the cognitive structure which is useful for understanding a new situation or an unknown problem (Al-Diban, 2012). Their dynamic nature makes mental models useful in safety-critical situations as they hold more situation specific knowledge.

Because mental models are internal representations of something external and observable, and because people's ability to represent the world accurately is limited, mental models are unique for every individual (Jones et al., 2011). Some defining characteristics are frequently referenced when mental models are being discussed. Mental models are usually thought to mirror the structure that they represent (Johnson-Laird, 2004). Early portrayals of mental models described them as internal images (Wilson & Rutherford, 1989). However, mental models can be distinguished from internal images because of their function (Held, 2006). Mental models are believed to be an internalised version of a physical system that allows for more flexibility, as opposed to a linear temporal order of structuring information (Gentner, 2001). Because mental models are internal representations, the elements they are made up of are merely imitations of reality (Johnson-Laird, 1983). A real-life three-dimensional structure does not necessarily call for a three-dimensional representation in the brain (Johnson-Laird, 2004). In this sense, a mental model is simply a theoretical entity, an idea that is employed to account for empirical data (Wilson & Rutherford, 1989).

Mental models are thought to be constructed in the working memory (Barrouillet & Lecas, 1999). The working memory has been identified as the system responsible for selecting and manipulating information for the purpose of reasoning and learning (Baddeley, 1992). Mental models therefore allow individuals to test and explore different options mentally before acting (Jones et al., 2011). They are formed based on experience and formal knowledge acquisition (Westbrook, 2006), and they provide a mechanism through which new information is filtered and stored (Jones et al., 2011). Research on knowledge acquisition found that the mental models and problem-solving skills held by students at the end of the semester were distinctly more complex, than those they held prior to the semester (Hegarty, Stieff, & Dixon, 2013). Rouse and Morris (1986) theorise that necessary models can be provided through instruction, as the aim of instruction is to provide the learner with necessary knowledge and skills and to improve their confidence and attitude.

Conceptual models

As mentioned previously, what constitutes a mental model is a topic of contention (Moray, 1996; Wilson & Rutherford, 1989). This discussion also addresses confusion surrounding what constitutes a conceptual model. Wilson and Rutherford (1989) suggests that a conceptual model should simply be seen as the user's representation of a system. Young (1983), on the other hand, propose that a conceptual model is a representation of a system that is used in order to guide actions and interpret system behaviour. Differences between a conceptual model and a mental model have been suggested. Whilst some argue that a conceptual model is similar to a mental model and subsequently internal in nature (Richardson & Ball, 2009), others suggest that conceptual models can be viewed as external representations created to facilitate the comprehension of systems (Greca & Moreira, 2000).

Following the distinction drawn by Norman (1983), mental models and conceptual models are understood to be separate concepts. A mental model is an individual's internal representation of the system, and a conceptual model is an external representation of the target system characterised through displays, documentation, structures, and operations. Conceptual models can represent the target system in different ways, one example being through digital twins. It is not unusual for a digital twin to contain a collection of different conceptual models that can be accessed in several ways. How information is presented depends on its purpose and use, and it influences how people process and understand the information.

Visualising information. Information presented in a digital twin can be either 2D or 3D and accessible through visual displays or as augmented reality (AR) layered on top of the visual field. The different representations can be informationally equivalent even though they are presented differently. The computational efficiency of the information depends upon how the individuals process the information (Larkin & Simon, 1987). Conceptual models representing information visually are often more efficient than textual representations. Visual representations lend themselves to more implicit and intuitive information retrieval, as they require less computational effort to encode and subsequently understand (Larkin & Simon, 1987), making visualisations conductive to representing surroundings.

When comparing 2D and 3D models, Smallman, St. John, Oonk, and Cowen (2001) found several benefits to 3D models. They report that 3D models reduce users' mental workload through the integration of all three spatial dimensions into one representation; this is supported by Wickens and Andre (2016). Smallman and colleagues (2001) also found that users prefer the simplicity and the familiarity of the 3D model. However, there is a risk of ambiguity with 3D models, which may result in positioning issues (Smallman et al., 2001). A study conducted by Gramss, Schweizer, and Mühlhausen (2008) compared the sense of presence found in 2D and 3D models when processing information. Contrary to what one would expect, their participants rated 2D models higher than 3D models in terms of presence. These findings could relate to 3D models being more intuitive, allowing participants to shift focus to and from the task without having to re-orientate themselves. Participants using a 2D model also experienced the task as being more mentally draining (Gramss et al., 2008). As a visual representation, 2D models require more computational effort, making 3D models more efficient in use (Schweizer, Gramss, Mühlhausen, & Vogel-Heuser, 2009).

How information is displayed can affect how information is understood and can thus affect the efficacy of the visualisation. One concern regarding visual displays is that there is no apparent restriction on how much information can be included in them. When too much information is presented, it leads to difficulties in error detection and decision-making (Gramss et al., 2008). Wearable AR displays, such as AR-glasses, provide operators with visual information superimposed on the real world, situated close to the physical object (Rowen et al., 2019). Presenting information this way can provide operators with timely, relevant information anywhere within their workspace; however, it may also increase mental workload and lead to information overload (Rowen et al., 2019).

Relationship between models

Conceptual models require users to interoperate the information that is being presented. Mental models allow users to make inferences based on the information provided by the conceptual model. Neisser (1976) suggests a perceptual cycle theory in order to explain the relationship between how individuals understand and interact with their surroundings. The theory proposes a cyclical, reciprocal relationship where environmental experiences result in the modification and updating of the cognitive knowledge structure. This in turn influences further interactions with the environment.

Whilst the perceptual cycle theory explains how individuals interact with their surroundings, it does not consider how conceptual models influence this relationship. In recent years, advances in technology have made it possible to create new conceptual models such as digital twins that represent information in novel ways in order to augment and amplify human cognition (Hegarty, 2004b). The augmented approach views conceptual models as a replacement for mental models, freeing up cognitive processing resources so that a person can make further inferences without the need for a mental model of the system (Zhang and Norman, 1994). Because conceptual models relieve individuals of the need to maintain this internal visualisation of the system, individuals with low spatial understanding can become more successful in solving problems (Hegarty, 2004b). However, the augmented approach views mental models purely as mental images and fails to consider their function as a mechanism of human reasoning beyond that (Held, 2006). This makes the augmented approach inconsistent with the notion of mental models as complex cognitive structures (Jones et al., 2011).

Hestenes (2006) outlines a more comprehensive modelling theory of cognition that, in addition to explaining the relationship between individuals' mental models and their surroundings, also examines how conceptual models fit into this relationship. The modelling theory of cognition describes three separate worlds, as seen in Figure 1: the physical world, where people interact with the observed system; the mental world, where mental models are created to explain the system; and the conceptual world, where mental models are communicated to others using a conceptual model (Amin, Jeppsson, & Haglund, 2018). Similar to Neisser's (1976) model, Hestenes' (2006) theory suggests a reciprocal, cyclical relationship between worlds. Individuals' ideas of their surroundings are influenced both by their perceptions of their physical surroundings and by their understandings of conceptual models that represent those surroundings (Hestenes, 2006). Following this reasoning, a conceptual model (e.g. a digital twin) would influence an individual's mental model, by offering an alternate interpretation of the physical world. However, a conceptual model is only an interpretation of the observable surroundings, which means that it does not always represent the physical world accurately.

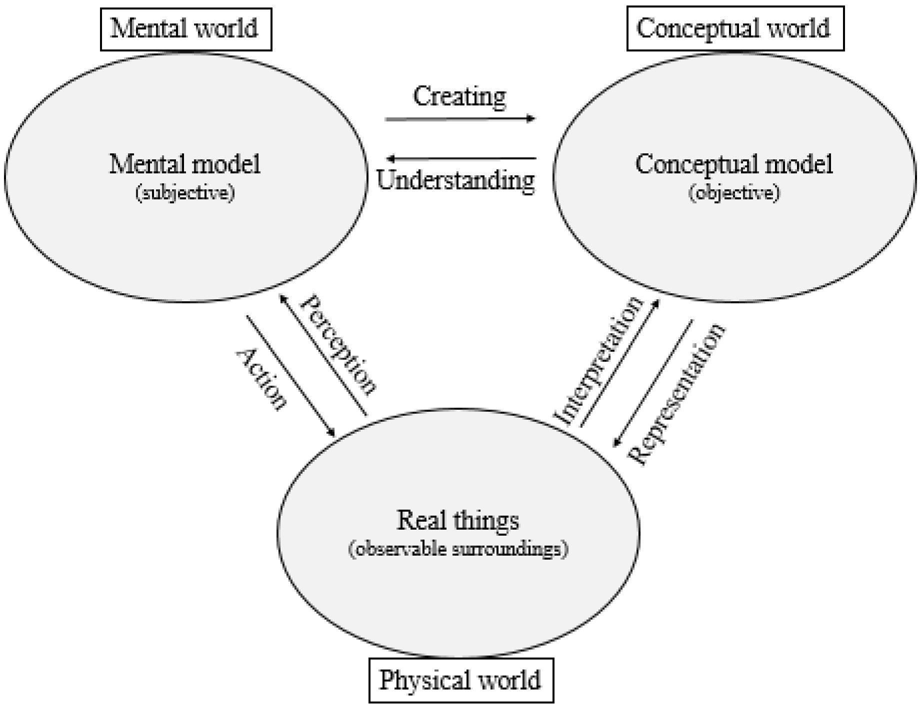

Figure 1: Interaction between different models of representation. Adapted from Hestenes' (2006) figure of the Modelling Theory of Cognition.

Discrepancies between models. Disparities between an individual's mental model and a system's real-time behaviour are called *cognitive mismatches* (Baxter, Besnard, & Riley, 2007). If an existing cognitive mismatch is not detected, it can lead to hazardous situations, especially within an HRO (Baxter et al., 2007; Besnard, Greathead, & Baxter, 2004). Baxter and colleagues (2007) suggest that a cognitive mismatch can be categorised along two dimensions: detection of mismatch and type of mismatch. Type of mismatch relates to whether the mismatch is real or perceived. A real mismatch occurs when there is an actual discrepancy between the models, while a perceived mismatch occurs when an individual believes that there is a discrepancy between the models that does not, in fact, exist. Detection of mismatch relates to whether a mismatch is detected or not. If a mismatch is detected, it can be diagnosed and solved.

Johnson-Laird, Girotto, and Legrenzi (2004) propose that when faced with inconsistencies, individuals try to reason to consistency. In other words, they use their mental models to explore the different possibilities and create explanations for what led to the inconsistency. As cognitive capacity is a limited resource, functional mental models cannot always be complete (Jones et al., 2011). Instead, they are built on partial pieces of evidence (Besnard et al., 2004). Likewise, when a person is pressed for time, they tend to satisfice rather than optimise. This reasoning process can result in problems being resolved quickly and efficiently, but it can also yield an erroneous model of the situation where a false alarm is wrongfully acted upon (Johnson-Laird et al., 2004). The dynamic nature of mental models allows them to be highly adaptive. However, factors such as cognitive resources, confirmation bias, and time pressure can lead to construction of erroneous explanations to account for a mismatch (Besnard et al., 2004)

Rasmussen (1986) states that errors must be seen as marginal events caused by the same mechanisms that generate correct actions most of the time, rather than as cognitive dysfunctions. Dekker (2001) suggests that progress in safety is only achieved with the acknowledgement that safety is not built into a system or introduced by procedural fixes, but instead created by individuals themselves. Gentner (2001) poses that by studying incorrect models, one can identify the types of errors that typically occur. This can inform the development of future systems and learning processes in order to minimise the likelihood of the same errors being made in the future (Gentner, 2001). Instructing operators about potential pitfalls and biases, as well as creating thoughtful design, can help support mental model formation and, in turn, decision-making in critical situations.

Research question

Few existing studies examine the impact that digital twins have on how users understand and interact with their surroundings. Based on the theoretical framework presented, our aim is to answer the following research question:

How does the implementation of a digital twin in an HRO impact users' mental models? To answer this research question, we chose to focus our study on three areas where we believed the introduction of a digital twin would have an impact. First, we looked at how the users formed their understandings of their work tasks. Second, we examined the users' attitudes towards new technologies. The way they trusted both their own models and the information they had access to was important to consider. Third, we explored how discrepancies between different models were handled.

Method

The previous section has outlined a theoretical framework forming the current study's foundation for understanding how the implementation of a digital twin impact users' mental models. The following section outlines the methodological procedure and ethical considerations related to the study. The results from the analysis will then be presented and subsequently discussed.

Design

A qualitative research approach was used for this study, as this allows the capturing of individuals' perspectives. Qualitative methods are widely used by researchers who wish to explore research questions that have seen little prior examination (Repstad, 1993). The strength of qualitative methods lies in the opportunities they offer researchers to explore individuals' personal experiences of different phenomena (Robson, 1993). The qualitative approach allows for the capture of rich information about the phenomena being observed that can then be used for further development of hypotheses and theories (Repstad, 1993). We conducted semi-structured one-on-one interviews to collect our data. According to Kvale (1997), semi-structured interviews are used to obtain descriptions of the interviewee's world with the purpose of interpreting the described phenomena. These interviews offer the flexibility to gain additional context through specific follow-up questions that can be difficult to foresee prior to conducting the interviews (Dalland, 2000). We are confident that semi-structured interviews are a satisfactory method to gather data about mental models for this study. This approach provides the freedom to explore the informant's experiences of their mental models in depth.

Recruitment. The informants selected for this study all had some experience using digital twins, either on a tablet or with AR glasses, in their daily work. The informants were recruited through a contact in a Norwegian energy company, where they worked either offshore or onshore. We were provided a list of possible informants and emailed them invitations to partake in our study. Our initial aim was to recruit up to 15 informants; however, this turned out to be difficult because we had limited time to conduct our interviews. In order to increase the number of participants, we approached another contact person in the company and obtained a second list of possible informants. Their participation was voluntary and anonymous.

Sample. Nine informants, all male, were interviewed for this study. The lack of female informants could reflect the dominance of male workers in the industry. The informants were between 34 and 56 years of age (M = 44.7) and had between 9 and 31 years of experience (M = 21.5) in the energy industry. Seven of the informants worked on offshore locations, whilst two worked onshore. As AR glasses are not certified for offshore use, only the two onshore-based informants used this device in their daily work. Our sampling procedure was a combination of purposive and convenience sampling. It was purposive because we only considered informants who used digital twins in their work. The sample consisted of employees from different departments of the company who therefore had different work tasks depending on their field of expertise. This allowed us to explore how digital twins are used and how they impact users' understandings across different fields. The sample was contingent on a few possible informants provided by our contact persons, making it also a convenience sample.

Data collection and procedure. The interviews with our informants were conducted between late November 2019 and late January 2020. The informants were interviewed individually, and each interview lasted approximately fifty minutes. The same two researchers conducted all the interviews, ensuring consistency. Six of the interviews were conducted using video calls, as the informants were either offshore or located far from Bergen. Three interviews were completed face-to-face, with one at the University of Bergen and two at the offices of the energy company. Prior to the interviews, the informants received information about the study, including the consent form, and were encouraged to ask any questions they had regarding participation. At the start of the interview the informants were given information about the purpose of the study, procedures, and their rights as voluntary informants. They were then asked for an oral consent that was recorded. The interviews were recorded on an audio recorder and later transcribed word-for-word. The audio files were deleted after all the interviews had been transcribed.

Ethical considerations

It is important to perform reliable and responsible research that follows the fundamental norms and values of the research community. To achieve this, we relied upon guidelines developed by The National Committee for Research Ethics in the Social Sciences and the Humanities (NESH) (2016). We collected personal information about our informants in the form of demographical data (age, gender, and time spent working in the industry), as well as audio recordings of the interviews. In light of this, it was important to address the privacy and informed consent of our informants.

Informed consent is integral to ensuring the research participants' autonomy, integrity, freedom, and right to co-determination within research (NESH, 2016). As this study seeks to collect personal data from informants, we were obliged to provide information about the research and to obtain the informants' consent. Freely given consent could be challenged by informants feeling pressured to participate, as they were recruited by their employer. It was therefore important to provide the informants with thorough and understandable information about the study and their rights as participants. Prior to their interviews, each informant was sent an information leaflet (Appendix A) outlining the study and its purpose, how their personal data would be handled, and their rights to withdraw from the study. Before each interview, informants were provided a summarised oral version of this information, and formal consent was obtained.

To ensure that the personal information collected about our informants was handled adequately according to personal protection legislation, NSD (Norwegian Centre for Research Data) was notified and approved (Appendix B) our study prior to data collection. Audio files were stored under password protection, with an accessible version log on servers belonging to the University of Bergen. The audio files could only be accessed by the students responsible for the study and the supervisor of the master project. After being transcribed and anonymised, the audio files were destroyed in compliance with NSD’s recommendation. Only excerpts of data material that have been anonymised and therefore cannot be traced back to the individual informants will be accessible to the energy company that assisted in obtaining informants for the study.

Interview guide

An interview guide was used to conduct the semi-structured interviews (Appendix C). To develop the interview guide, preliminary interviews were conducted with project managers responsible for the implementation of the digital twin during a site visit to a yard. We were also provided a demonstration of how they use the digital twin, either through AR glasses or tablets, to verify work during construction. This was informative, as we were able to see the intended use of the digital twin for different work tasks using different devices (AR glasses, tablets, or computers). Each interview started with demographic information. This included questions about age, work experience, daily work tasks, and previous experience with technological tools.

The interview guide consisted of five sections, each containing a main question and potential follow-up questions. The first section was concerned with how informants used the digital twin in their work. The second section questioned how digital twins influenced the informants’ work compared with previous projects where they were without this tool. The third section was related to how the informants went about finding information they trusted using the digital twin and whether they investigated the discrepancies they discovered between the physical world and the digital twin. The fourth section looked at whether the informants had experienced an internal representation of their surroundings and their work tasks. The fifth section entailed whether the implementation of a digital twin had led to changes in how the informants collaborate and communicate.

When concluding the interviews, informants were asked whether they had anything they wanted to add or any questions regarding our research project. Every informant was asked all the main questions, but the degree to which they were asked follow-up questions was determined by how elaborate their responses were. The follow-up questions were adapted to the informants' responses and use of terminology.

Analytical Procedure

To analyse the collected data, we employed a template analysis. This is a form of thematic analysis which emphasises the use of hierarchical coding (Brooks, McCluskey, Turley, & King, 2015). We chose to use this framework because it maintains balance between the high degree of structure needed when analysing textual data and the flexibility needed to adapt it to our study (Brooks et al., 2015). Before starting the analysis process, we created an *a priori* coding template based on the interview guide and the objectives of the study (Appendix D). *A priori* themes are aspects of the phenomena under investigation that are of particular interest (Brooks et al., 2015). Four main themes were identified as areas of interest in the study and formed the level in our *a priori* coding template. The underlying levels were based on information from the preliminary interviews and the interview guide.

When analysing the data gathered in the interviews, four main procedural steps were undertaken. The first step was familiarising ourselves with the interview data through transcribing the interviews and re-reading the transcribed material. In the second step, we carried out preliminary thematic coding separately using the data processing software Nvivo 12. We used the *a priori* template as a guide, while recording any new themes emerging from the data that seemed interesting and relevant. The third step consisted of comparing the individual templates we constructed from the preliminary thematic coding. This involved organising our emerging themes into meaningful clusters and defining the final coding template based on *a priori* and new emerging themes. In the fourth step, we applied the final coding template to our interview data separately before merging the final results.

The decision for us to code the interview data separately was made in order to ensure interrater reliability of the measures. After coding the interview data using the final template, it indicates an agreement percentage of 96.8% between the researchers across all codes and nodes, and the Cohen's kappa (κ) is 0.549. The analysis process was completed when both researchers were satisfied that the final template provides a comprehensive representation of our interpretation of the interview data. The final coding template was comprised of themes derived both from the *a priori* coding template and what emerged through the analysis process (Appendix E).

Results

During the interview process, we found that most of our informants were glad to talk about their work and expressed that they appreciated the way their experience could contribute to our research. How much the informants had to say varied, but the interviews never went over the allotted time, and we were able to ask our follow-up questions without having to hurry. Informants found it easier to answer more practical questions tied to their actions, as opposed to questions surrounding unconscious processes such as internal representations. Questions regarding how the informants perceived their own internal representations generally required more clarification to prompt an answer, and more follow-up questions were necessary to ensure that we understood what the informants meant by their responses. This tendency is to an extent illustrated in Table 1, which indicates how many of the nine interviews were scored with each code and how many instances of the code were applied across all interviews.

The *a priori* template developed prior to analysing the data formed an appropriate, though somewhat rough, framework for structuring our interview data. Our final template confirmed that influence on work, perceived reliability, influence on internal representations, and shared understandings constituted the four main themes at the first level of the template. The only difference at the second level was that communication was identified as a reoccurring theme important for forming shared understandings. More detailed and specific features of the data were identified at higher levels of the hierarchy (3rd, 4th, and 5th levels), which led to necessary revisions of the template there. The revisions made to our templates are no different from what would be expected in most qualitative research. As higher levels of the hierarchy are characterised by more detailed and specific information, new emerging themes are expected.

Table 1

Quantitative representation of template analysis, presenting the codes at the three highest levels.

Level	Code	Source	Instances	Number of instances in each interview								
				1	2	3	4	5	6	7	8	9
1	**Influence on work**	9	265	30	26	20	39	25	37	32	23	33
2	Use of the tool	9	197	22	23	14	18	23	30	23	19	25
3	*Tools that are in use*	9	65	4	8	5	5	7	12	7	8	9
3	*Tasks tool is used for*	9	108	19	12	6	9	12	12	14	7	17
3	*Possible uses of the tool*	9	62	6	6	5	8	10	9	3	7	8
2	Change in work	9	134	18	10	10	27	12	14	20	11	12
3	*Availability of information*	9	62	11	6	7	12	6	7	7	3	3
3	*Effective workflow*	9	96	12	7	8	20	8	7	16	10	8
1	**Reliability**	9	194	15	20	22	21	15	35	30	19	17
2	Trust	9	103	10	11	16	14	6	14	14	10	8
3	*In one self*	9	33	4	4	4	5	3	4	4	2	3
3	*In the tool*	9	76	6	9	12	11	3	10	11	8	6
2	Perceived reliability	9	121	10	12	11	10	10	25	21	10	12
3	*Of the tool*	9	59	4	8	6	3	7	6	14	3	8
3	*User-friendliness*	9	71	6	5	6	8	6	20	8	8	4
1	**Influence on internal representations**	9	112	8	16	15	13	13	13	14	10	10
2	Characteristics of internal representations	9	77	4	10	11	8	10	8	9	7	10
3	*Limitations of internal representations*	7	20	0	4	2	0	4	2	2	2	4
3	*Impact of external representations*	9	29	3	5	5	2	1	3	4	2	4
3	*Impact of experience*	9	40	3	5	4	5	8	4	3	3	5
3	*Change in internal representation over time*	6	18	0	0	3	5	4	3	1	2	0
2	Discrepancies between representations/models	8	38	4	5	5	5	4	6	6	2	0
3	*Discrepancies between digital twin and physical surroundings*	8	22	3	2	2	3	2	4	4	2	0
3	*Handle discrepancies between models*	8	21	1	3	4	3	2	3	4	1	0
1	**Shared understanding**	9	140	16	14	23	18	17	16	15	10	11
2	Knowledge	9	114	9	12	21	16	14	15	12	5	10
3	*About the tool*	9	80	9	9	12	13	10	6	10	4	7
3	*About colleagues understanding*	9	45	1	5	9	5	8	11	2	1	3
2	Communication	9	55	10	6	5	7	5	9	5	5	3
3	*Use tool to communicate*	7	21	5	4	2	2	0	2	2	4	0
3	*Use tool as a visual guide in collaboration*	9	36	5	3	3	6	5	7	3	1	3

The following presentation of findings will be structured around three areas of interest, where we believe the introduction of digital twins will have had an impact. These being, how individuals form their understanding of their work tasks, how individuals trust their understanding and the information they have access to, and finally how individuals resolve challenges to their understanding. Note that this deviated from the structure of both the interview guide and the final coding template. However, shared understanding is a theme identified in our final template, that we have chosen not to explore further. We, therefore, believe that this structure best allows for a discussion of the results, as they relate to our research questions. When presenting our findings, we have chosen to include and focus on excerpts from the interviews conducted with the informants. We believe that giving this insight, into how they themselves describe their experience the impact digital twin has had on their mental models, helps further enrich and clarify the following findings (translations of excerpts made available in Appendix F).

Forming understandings

When answering the question of how digital twins have impacted the way our informants form their understandings of their work tasks, it is important to establish how the digital twin is used. This section outlines how the digital twin has been implemented in the examined workplace and how it has been applied to different work tasks there. Findings regarding the informants' experiences and their formations of their own internal representations are also presented, along with their perceptions of how the digital twin has impacted their internal representations.

Implementation of digital twin in the workplace. Which tools the informants use in their work is summarised in Table 2. In line with our expectations prior to conducting our interviews, the informants reported that the digital twin is used on various devices. The tablet is the main device being used when working in the field. For most of the informants, the preferred application on the tablet shows the 3D model of the digital twin, with other applications being utilised in order to retrieve information that is not part of the 3D model. When in the office, most informants reported that they prefer other programs that show a more detailed 3D model compared to what is available on the tablet. In the case of AR glasses, five informants in total reported having used the digital twin on that device, and only two of those five said that they use the tool on AR glasses regularly as part of their work. This is not an unexpected finding, as it could be explained by the fact that AR glasses are not approved for use offshore on installations that are in production. The two informants who reported that they use the digital twin in their everyday work are also the only two informants who work at an onshore location, rather than offshore.

Table 2

Overview of the tools informants use in their work.

	Tablet		PC		AR-glasses	
	Digital twin	**Other applications**	**Digital twin**	**Other programs with 3D-models**	**Have tried**	**Use regularly**
Number of informants (n =9)	7	5	5	8	5	2

Eight out of nine informants reported that they have received formal training in using digital twins. Formal instruction has taken place in different settings, but usually in group lectures or seminars, and has focused on instruction on how to use and navigate the digital twin. There have also been sessions focused on information exchange, where designers explain what features are available and users offer feedback on how they have experienced using the tool. Even though they have received formal training, most informants still pointed to *learning by doing* or colleagues sharing skills and knowledge as being more influential in their understanding of how to use the digital twin. Informant 2 said:

> Regarding the IT stuff, I have the impression that people learn the fastest from just fiddling around with it and trying to figure it out by themselves. Ask a colleague. It gets boring if you have to take a course, I think.

Several informants also suggested that having access to learning materials that could be used to learn at work in their own time would be more beneficial than formal instruction.

When asked what factors they believe could lead to increased use of the digital twin, informants highlighted the importance of confidence in their own abilities and applicability to their work. Informants stressed that it is essential to increase the user's confidence in using the digital twin, and most informants pointed to training and practice as being important for achieving. Several informants also pointed to experiencing the usefulness of the tool as being important for generating use. Informant 6 stated:

> The problem is often that it's difficult to use, and then people won't use it. It has to be simple, and there has to be some work tasks [it applies to] that match their job situation so that they benefit from it [the digital twin].

Experiencing first-hand how the digital twin can increase effectiveness to work and seeing the applicability to their own work tasks are seen as important for use.

Application of digital twin in the workplace. As mentioned previously, the digital twin is used on several different devices, which allows the tool to be used for various tasks depending upon the situation. Seven informants reported using the tool for the purpose of planning. Planning is usually done on a tablet or a computer ahead of starting a new work task or project. Six of the informants reported that they also use the digital twin to familiarise themselves with their surroundings as a part of the planning process. The implementation of the digital twin has also led to changes in communication and collaboration. All the informants reported that the digital twin has affected how they communicate with colleagues by allowing them to use the 3D model in the digital twin as a reference when discussing the system. A majority of the informants reported using the digital twin either for navigating and orienting themselves in their surroundings or for verifying work that was completed by others when they are in the field. Using the digital twin as a navigational aid is common because offshore installations are huge structures where the surroundings can be very uniform, making it difficult to stay oriented. Verification tasks are often dependent on detecting tiny components amidst vast machinery, such as specific pumps or valves. This procedure is made easier because the digital twin allows the informants to identify the equipment in the 3D model by searching for the allocated tag number, in turn making it easier to then find the component in the field.

The most significant effect of the digital twin is on the availability of information in the field. As 3D models could previously only be accessed on a computer in the office, the only external representations of the system available in the field were 2D drawings that the informants printed beforehand and brought with them. Informants stressed that the newfound availability of information has had a significant impact on their workflow. The digital twin has made it easier for them to obtain a better overview of their surroundings. Less paperwork needs to be printed and brought out into the field. The digital twin thus saves valuable time that previously would have been spent retrieving information that is now accessible in the field.

Experience and formation of internal representations. The notion of internal mental representations of their surroundings elicited different responses from the informants. When asked to describe his internal representations, one informant drew the comparison to watching a movie that is playing inside his head. Informant 2 explained that his internal representation is no different from what he would experience if he was walking around the installation:

> If I envision it, then it is more like where I've actually walked. This and that walkway, then I have the structure on that side and those things on the other side. I think about it

> as if I'm walking. Just like I'm walking in the streets outside. Then there's that house on that side.

Whilst some gave rich descriptions that drew parallels to other media such as movies or likened their internal representations to known activities, others employed a more unquestioning attitude towards their representations. When questioned about whether he felt that he had an internal representation of the construction site, Informant 4 simply stated, "I have been building since I was 16, so you form images of what it should look like."

What informants reported as included in their internal representations varies. Informant 6 described his internal representation as differing in degree of detail depending on his familiarity with the area:

> Well, it works on larger things. Big equipment, the shape of the room, larger components in the area, the big walkways around the platform. On specific things, however, there may be smaller components that I know where should be, where they should be based on how the system is built.

Three informants acknowledged that they often have a rough understanding of where different components are placed, pointing out that the construction site was too large to conjure a complete representation. Larger components and recently visited areas were generally seen as easier to recall than more detailed or less visited areas. A common reply from informants when questioned directly about their internal representations was that they are not able to produce detailed internal representations of the platform without some form of external representation. A total of six informants reported that they lack the detailed information necessary for a satisfactory internal representation, stressing the need for a fundamental understanding of the system in order to have an internal representation. Most informants appeared to be aware of the limitations surrounding their own internal representations, and a third of the respondents said that because of this, they rely on the digital twin for support.

Whether their internal representations are based on their perceptions of their physical surroundings or their understandings of 3D models varies. Most often, the informants reported that their internal representations are based on a mix of the two rather than one or the other. Informant 4 stated:

> For example... if there is a pipe going through a room, then I usually know what other equipment is in there. I've looked at drawings or the model and know what it looks like. So then you create an internal image of how it will be when you go out [in the field]. You think about potential hows and whats regarding the challenge you face or the problem you are set to solve. It helps that you've been in the model and seen what it looks like.

Whilst interaction with 3D models was reported as important for their overall understanding of the installation, the informants' experiences of their physical surroundings forms the basis for their understanding of the overall shape of a room and the location of larger components.

Digital twin's impact on internal representations. All nine informants agreed that the digital twin, with its 3D model, is important for the creation of their internal representations. The digital twin is seen as meaningful because it allows for interactions with the surroundings through the 3D model. This provides the informants with an opportunity to create an understanding of areas of the installation that are less accessible when in the field. As Informant 2 said:

> Maybe things that are not as visible from where you walk, for example, the exterior of the platform, then I rely more on the drawing. I have no possibility of getting a [mental] image of it otherwise.

Although the digital twin allows the informants to interact with surroundings that are not visually observable, such as the outside of the installation where they are not able to walk around, several informants still reported that personal experiences with their physical surroundings was important for how they understood 3D models. Informant 5 explained that:

> It [the model] is too rough, so that I cannot recognise my surroundings in the field just by studying the model. It works the opposite way. After studying reality, I can understand the model.

A pre-existing internal representation is useful in understanding and utilising the digital twin in their work tasks.

Several informants pointed out that their internal representations change over time. The informants reported that internal representations become more detailed as the informants become familiarised and more knowledge is obtained, which in turn leads to a more precise understanding over time. Informant 6 explained that:

> Earlier, I had an idea of how things would look based on the 3D model... Now, after I have walked around the platform for more than two years, from the first piece of steel until it was finished, then it's my memory of how things look and where equipment is placed. I remember quite a lot. It's the memory of all of that I use in my work today.

With the introduction of the digital twin, it is possible to create an understanding of the installation even before the construction is finished. By exploring the construction through a 3D model before it is built, the informants gain this understanding faster. This makes it possible to identify potential challenges earlier and better prepare for what they will discover in the field.

Informants drew parallels between the digital twin and other types of external representations they are used to using, such as 2D drawings. Whether informants reported that they found 2D or 3D more beneficial when creating internal representations varies. Informant 2 points to 3D models having an advantage over 2D drawings, as he finds them to be more easily interpreted:

> You get a better picture of the size of what you're working on and what it really looks like. I'm not very good at 2D drawings, or it takes an effort to go from 2D to 3D in my head. Then it's easier when it's already done for you.

All of the informants see benefits to having 3D models; however, only two informants explicitly said that they prefer 3D models to 2D. Informant 2 continued his explanation by arguing that you cannot compare 2D drawings with 3D models because they offer different types of information:

> I would say that a 3D model makes it easier to understand what you're going to look at, but in order to get the smaller details, you need to include drawings. And yes, check if the bolt holes are placed correctly and things like that. There are more details in a drawing.

Whilst 3D gives a better overview of the system, 2D-drawings are seen as necessary for understanding the smaller details, making them both important in forming internal understandings of the system.

Trust and reliability

When it comes to how informants rely on their own understanding and on the information they have access to, factors such as trust and reliability were highlighted as important. The following section outlines how informants experience trust as a factor when gaining understanding. Findings regarding the informants' perceived reliability in the tool and how they experience the user-friendliness of the tool are also presented.

Trust as a factor when gaining understanding. When answering questions regarding trust in their own competence, five informants reported having a great deal of confidence in their own capabilities, whereas three informants displayed a cautious attitude towards their own capabilities. Most of the responses regarding self-confidence reflected informants' subjective competence with using the visualisation tool. Informant 7 reported being confident in his own capability to use the visualisation tool and reflected that this was due to his knowledge of computers and technology in general:

> No, I am actually really confident. Because I see that it is built very basic, so if you have a decent knowledge about computers then…

The informants with a more cautious attitude pointed out that this was because they did not have enough experience with the tool. As Informant 5 said:

> … I am not familiar with all the applications [on the tablet], I haven't tried them all. I may not have felt that I need them. But then there is something about it. You don't always understand what you need because you don't know the benefits of it.

When talking about their confidence in own abilities the informants highlight their previous experiences with using similar tools as important.

When talking about trust in their own competence, most of the informants pointed out the importance of their previous knowledge. All but one informant expressed that they, to different extents, rely on their previous experiences when evaluating the extent of a problem and whether further actions are needed. One informant expressed that his experiences with and understanding of different systems and processes were decisive when dealing with potential issues and that the visualisation tool and the physical world were supporting tools. Informant 4 highlighted that his experience was important when evaluating whether a discrepancy between the physical world and the visualisation tool was something that needed to be examined or not:

> It depends on what I discover. If a support is located half a meter from what I see on the drawings, then it doesn't worry me. But if I see a valve or a pipe that has a thinner wall thickness, or a thicker [wall thickness] than what is in the field, then yes, I would be more scared, or not scared, but I would checked it further.

The trustworthiness of the visualisation tool was expected to play a role in how much the informants rely on the information they have access to while using the visualisation tool.

Eight informants reported that they trust the visualisation tool and trust that the information is up to date. However, informants reported that they trust the visualisation tool in some settings but not others. A contradictory finding was also uncovered regarding whether the informants verify information from the visualisation tool. Three informants said that they both do and do not verify the information. Seven of the informants reported that they trust drawings such as 2D documents more than the visualisation tool. Eight stated that they verify information from the visualisation tool with other documents. Informant 4's response is one example:

> It's probably the drawing I trust. Because that is the one that applies. The model may have been updated, but it is still the drawings that is the official [document]. The model can show whatever it wants, but it is the drawing that counts.

This could suggest that the informants place greater trust in 2D drawings than information from the visualisation tool.

Perceived reliability. Perceived reliability is regarded as the subjective reliability of the visualisation tool reported by the informants. We expected that informants that showed a lot of trust in the visualisation tools also perceived it as reliable.

The way the informants experience the visualisation tool depends on the tasks it is being used for, as different uses require different degrees of accuracy in the model. AR glasses are primarily used to identify deviations between the model and the physical structure, whereas tablets are used for navigating, documenting findings, and reviewing information. The majority of informants reported that the precision of the visualisation tool is appropriate; however, they pointed out that it is not as detailed as the real world and that some smaller items are missing. When discussing the tablet version, Informant 5 stated:

> After all, not everything is drawn in [the digital twin], especially smaller things. But it has matched very well so far. I'm really impressed with how well it has matched.

The informants using AR glasses reported that the model often drifts when walking so that it does not align accurately with the physical world. Informant 2 said:

> Well, I mean, there is so much information in the field, there are so many things there, so it is a little too slow maybe, gets a little too inaccurate…You get a 3D model layered on top of the structure, so it will always look a bit skewed because you can't get it perfectly aligned between the visualisation and reality.

In line with our expectations, all informants reported that 3D models make it easier to obtain a better overview of a situation, especially when working on a computer or when using AR glasses. Informant 7 stated:

> You'll get an overview much faster, because you just bring the helmet [AR glasses] in your bag and go down there [to the build site].

However, the model used on the tablet is not able to load enough of the surroundings when used in the field, which makes it difficult to obtain a clear overview of and orientate oneself in the construction site. Informant 5 reported:

> The tools are not really good enough because you're not able to see… you see a small section, and then it cuts off whatever is not in your immediate proximity. However, that makes you unable to orient yourself.

When looking into the perceived reliability of the tool, the tool's usability was expected to be an important factor. As such, we discussed features that impact the usability of the tool, as well as annoyances related to training and time waste. All the informants using AR glasses reported limitations in the ergonomic aspects of the design. They highlighted that the glasses were too heavy when used over a longer period of time, that the battery capacity of the glasses is poor, and that it is difficult to align the glasses in the field. This difficulty with aligning the AR glasses leads to feelings of wasted time. Informant 8 stated:

> I think it's probably a tool that's here to stay, and it'll probably become more like I want it to, regarding weight and user-friendliness and safety, easier to align. However, it might prove difficult with the alignment, though.

Three informants using tablets reported difficulties with navigating the model (e.g., with zooming) and stated that the application takes too long to load. Two of the informants also said that they found it annoying that the tablet cannot be used with gloves or when their fingers are cold. Informant 2 expressed:

> We're not there yet; the tablet is not always the easiest… With the tablet, you have to have two hands and touch the screen, taking off your gloves is troublesome, small things like that. A pen in your pocket and a piece of paper are much quicker then.

All the informants reported that they wanted more training in using the tool. Most informants had completed some form of training, usually in a one-day seminar, but they stated that this form of training were not useful, as different work tasks have different needs and use the application differently. Some informants wanted options where they could learn about the tool in their own time, as either an e-learning module or a manual, rather than completing training in a formal setting. Informant 2 said:

> I'd rather have it on a PDF, so I can look it up if I'm unsure about something, rather than sit for hours listening.

The instruction and training the informants' report having received was very limited, in which most informants request a need for improvement of the training provided.

Handling discrepancies between models

In this section, when examining how digital twins impact the way informants handle discrepancies between their representations, we first establish what type of discrepancies the informants experience. Second, we outline how the informants go about detecting, evaluating, and handling the discrepancies they discover. Finally, we present strategies that that informants have implemented in order to avoid limitations posed by the digital twin that impact these discrepancies.

We expected informants to talk about discrepancies between their internal representations and the digital twin or between their internal representations and their physical surroundings. Instead, we found that the informants exclusively reported on discrepancies between the digital twin and their physical surroundings. In general, they reported few discrepancies. When asked, several informants could not think of an instance where they had identified errors whilst using the model. They expressed that they are impressed with the accuracy of the digital twin. The discrepancies that informants did report were usually of little significance for system functioning and could easily be explained by technical limitations. Typical problems entail the digital twin not being updated, not being detailed enough, or only displaying limited areas of the construction. In the case of AR glasses, another issue is the model not being calibrated correctly, resulting in drift.

Detecting, evaluating, and handling discrepancies. When questioned about how he discovers possible errors or discrepancies, Informant 2 said:

> I either use drawings or the digital twin as a safe reference on how it should be... If someone claims that a place is too tight or an opening in the railing is too big or something like that, then you use that as a reference to how it should be, so that you have a picture of what it should be, either a drawing or 3D model or the digital twin.

The informants report using the digital twin as a guide. If the surroundings does not match the model, the digital twin as is used to decide if the discrepancy needs further investigation.

What source the informants believe offers the best guide varies. As mentioned previously, several informants use the digital twin as a guide in their work, but still verify information using 2D drawings and master documents. Only three informants reported that they rely on their own experiences and knowledge over the digital twin. Informant 5 stated that what offers the best guide depends on the situation:

> If there's a system you need to understand and you go out [in the field] to look at it and only see a lot of pipes, you can't understand what is really happening there. But then you have an internal representation of how this process must work. If there is a tank that connects to a valve that continues to a regulation, then I know how this type of regulation must work. I sort of have a model that allows me to identify the pipes I see and can understand pretty quickly how thing are connected.

One informant suggested that his preference for his own knowledge can be tied to him primarily working in the field; he then went on to say that different professions might prefer other representations that they are more exposed to, such as engineers preferring 3D models and 2D drawings. In general, however, the informants reported that a combination of their own internal representations and experiences, the 3D model presented by the digital twin, and 2D drawings is necessary in order to efficiently handle discrepancies that are discovered.

When faced with discrepancies, the informants reported that they try to evaluate and resolve the problem in the field. Several informants named experience as being important for the process of detecting and evaluating discrepancies. One informant who specialised in piping noted that many of the systems are similar across platforms, which makes it possible to identify deviations. These deviations are, however, often a result of conscious decisions, made in order to account for system-specific problems. As such, they do not constitute an actual problem in the system. Whether the informants verify the discrepancy is, as mentioned previously, dependent upon the perceived severity of the problem that has been discovered. In the case of smaller discrepancies, informants reported that they rely on their experience and the available information in the field to decide on further actions. Informant 5 explained that relying on his internal representation is effective:

> If you see something in reality that doesn't match your model, then you need to update the model in your head so you have the correct model. This way, you can become very efficient.

The informants' evaluations of the discrepancies seem to largely be based on experience, which in turn informs whether further actions are taken. If, however, a discrepancy is hard to resolve or evaluate in the field, informants reported that they verify the disparity with another information source. Informant 1 stated:

> If I discover something in the field, I would likely take a picture of it, take a picture with the tablet and bring it back inside to have a look at it, check the 3D model and drawings. Or maybe the choice of material: why have they used those bolts there, that was a bit strange, and that sort of thing. Then you look at the general procedures for, we have a structure document, how the structure should be built, the bolts we usually use… But I usually start to look at it in the field, take a picture, get into the office, start to dig through the documentation and procedures.

Several informants stated that in case of any uncertainty, they always double-check against another source (e.g., 2D drawings or a 3D model on a computer) to verify a problem or discrepancy. Most of the informants pointed to 2D drawings as being the master document giving the definite answer of how the site is supposed to be.

Strategies employed when using the digital twin. As the digital twin has been implemented, it has replaced the use of drawings to some degree. Through the course of the interviews, several informants raised questions themselves regarding possible limitations in the use of the digital twin. Informant 1 reported that his use of 2D drawings has decreased following the implementation of the digital twin; however, he went on to suggest that this could affect the identification of errors:

> I use floor plans a lot less now. Now I mostly use the model, so if the model is not correct, it may take longer before you discover that the drawing is wrong.

Not discovering the errors in the drawings is one possible downside of the increase in use of the digital twin. This concern was echoed to a degree by Informant 2, who pointed out that he can be too fixed on the information provided by the digital twin:

> You can get a bit stuck in the 3D model. That's what it should look like or the way it should be, but there could also be an error there. You become very tied to that medium. It can be like that with drawings too. If the drawing is incorrect, then you can perceive things wrong, so perhaps the risk is the same as before.

The informants are aware that external visualisations have potential limitations when it comes to error detection. The majority of our informants reported that in order to avoid these challenges with the digital twin, they have adopted new strategies or behaviour. These strategies serve to prevent potential mistakes or to minimise perceived discrepancies between models, allowing for more effective use of the digital twin. However, as mentioned earlier, the types of trouble the informants reported depend upon the device they use.

One feature that is available when the digital twin is used on the tablet enables the user to remove layers of the model. By using this feature, an informant can decide to only display the piping system or to remove any distracting structures in order to find the nearest escape route. Informants reported that this can be useful for simplifying a complex system. Informant 5 said:

> There are some techniques [filters]. You can show just one system, for example, a pipe system... You can remove everything and only show oil pipes, and it looks like a spider web because it is so complex. But it can be helpful in some cases to know where the pipes are going.

Features such as these allow informants to break down the complexities of the system, providing a new perspective of the workings of the system. However, informants also raised concerns regarding features such as these. Informant 2 pointed to the limited picture provided by the digital twin:

> You might get a small picture of what you're going to look at, if you look at the model and then you only look at the equipment. But there can be lots of things around that makes you lose focus. You might use the magnifying glass a bit too much. Maybe you get blind. The focus is only on details so that you lose the big picture.

The main problem informants reported with the use of AR glasses was the tendency for the model not to align properly with their physical surroundings. The informants using the AR glasses in their daily work assignments reported several different strategies that they have developed in order to counter this effect. Informant 7 reported that, to avoid drifting, he tries to limit his movements when wearing the helmet:

> We stand in a place where we manage to check a lot at once. Then when we move, we take it off and put the other [protection] helmet on, and then we move and put it [helmet with AR glasses] on again.

Informant 8 reported that he deals with the drifting by aligning the model regularly, making sure that it does not drift too much over time. However, he stressed that this process can be time-consuming and that he sometimes uses a more time-saving strategy:

> But it's a bit like that you get less strict, is that the correct way to say? You see that it's acceptable and okay, or shall we say, "good enough".

The informants using AR glasses generally reported finding few discrepancies that are not a result of drifting. If they encounter a real problem, however, it is usually easy to separate from drifting. If they are unsure, they always verify a suspected problem.

Discussion

The following section outlines how the findings we have presented can be regarded, considering the theoretical framework discussed previously. In doing so, we seek to further enlighten the question of how digital twins impact the users' mental models.

Elicitation of mental models

Throughout the study, we found that it was challenging to induce the informants to offer detailed descriptions of their internal representations. Other studies where qualitative interviews have been used have not reported this as a problem to the same extent (Kalantzis, Thatcher, & Sheridan, 2016; Tullio, Dey, Chalecki, & Fogarty, 2007). Kalantzis and colleagues (2016) supplemented their interviews with a visual task where interviewer and interviewee collaborated in creating a diagram of the system they were interested in. In the study by Tullio and colleagues (2007), the researchers supplemented their interviews with field observation. It is plausible that a visual diagram or a more natural setting makes it easier to elicit detailed descriptions from the informants, as there is less need for the informants to recall previous behaviours and thoughts. A study conducted by Jones, Ross, Lynam, and Perez (2014) found that a diagrammatic-oral interviewing technique does not have a significant impact on the elicitation of mental models. However, the study indicated that when informants are interviewed in a natural setting, they use more concepts and are more specific when describing their mental models compared to in interviews in a more controlled environment. This supports the notion that location is an important factor when describing mental models.

During the interview, the informants generally did not refer to their descriptions or expressions as *mental models*, but rather used related terms such as *internal representation*, *mental image*, *knowledge* or simply *experience*. We perceive all these to be oral accounts of their mental models, as they express their internal representations in terms of their function: to describe, explain, and predict the system. This follows Rouse and Morris's (1986) definition of a mental model. When our informants described their internal representations, they used examples and relied on imagery from everyday life (e.g., likening their internal representations to watching a film or to the experience of walking around and observing their surroundings). These descriptions correspond with the general idea that mental models mirror the structure they represent (Johnson-Laird, 2004). Following Held (2006), what separates these descriptions from internal images is the function they have. In our current study, the informants reported that their internal representations have a purpose, for example to aid when navigating in their surroundings

In order to save resources and be useful, mental models must be simpler than the structure they represent and are therefore built on partial pieces of evidence (Besnard et al., 2004; Johnson-Laird, 1983). Our informants reported that their mental models vary in detail. Whilst some find it hard to create a model of the construction site at all, others pointed out some areas of the construction site as being easier to recall than other areas. The informants pointed to factors such as recency and familiarity influencing the detail of their mental models. One possible explanation for this is that because mental models are created in the working memory, the degree of detail in the models depends upon memory retention. Factors such as recency, duration, and amount of exposures have an influence upon memory retention that has been well-established (Miller & Miller, 1976). It is therefore feasible that recency and exposure impact the degree of detail in mental models created in the working memory. Informants also reported that familiarity with different areas plays a part in how detailed their mental models are. They stressed that their models become more detailed as they become more familiarised with their surroundings. Hegarty and colleagues (2013) demonstrated that, in a school learning setting, mental models change over time, becoming more complex and detailed. This supports our findings of familiarity having an impact on the detail of mental models.

The impact of the digital twin

The digital twin has impacted several aspects of our informants' work. The digital twin is used across different devices, allowing the tool to be used for different tasks depending on the situation. The biggest difference posed by the digital twin, according to our informants, is the availability of information in the field. This saves time and makes work more effective, supporting Dzindolet and colleagues (2001) notion that they function as a human-computer team. Whereas AR glasses has limited utility, because it requires the user to be in a specific location, the tablet allows the users to access the digital twin from any location, both offshore and onshore. This makes it difficult to compare the impact of the digital twin across devices, as it is used for different tasks and purposes. For example, our informants report using the digital twin on tablet as an aid when communicating with others, whilst this is not possible when using AR-glasses as only one person can view the model at a time. Therefore, the digital will have a different impact depending on which device it is accessed, this could, in turn, lead to differences between our informants' experience of using the digital twin.

The digital twin is an external representation that can facilitate the understanding of a system (Greca & Moreira, 2000). All the informants reported that the digital twin plays an important part in creating their internal representations. The 3D model is intuitive in its representation of information, making the digital twin a valuable tool for enhancing understanding (Gramss et al., 2008; Larkin & Simon, 1987). Some informants reported 3D models to be easier to interpret, which is likely due to its explicit and intuitive way of representing information (Larkin & Simon, 1987; Smallman et al., 2001). However, there were large differences in the informants' work tasks and their reasons for using the digital twin. Some informants use the digital twin to look for discrepancies and verify work, whereas others use it primarily for navigation and finding components. As several informants pointed out, the 3D model available in the digital twin is not detailed enough. For smaller details and specific information about components, the informants prefer 2D drawings or written information. Previous studies have indicated that exposure to different types of conceptual models corresponds with the formation of different mental models (McDougall et al., 2001). This could explain why the informants prefer different conceptual models depending on the task.

Studies examining the difference between 2D and 3D visualisations have yet to yield a conclusive result that favours one type of visualisation over the other. Smallman and colleagues (2001) found that users often prefer 3D over 2D due to its familiarity and simplicity. However, a study by Gramss and colleagues (2008) found that participants generally perform better when using 2D visualisation. In our study, there were mixed responses regarding whether informants found 2D or 3D visualisations to be more beneficial when forming mental models. However, our sample included both engineers and production workers. Whilst engineers are used to working with 3D models on the computer, workers involved in production and maintenance have until recently used 2D drawings as their main source of information. It is therefore possible that the mixed response expressed by the informants could reflect the users' familiarity with 3D visualisation.

Trust and reliability. The perceived trust of the digital twin is one of the most critical psychological factors influencing the operators initial use of the system (Dzindolet et al. 2001). This trust is determined based on a comparison process between trust in the tool and trust in one's own abilities (Dzindolet et al., 2006). Our informants reported various degrees of confidence in their own capabilities when using digital twins. Some reported being highly confident, whereas others portrayed a more cautious attitude. Several of the informants linked their confidence to previous experience with technology and similar tools. Previous studies have demonstrated that individuals with high technological familiarity use new technology faster and utilise it in a better way compared to those with less familiarity (Blackler, Popovic, & Mahar, 2003a; Blackler, Popovic, & Mahar, 2003b). However, high self-confidence in their own capabilities could also make the informants vulnerable to underutilising the digital twin and thus not recognising the possible benefits of the aid (Dzindolet et al., 2006).

Regarding the trustworthiness of the digital twin, almost all the informants reported trusting the information they received from the tool. However, half of them also reported double-checking information received from the digital twin. These contradictory findings could suggest that informants' trust in the digital twin depends on their aims and work tasks. The informants seem to trust the digital twin with low-risk tasks, such as navigating or planning. However, the informants verify information from the digital twin with other information sources when tasks involve more complex decision-making. Based on these accounts, it seems as though verifying information with other sources may be due to the routines and the precarious nature of HROs. 2D drawings require more computational effort to interpret (Schweizer et al., 2009), as the informants' attention has to be more focused when using 2D visualisations (Gramss et al., 2008). 2D visualisations could therefore seem to be a more correct information source when the difference is actually due to the increased focus of attention. This could explain why most of the informants reported trusting 2D visualisations more than the 3D visualisation.

Perceived reliability of a digital twin can impact use of the tool and is thought to be related to perceived trust in the tool (Dzindolet et al., 2006; Parasuraman & Riley, 1997). Informants generally reported that they perceive the tool to be accurate, making it reliable. When using the interactive 3D model on the tablet, they expressed that there sometimes is too much information, making it difficult to find what they are looking for. To address this, the informants expressed that they have developed strategies like using the filter function on the tablet to scale backing layers and obtain a better overview. Informants using AR glasses reported difficulties when calibrating and aligning the 3D visualisation with the physical world. As they move around, the 3D visualisation drift, making it difficult to detect discrepancies. The strategy they employ to deal with this involves lowering their sensitivity for errors (i.e., letting smaller discrepancies pass without follow-up). This strategy could be detrimental to safety, as users might overlook potential biases and pitfalls that could lead to real problems going undetected (Baxter et al., 2007).

The users' trust and perceived reliability of the tool and own abilities determines their perceived utility of the tool (Dzindolet et al., 2006). Our informants reported various degrees of confidence in own abilities, depending on their experience with technology. As mentioned above we found contradictory attitudes regarding the informants' trust in the tool. These contradictory findings make it difficult to say anything about our informants' utility of the tool as their confidence and trust in the tool varies depending on the aim and work task. To utilise the tool correctly, it is important that the users evaluates the reliability of the tool, as well as own abilities, appropriately. In order to aid the users in making correct judgements about the tool, sufficient training and instruction is therefore important.

Instruction and training. It has been suggested that sufficient training during the implementation phase can ensure safer and better use of new technology (Janssen et al. 2019). Training allows users to become aware of potential biases and to learn to recognise and prepare for situations in which they are prone to these biases (Mosier & Skitka, 1996). Rouse and Morris (1986) propose that instruction is useful in forming mental models, as it provides the learner with necessary knowledge and skills. Despite this, the majority of informants in our study reported that the instruction they have received has little effect on their understanding of the digital twin and, consequently, of their surroundings. Our findings indicate that almost all the informants are discontented with the training they have received in using the digital twin. This may mean that they have not received sufficient instruction and training in the implementation phase, making them unaware of the typical cognitive pitfalls related to using the tool.

The informants wanted to receive training in various ways. Whilst some wanted more formal training like tutorials, others expressed desire for an e-learning course or a pdf booklet where they could find the information they needed. This could be explained by the nature of the instruction that has been provided, which informants reported to be basic with a low degree of novelty. Following Blackler and colleagues' (2003a; 2003b) studies on technological familiarity, the informants' levels of familiarity with similar tools could further explain their preferences for learning by doing. Hegarty and colleagues (2013) demonstrated that learning supports mental model formation. Well-designed training programs could in turn lead to better decision-making in critical situations.

Relationship between mental models and the digital twin

Regarding the relationship between mental models and the digital twin, several informants stressed that having pre-existing mental models, based on the physical surroundings, was useful when operating and understanding information from the digital twin. Our current study found no support for the augmented view of mental models. Our informants highlight their mental models as important for interpreting information, making it inconceivable to believe that the digital twin alleviates the need for mental models. Both Neisser (1976) and Hestenes (2006) suggest a reciprocal, cyclical relationship between an individual's perception of their surroundings and their actual surroundings. The cyclical view of the relationship is supported by our informants, as they point out that their internal representations change over time. As previously mentioned, factors such as recency and exposure are important for the detail of the model, this could indicate that the users' mental models are updated when new information is received. One informant even stated that when encountering things in reality that did not match the model in his head, he would consequently update his mental model to fit with the new information.

Several of the informants reported that they have experienced few instances where the digital twin does not match the physical surroundings. This suggests that the digital twin matches the physical surroundings well. However, the implementation of a digital twin is a recent development that most of the informants have little experience with. This could influence the detection of errors, either through lack of exposure or through other factors, such as difficulties using the digital twin. Baxter and colleagues (2007) state that cognitive mismatch can be either detected or undetected. Several studies have suggested that there is a margin of error in a human operator’s error detection (Besnard et al., 2004; Kontogiannis & Malakis, 2009). This could mean that real errors are going undetected, whilst perceived errors are being detected. Undetected errors are, in their nature, harder for informants to report on, as they are usually oblivious to their existence. However, several of our informants raised questions regarding the implementation of a digital twin and its impact on their detection of errors.

A majority of the research done on error detection and mental models comes from the context of aviation (Baxter et al., 2007; Besnard et al., 2004; Kontogiannis & Malakis, 2009), where critical situations arise quickly, resulting in time pressure. Informants in our study did not mention time pressure as a factor when encountering discrepancies. Instead, several informants stated that in case of any uncertainty concerning detected discrepancies, they always double-check against another source. This supports the notion that HROs favour a high false alarm rate over potentially missing a real event, which could bring about catastrophic outcomes (Aven & Krohn, 2014).

Several informants recalled experience as being important for detecting and, especially, for evaluating discrepancy. Some informants reported that they rely solely on their experiences gained from interaction with their physical surroundings. However, most informants stressed that their experiences are the product of information gained from several sources (e.g., the digital twin, drawings, and physical surroundings). Studies have supported the view that mental models of physical systems involve interplay between a range of representations and strategies, from the more imagistic to the more abstract (Hegarty, 2004a; Hegarty et al., 2013). This is not to say that the mental models created from different types of representations are similar to each other. Learners seem to construct different mental models of the same learning content depending on the kind of visualisations presented (Schnotz & Kürschner, 2008). This has led to the suggestion that mental models are differently suited for different tasks. The informants taking part in our study have different work tasks and are concerned with different parts of the system. This could be the reason why they rely on different representations when constructing mental models.

Methodical considerations

Our study had to be carried out while adhering to a preconceived timeline. This led to some practical limitations that are important to address when considering our findings. We consider the inconsistency in data collection to be another limitation with our study. Whilst some interviews were conducted face-to-face, others were done over Skype. This was deemed necessary, as most informants were either offshore or at other locations spread around the country, and the benefits of doing face-to-face interviews with the informants would not have outweighed the cost. Consequently, some of the interviews were subject to faulty connections and interruptions that could have had an impact on the quality of the interview.

An issue regarding our study that could have affected the results is that our sample was not random and the way informants were recruited allows for the possibility of bias. The informants were asked by their supervisor to volunteer for the study, meaning that the informants who agreed to participate were likely to be the ones who had a special interest in the new technology. The fact that it was their supervisor asking them to participate could also have affected their willingness to volunteer. Generalisability refers to the transferability of data, or the extent to which the findings of our study are applicable to other settings. Qualitative research does generally not allow for generalisation of findings to other populations and contexts (Robson, 1993). Rather than measuring the impact of digital twins on mental models, our study explored how users experienced the implementation of the digital twin and its impact on their mental models.

In qualitative studies, validity refers to the *appropriateness* of the tools, processes, and data (Leung, 2015). Mental models are unconscious processes, which poses a great problem for the researchers, as it also makes them unobservable. Rouse and Morris (1986) state that the *black box* of human mental models will never be completely transparent. In our study, we chose to take a qualitative approach to the topic, allowing the informants themselves to explain how they experience their mental models. Norman (1983) suggests that simply asking participants is less reliable than collecting data in a situational or problem-solving context, as people are generally unable to fully articulate their knowledge. One way to validate and expand on the informants' mental models would be to conduct a second study where the informants are observed in the field. This would, however, not overcome the problem of separating the researchers' mental model from the informants' mental model. It is near impossible to avoid some degree of interpretation and bias when studying unobservable processes.

In qualitative research, reliability refers to the exact replicability of the processes and the results (Leung, 2015). Interrater reliability is an important measure, as it represents the extent to which the data collected in our study are correct representations of the variables measured. As our interview data were subject to more than one coder, it is possible that interpretation of the informants' interviews differed between the researchers. It was therefore important to establish to what degree the coders agreed. The overall agreement between the two coders demonstrated a Cohen's Kappa Coefficient of 0.549, which is deemed a moderate agreement following the standards suggested by Cohen (1960). The overall agreement percentage, however, was found to be very high, at 96.8 %. Cohen's Kappa is often favoured as a measure of interrater reliability because it considers the possibility of chance agreement (Cohen, 1960). However, McHugh (2012) suggests that it is not useful to look at Cohen's Kappa without considering the agreement percentage, as there are strengths and limitations to both statistics. He argues that whilst the agreement percentage tends to overestimate the agreement between researchers, the kappa statistic tends to underestimate it. It is conceivable that more operationalised and fewer codes could ensure a higher Cohen's Kappa in this study. However, when the agreement percentage is considered, the overall interrater reliability seems to be at an acceptable level.

Further research

In order to fully understand the impact a digital twin has on users' mental models, it would be meaningful to supplement our study by conducting a second study. Triangulation has been identified as an appropriate approach for ensuring validity in qualitative studies, as it gathers information from several data sources (Patton, 1999). This allows for a comprehensive understanding of the phenomena under investigation. By examining the digital twin's impact using an additional research method, such as field observation, we would be able to further validate our findings. Other studies concerned with mental models have seen beneficial results using this procedure (Tullio et al., 2007). Jones and colleagues (2014) found that a natural setting is conducive to informants giving detailed descriptions of their mental models. A second study, conducted in a more natural setting, could benefit informants' ability to give a comprehensive answer to questions regarding their mental models.

Our study focused on the impact a digital twin has on users' mental models. In this, we discovered that the digital twin in question is used differently across devices and work tasks. Using the digital twin for verification with a tablet is not the same as with AR glasses. Each device the digital twin is used on provides a unique set of challenges to cognition and mental models. McDougall and colleagues (2001) found that different types of conceptual models correspond with the formation of different mental models. Whilst AR glasses provide users with visual information superimposed on the real world, tablets offer interactive 3D models where the user has to seek out information. The representation offered by AR glasses and tables are very different, which could potentially impact users' formation of mental models. In order to fully understand the implications the digital twin has on work, future research should investigate how the digital twin impacts mental models when used across different devices.

Conclusion

This study aimed to identify how the implementation of a digital twin impact users' mental models in an HRO. The findings suggest that implementation of a digital twin has aided users' mental models and led to more effective decision-making, through more availability of information. However, in more complex cases, e.g. when encountering discrepancies, the implementation of the digital twin has led users to compare and question their mental models of the system. A HRO requires a high degree of safety, a problem going undetected in this industry could have huge implications and lead to potentially catastrophic outcomes.

Based on a qualitative approach, digital twins have been found to influence users' mental models in several ways. First, the digital twin has impacted the formation of users understanding of their surroundings. The digital twin represents an additional information source that can be a useful aid in decision-making. However, it can also present a competing representation of the physical world that complicates an otherwise uncomplicated task. Second, users' trust in themselves and the reliability of the tool has been identified as important factors that influence the use of digital twins. Perceived trust and reliability varied greatly between informants, which influenced whether the information received from the digital twin was perceived to require further verification. Third, the digital twin has impacted how users challenge discrepancies between their own mental models and their surroundings. Instead of being a guide when encountering discrepancies, the use of a digital twin has led to the identification of more perceived errors that subsequently require further investigation.

Mental models are internal and unconscious processes that play out in the mind of individuals, which in turn make them difficult to study. We echo the frustration of previous researchers, who have suggested that mental models will never be fully transparent processes (Rouse & Morris, 1986). A qualitative approach to the study of mental models was chosen to ensure the users' descriptions in the exploration of their own mental models. Eliciting the full scope of a user's mental models in the duration of one interview proved challenging. We still believe we have made a useful contribution to the exploration of mental models, as we let the users themselves express their experience with the digital twin, and by honouring their statements. The current study, shows that the mental models presented by the informants, varied depending on which tasks they use the digital twin. This makes it evident that mental models are unique for every situation and individual.

The general attitude toward digitalisation, displayed by the informants, was that digitalisation should not happen only for the sake of digitalisation. There seemed to be a consensus that digitalisation should lead to work becoming more effective and ensure easier access to information. Based on this it could be meaningful to review the training and instruction procedures for use of the digital twin. Tailoring training and instruction specifically to the different disciplines that use the digital twin, could lead to more users being aware of the potential benefits of using the tool. Training could also inform users of the potential biases and pitfalls that could influence their decision-making when using the tool, in turn, minimising the risk of future errors. Adapting the specificity of training and its degree of difficulty, to account for users' individual differences, could ensure better and subsequently safer use of the digital twin.

It has been suggested that the role of research should be to observe how technological changes transform cognitive activities and demands, and how people in turn adapt to those changes (Woods & Dekker, 2000). The current study sheds light on the relationship between users' mental models and the conceptual models provided by a digital twin. The relationship between digital twins and mental models is an area of research that has not been explored extensively. Technology and design are evolving and transforming at a rapid rate. This makes it challenging for research to adapt to the constant development and in turn uphold its role in ensuring that the design maintain its intention. An unintended consequence of this could that the safety and effectiveness of new technological tools is weakened. Future research on the impact of digital twins is therefore needed, in order ensure the effectiveness of new tools.

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Appendix A. Information sent to informants prior to interviews

Intervju om bruk av Digitale visualiseringsverktøy

Dette er et spørsmål til deg om å delta i et forskningsprosjekt om bruken av digitale visualiseringsverktøy, på PC, tablet eller AR-briller. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg. Formålet med prosjektet er å undersøke om digitale visualiseringsverktøy påvirker måten man danner seg en forståelse av arbeidet og omgivelsene sine.
Studien er en del av en masteroppgave i kognitiv psykologi, ved Universitetet i Bergen. Oppgaven skal bidra til å se nye muligheter og bedre løsninger for bruk av digitale visualiseringsverktøy. Dataen som blir samlet inn kan være grunnlag for videre forskningsprosjekter ved det psykologiske fakultet ved universitet i Bergen.

Hvem er ansvarlig for forskningsprosjektet?

Det psykologiske fakultet ved Universitetet i Bergen er ansvarlig for prosjektet. Masterstudentene Synne Wiberg og Aina Møller skal gjøre intervjuer og analyse, mens førsteamanuensis Bjørn Sætrevik er ansvarlig forsker.

Hvorfor får du spørsmål om å delta?

Vår kontaktperson i selskapet har foreslått personer som kan være relevante å ha med i prosjektet, basert på arbeidsfelt, arbeidsmetode og erfaringer. På bakgrunn av dette ser vi deg som en god kandidat for prosjektet.

Hva innebærer det for deg å delta?

Vi ønsker å gjøre et 60-90 minutter langt intervju med hver deltager, over video-konferanse eller ansikt-til-ansikt. Intervjuet vil inneholde spørsmål om hvordan du bruker digitale visualiseringsverktøy i arbeidet ditt, dine erfaringer knyttet til bruken av digitale visualiseringsverktøy og hvordan dette har påvirket måten du jobber på. Det vil bli tatt lydopptak og notater fra intervjuet. Etter dette vil lydopptaket bli slettet og transkriberingen vil ikke inneholde informasjon som kan identifisere deg som enkeltperson.

Det er frivillig å delta

Du velger selv om du vil delta i prosjektet, og kan velge å trekke deg fra intervjuet også etter at det er i gang eller fullført, uten å behøve å oppgi noen grunn. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg, og det vil ikke bli delt med arbeidsgiver eller med de andre i arbeidsforholdet ditt hvem som deltar eller ikke.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- Det er kun masterstudentene og prosjektveileder som vil ha tilgang til innsamlet data.

- Vi vil ikke lagre ditt navn eller kontaktopplysninger sammen med intervjuet, og disse vil slettes når prosjektet er ferdig. Opptakene og notater lagres i henhold til retningslinjer for etikk og personvern hos UiB og NSD.
- Anonymiserte utdrag fra intervjuer kan bli en del av vitenskapelige publikasjoner og vil bli delt med arbeidsgiver i den ferdigstilte masteroppgaven og i en eventuell presentasjon av prosjektresultater. Du som enkeltperson vil ikke kunne bli gjenkjent i det som deles. Vi ønsker å undersøke trender blant innsamlet data og dine utsagn som enkeltperson vil ikke være fokus for vår forskning.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Prosjektet skal avsluttes 31.12.2020. Da slettes din kontaktinformasjon og lydopptak fra intervjuene, mens notater og analyser beholdes.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg,
- å få rettet personopplysninger om deg,
- få slettet personopplysninger om deg,
- få utlevert en kopi av dine personopplysninger (dataportabilitet), og
- å sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.
På oppdrag fra Universitetet i Bergen har NSD – Norsk senter for forskningsdata AS, vurdert at behandlingen av personopplysninger i dette prosjektet (referansekode 225336) er i samsvar med personvernregelverket.
Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Det psykologiske fakultet, Universitetet i Bergen ved prosjektansvarlig: Bjørn Sætrevik, bjorn.satrevik@uib.no, masterstudentene: Synne Wiberg, synne.wiberg@student.uib.no, Aina Møller, aina.moller@student.uib.no
- UiBs personvernombud: Janecke Helene Veim, personvernombud@uib.no
- NSD – Norsk senter for forskningsdata AS, på epost (personverntjenester@nsd.no) eller telefon: 55 58 21 17.

Med vennlig hilsen

Bjørn Sætrevik	Synne Wiberg	Aina Møller
Prosjektansvarlig	Masterstudent	Masterstudent

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet digitale visualiseringsverktøy og mentale representasjoner, og har fått anledning til å stille spørsmål.

Jeg samtykker til å delta på intervju og at mine opplysninger behandles frem til prosjektet er avsluttet, ca. 31.12.2020.

(Signert av prosjektdeltaker, dato)

Ved å signere samtykker du til å delta. Du kan beholde dette skrivet i tilfelle du ønsker å sjekke noe av informasjonen eller kontakte oss på et senere tidspunkt.

Appendix B. NSD confirmation

2.3.2020 Meldeskjema for behandling av personopplysninger

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Masteroppgaveprosjekt om visualiseringsverktøy og "mentale modeller"

Referansenummer

225336

Registrert

20.11.2019 av Synne Wiberg - Synne.Wiberg@student.uib.no

Behandlingsansvarlig institusjon

Universitetet i Bergen / Det psykologiske fakultet / Institutt for samfunnspsykologi

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Bjørn Sætrevik, Bjorn.Satrevik@uib.no, tlf: 99316588

Type prosjekt

Studentprosjekt, masterstudium

Kontaktinformasjon, student

Synne Wiberg, synne.wiberg@student.uib.no, tlf: 94804762

Prosjektperiode

25.11.2019 - 31.12.2020

Status

09.12.2019 - Vurdert

Vurdering (2)

09.12.2019 - Vurdert

NSD har vurdert endringen registrert 05.12.2019.

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg den 09.12.2019. Behandlingen kan fortsette.

Endringen gjelder at det er registrert i meldeskjema at Microsoft via Sharepoint er databehandler i prosjektet. NSD legger til grunn at behandlingen oppfyller kravene til bruk av databehandler, jf. art 28 og 29.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp underveis (hvert annet år) og ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet/pågår i tråd med den behandlingen som er dokumentert.

Lykke til med prosjektet!

Kontaktperson hos NSD: Jørgen Wincentsen

Tlf. Personverntjenester: 55 58 21 17 (tast 1)

21.11.2019 - Vurdert

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg 21.11.2019. Behandlingen kan starte.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde:

https://nsd.no/personvernombud/meld_prosjekt/meld_endringer.html

Du må vente på svar fra NSD før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige kategorier av personopplysninger frem til 31.12.2020.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake. Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a.

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

- lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke behandles til nye, uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: åpenhet (art. 12), informasjon (art. 13), innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), underretning (art. 19), dataportabilitet (art. 20).

NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Dersom du benytter en databehandler i prosjektet må behandlingen oppfylle kravene til bruk av databehandler, jf. art 28 og 29.

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og/eller rådføre dere med behandlingsansvarlig institusjon.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!

Tlf. Personverntjenester: 55 58 21 17 (tast 1)

Appendix C. Interview guide

Informasjon gitt muntlig

Hvorfor er vi her?

- Vi jobber med en masteroppgave i kognitiv psykologi ved universitetet i Bergen. Denne skal handle om hvordan digitale visualiseringsverktøy, på PC, tablet eller AR-briller, kan påvirke måten man danner seg en forståelse av arbeidet og omgivelsene sine.
- Vi håper masteroppgaven vår kan bidra til å se nye muligheter og bedre løsninger for bruk av digitale visualiseringsverktøy.

Hva er vi interessert i?

- Derfor er vi interessert i å høre om dine erfaringer med å bruke visualiseringsverktøy i arbeidshverdagen din.
- Vi har et psykologisk perspektiv, og er derfor opptatt av hvordan måten du løser oppgaver på blir påvirket av digitaliseringsverktøy, heller enn de tekniske aspektene hvordan visualiseringsverktøyet fungerer.
- Vi har ikke bakgrunn i oljevirksomhet, så vi håper derfor at du vil være tålmodig om vi misforstår noe eller ber om ekstra forklaringer. Si fra underveis om vi trenger å være tydeligere i våre spørsmål, eller om du lurer på hva hensikten med spørsmålene er.

Informert samtykke

- Anonymt, frivillig (ingen tvang) og deltakere kan trekke seg når som helst før, under og etter intervjuet.
- Utdrag fra intervjuene vil bli delt med arbeidsgiver, og kan bli del av vitenskapelige publikasjoner. Vi vil passe på at du som enkeltperson ikke vil kunne bli gjenkjent i det som deles.
- Det vil bli gjort lydopptak av intervjuet, som videre blir transkribert. De eneste som har tilgang på dette er studentene (Synne Wiberg og Aina Møller) og veileder i prosjektet Bjørn Sætrevik.

Demografisk bakgrunn

- Hva er din rolle i prosjektet?
- Hvor lenge har du jobbet i bransjen?
- Hvor lenge har du vært knyttet til det nåværende prosjektet?
- Har du brukt visualiseringsverktøy, eller lignende 3D-modeller/ tegninger, i tidligere prosjekter?

Intervjuguide

1. **Hvordan bruker du digitale visualiseringsverktøy) i arbeidet ditt?**
   - Hvilke digitale visualiseringsverktøy bruker du? (digital tvilling på mobil / tablet / pc, AR-briller...)
   - (Har du fått trening i bruk av visualiseringsverktøy/ disse verktøyene?)
   - Hvor trygg er du på din egen kompetanse når det kommer til bruk av disse visualiseringsverktøyene?

2. Hvordan har digitale visualiseringsverktøy påvirket arbeidet ditt, sammenlignet med slik du jobbet i tidligere prosjekter der du har vært uten denne støtten?

- Hvilke oppgaver gjør du i dag forskjellig?
  - Hva er forskjellen?
  - Blir resultatet forskjellig?
  - Får du bedre oversikt? For eksempel å ha tilgang til 3D-modeller versus 2D-visninger på skjerm eller papirbaserte plantegninger.
- Hvordan ville du gått frem for å gjennomføre arbeidet ditt hvis du ikke hadde visualiseringsverktøy?
- Har du sluttet å gjøre noe på bakgrunn av visualiseringsverktøy?

3. Hvordan bruker du visualiseringsverktøy til å finne informasjon du stoler på?

- Hvordan tester du informasjonen du får fra visualiseringsverktøy?
  - Eksempel: dersom du merker avvik, hvordan verifiserer du det?
- Føler du deg tryggere på at du har lest/forstått plantegningene riktig, nå med visualiseringsverktøy enn det du gjorde uten?
- Hvordan oppdager du feil / uoverensstemmelser på konstruksjonen ved hjelp av visualiseringsverktøy?
  - Hvordan er dette forskjellig fra slik det skjedde når du ikke hadde tilgang til visualiseringsverktøy?
- Dersom du får inntrykk av at noe ikke stemmer med hvordan du forventer det skal være, hvordan sjekker du det ut?

4. Tenker du at du har "en indre forestilling" av hvordan konstruksjonen skal se ut?

- Bygger en slik forestilling på det du har sett "i virkeligheten", på planer du har sett på papir, 2D på PC-skjerm, visualiseringsverktøy på PC (på kontor), tablet, mobil eller AR-briller (on-site)?
- Hva stoler du mest på / hva er den beste guiden for "slik det skal være": din indre forestilling, papir-løsning, digital løsning, eller det du ser rundt deg/det som er logisk?

5. Har innføring av visualiseringsverktøy ført til endringer i måten dere samarbeider?

- Hvordan tror du visualiseringsverktøyet kan være med å påvirke samarbeidet?
- Hvordan vet du at dere snakker om det samme?
- Hvordan kan du vite (verifisere) at en kollega du samarbeider med – som sitter på en annen lokasjon –har samme informasjon som deg?
- Føler du digitale virkemiddel kan være med å skape avstand mellom dem som har tilgang og ikke?

Oppsummering og avslutning

- Er det noe du ønsker å fortelle, som du ikke har fått sagt?
- Har du noen spørsmål om forskningsprosjektet

Appendix D. A-priori coding template

Nivå 1	Nivå	Nivå 3	Nivå 4
1. Påvirker arbeidet	1.1 Anvendelse av verktøyet/teknologi	1.1.1 Verktøy som er i bruk	1.1.1.1 Digital tvilling på tablet 1.1.1.2 Digital tvilling på PC 1.1.1.3 Digital tvilling på AR-briller
		1.1.2 Oppgaver man bruker verktøyet til	1.1.2.1 Planlegging 1.1.2.2 Familiarisering 1.1.2.3 Verifisering av utført arbeid
	1.2 Endringer i arbeid	1.2.1 Sluttet å gjøre 1.2.2 Begynt å gjøre 1.2.3 Endret utfall/resultat	
2. Pålitelighet	2.1 Tiltro	2.1.1 Til seg selv 2.1.2 Til verktøyet/teknologi 2.1.3 Til informasjon 2.1.4 Til andre (f.eks. kollega)	
	2.2 Opplevd reliabilitet (presisjon/korrekthet)	2.2.1 Verktøyet	
3. Teste indre forestilling	3.1 Karakteristikk ved indre forestilling	3.1.1 2D-modell (tegning) 3.1.2 3D-modell 3.1.3 Fysiske omgivelser	
	3.2 Avvik mellom modeller	3.2.1 Indre forestilling og fysisk omgivelse 3.2.2 Indre forestilling og verktøyet 3.2.3 Verktøyet og fysisk omgivelse	
4. Bygge felles forståelse	4.1 Kunnskap/kompetanse om	4.1.1 Verktøyet 4.1.2 Kollegaer 4.1.3 Oppgaver	
	4.2 Holdning og forståelse	4.2.1 Verktøyet 4.2.2 Kollegaer 4.2.3 Digitalisering (trend)	

Appendix E. Final coding template

Nivå 1	Nivå	Nivå 3	Nivå 4	Nivå 5
1. Påvirker arbeidet	1.1 Anvendelse av verktøyet/teknologi	1.1.1 Verktøy som er i bruk	1.1.1.1 Tablet	1.1.1.1.1 Digital tvilling 1.1.1.1.2 Andre programmer
			1.1.1.2 PC	1.1.1.2.1 Digital tvilling 1.1.1.2.2 Andre modellerings verktøy
			1.1.1.3 AR-briller	
		1.1.2 Oppgaver man bruker verktøyet til	1.1.2.1 Planlegging 1.1.2.2 Navigere og orientere seg 1.1.2.3 Verifisering av utført arbeid 1.1.2.4 Kommunikasjon og samarbeid	
		1.1.3 Mulige bruksområder for verktøyet	1.1.3.1 Funksjoner som er savnet	1.1.3.1.1 Integrering av informasjon 1.1.3.1.2 Navigasjon
			1.1.3.2 Nye bruksområder	1.1.3.2.1 Kommunikasjon og samarbeid
	1.2 Endringer i arbeid	1.2.1 Tilgang på informasjon	1.2.1.1 Deling av info og kommunikasjon 1.2.1.2 Tilgang i felt	
		1.2.2 Effektivisert arbeid	1.2.2.1 Oversikt 1.2.2.2 Tidsbesparelse 1.2.2.3 Mindre ark og kopiering	
2. Pålitelighet	2.1 Tiltro	2.1.1 Til seg selv	2.1.1.1 Erfaring 2.1.1.2 Trygg på egen kompetanse	
		2.1.2 Til verktøyet/teknologi	2.1.2.1 Stoler på informasjon fra verktøyet 2.1.2.2 Stoler på tegningene over verktøyet 2.1.2.3 Stoler ikke på verktøyet	
			2.1.2.4 Verifiserer ved uoverensstemmelser	2.1.2.4.1 Verifiserer informasjon 2.1.2.4.2 Verifiserer ikke informasjon

	2.2 Opplevd reliabilitet (presisjon/korrekthet)	2.2.1 Verktøyet	2.2.1.1 Oversikt 2.2.1.2 Modellens presisjon
		2.2.2 Brukervennlighet	2.2.2.1 Funksjoner, ergonomi og utforming 2.2.2.2 Opplæring 2.2.2.3 Tidsbruk
3. Teste indre forestilling	3.1 Karakteristikk ved indre forestilling	3.1.1 Begrensinger ved indre forestillinger	
		3.1.2 Danne forståelse basert på 2D og 3D	
		3.1.3 Erfaring	3.1.3.1 Fysisk omgivelse 3.1.3.2 Miks mellom modell og virkelighet
		3.1.4 Utvikling eller endring over tid	
	3.2 Avvik mellom modeller	3.2.1 Indre forestilling og fysisk omgivelse	
		3.2.2 Håndtere avvik mellom modeller	3.2.2.1 Erfaring
4. Bygge felles forståelse	4.1 Kunnskap/kompetanse om	4.1.1 Verktøyet	4.1.1.1 Problemløsende strategi 4.1.1.2 Trening og opplæring
		4.1.2 Kollegaers forståelse	
	4.2 Holdning og forståelse	4.2.1 Digitalisering (trend)	
	4.3 Kommunikasjon	4.3.1 Bruke verktøyet for å kommunisere 4.3.2 Bruke verktøyet som en visuell guide i samarbeid	

Appendix F. Translations of excerpts from interviews

Informant 1

«Hvis jeg oppdager det i felt tar jeg jo gjerne et bilde, kan jo ta bilde med tablet og ta det med inn og se litt på det, sjekke 3D-modellen og sånn, tegninger. Eller kanskje noe material valg, hvorfor har de brukt de boltene der liksom, det var litt rart, og sånne ting. Så det er å se på de generelle prosedyrene for, vi har et sånn strukturdokument, sånn skal strukturen bygges, sånne bolter pleier vi å bruke. … Men begynner gjerne med å se på det i felt, ta et bilde, komme inn på kontoret, begynne å grave litt da i dokumentasjonen og prosedyrer.»

> « If I discover something in the field, I would likely take a picture of it, take a picture with the tablet and bring it back inside to have a look at it, check the 3D model and drawings. Or maybe the choice of material: why have they used those bolts there, that was a bit strange, and that sort of thing. Then you look at the general procedures for, we have a structure document, how the structure should be built, the bolts we usually use… But I usually start to look at it in the field, take a picture, get into the office, start to dig through the documentation and procedures.»

«Jeg bruker plantegninger mye mindre nå. For nå bruker jeg mest modellen, så hvis ikke modellen er rett så tar det kanskje lengere tid før du oppdager at tegningen er feil.»

> « I use floor plans a lot less now. Now I mostly use the model, so if the model is not correct, it may take longer before you discover that the drawing is wrong.»

Informant 2

«Så på sånne IT-ting har jeg inntrykk av at folk lærer kjappest av å bare knote og prøve seg frem, spørre naboen, det blir kjedelig å ha det på kurs tror jeg. »

> «Regarding the IT stuff, I have the impression that people learn the fastest from just fiddling around with it and trying to figure it out by themselves. Ask a colleague. It gets boring if you have to take a course, I think.»

«hvis jeg skal se for meg så er det mer sånn hvor jeg har gått egentlig. Den og den gangveien, da har jeg strukturen på den siden og de tingene på den andre siden. Tenker at jeg går da liksom. Samme som at jeg går i gatene her ute liksom, da er det huset på den siden.»

> « If I envision it, then it is more like where I've actually walked. This and that walkway, then I have the structure on that side and those things on the other side. I think about it

as if I'm walking. Just like I'm walking in the streets outside. Then there's that house on that side.»

«Kanskje ting som ikke er så synlige fra der du går, for eksempel utsiden av plattformen, da stoler jeg mer på tegning, har ikke noe særlig mulighet til å få [mentalt] bilde av det ellers.»

« Maybe things that are not as visible from where you walk, for example, the exterior of the platform, then I rely more on the drawing. I have no possibility of getting a [mental] image of it otherwise.»

«Du får et bedre bilde av størrelsen på det du jobber med, og hvordan det egentlig ser ut. Jeg er jo ikke så god på 2D-tegning, eller det er en jobb å fra 2D til 3D i hodet da. Så da er det jo lett når du får det ferdig laget.»

« You get a better picture of the size of what you're working on and what it really looks like. I'm not very good at 2D drawings, or it takes an effort to go from 2D to 3D in my head. Then it's easier when it's already done for you.»

«Vil si at en 3D-modell gjør det lettere å skjønne hva du skal gå å se på, men for å få de små detaljene må du ha med tegninger. Og ja, sjekke er bolthullene plassert riktig eller sånne ting, mer detalj tegning.»

« I would say that a 3D model makes it easier to understand what you're going to look at, but in order to get the smaller details, you need to include drawings. And yes, check if the bolt holes are placed correctly and things like that. There are more details in a drawing.»

«Vel, jeg mener, det blir så mye informasjon i felt, det er så mange ting der, så den er litt for treig kanskje, blir litt for unøyaktig da. ... Du får en 3D-modell lagt oppå strukturen, da vil den liksom alltid se skeiv ut for du klarer ikke å få den helt perfekt opp linjert mellom visuell virkelighet og virkelighet da.»

« Well, I mean, there is so much information in the field, there are so many things there, so it is a little too slow maybe, gets a little too inaccurate…You get a 3D model layered on top of the structure, so it will always look a bit skewed because you can't get it perfectly aligned between the visualisation and reality.»

«Så vi er ikke helt der at tablet er det aller enkleste alltid. ... med tablet må du liksom ha to hender og trykke litt, ta av hanskene er plagsomt, så sånne små ting da. Penn i brystlommen og en papirlapp er mye kjappere da.»

« We're not there yet; the tablet is not always the easiest… With the tablet, you have to have two hands and touch the screen, taking off your gloves is troublesome, small things like that. A pen in your pocket and a piece of paper are much quicker then.»

«Jeg vil heller ha det på en PDF, så jeg bare kan slå opp hvis jeg lurer på noe, enn å sitte noen timer å høre.»

> « I'd rather have it on a PDF, so I can look it up if I'm unsure about something, rather than sit for hours listening.»

"Da bruker jeg jo enten tegninger eller visualiseringsverktøy, for å ha en trygg referanse på hvordan det skal være. ... Hvis noen påstår at her er det for trangt eller her er det for stor åpning i rekkverket, eller ett eller annet sånt. Da bruker en jo det som fasit da liksom, at en har et bilde av hvordan det skal være, enten tegning eller 3D-modell eller visualiseringsverktøy da.»

> « I either use drawings or the digital twin as a safe reference on how it should be... If someone claims that a place is too tight or an opening in the railing is too big or something like that, then you use that as a reference to how it should be, so that you have a picture of what it should be, either a drawing or 3D model or the digital twin.»

«Ja, du kan bli litt låst i 3D-modellen da. At det er sånn det burde se ut eller er sånn det skal være, men så kan det jo være feil der, du blir veldig bunnet til det mediet da. Det kan jo være med tegninger også da, er tegningen feil så kan du jo oppfatte ting feil da også, så det er kanskje samme risiko som før da.»

> « You can get a bit stuck in the 3D model. That's what it should look like or the way it should be, but there could also be an error there. You become very tied to that medium. It can be like that with drawings too. If the drawing is incorrect, then you can perceive things wrong, so perhaps the risk is the same as before.»

«Du kan kanskje få et litt lite bilde av det du skal se på da, hvis du ser på modellen og så ser du bare på utstyret, men så er det kanskje mye rundt som du mister litt fokus på da. Du bruker litt for mye forstørrelsesglass da, blir kanskje blind, blir sånn detaljfokus da og så mister du det store bildet da.»

> «You might get a small picture of what you're going to look at, if you look at the model and then you only look at the equipment. But there can be lots of things around that makes you lose focus. You might use the magnifying glass a bit too much. Maybe you get blind. The focus is only on details so that you lose the big picture.»

Informant 4

«Ja. Jeg har drevet og bygget siden jeg var 16, så du danner jo deg bilder over hvordan det skal se ut.»

«I have been building since I was 16, so you form images of what it should look like.»

«For eksempel ... hvis det er et rør som skal gå gjennom et rom, så vet jeg gjerne hva annet utstyr som er der inne. Og så har jeg sett på tegninger eller i modell hvordan det ser ut, men så lager du deg et indre bilde av hvordan det er når du kommer ut. Og så tenker du eventuelle hvordan og hva, i forhold til utfordringen du har fått eller hva problem du er satt til å løse. Og da hjelper det jo at du har vært i en modell og sett på hvordan det er.»

> « For example... if there is a pipe going through a room, then I usually know what other equipment is in there. I've looked at drawings or the model and know what it looks like. So then you create an internal image of how it will be when you go out [in the field]. You think about potential hows and whats regarding the challenge you face or the problem you are set to solve. It helps that you've been in the model and seen what it looks like.»

«Det kommer litt an på hva jeg oppdager. Hvis det er en support som er plassert en halv meter forskjellig fra det som jeg har tegninger på, så er det ikke noe som gjør meg urolig. Men hvis jeg ser en ventil eller et rør som er av en tynnere veggtykkelse enn det som, eller det som viser er tykkere enn det som er i felt, så ja ville jeg vært mer redd, eller ikke redd, men tatt og sjekket det»

> «It depends on what I discover. If a support is located half a meter from what I see on the drawings, then it doesn't worry me. But if I see a valve or a pipe that has a thinner wall thickness, or a thicker [wall thickness] than what is in the field, then yes, I would be more scared, or not scared, but I would checked it further.»

«Nei, det er nok tegningen jeg stoler på. For det er den som gjelder, modellen kan de ha oppdatert og så er det sånn at det er tegningen som er det offisielle. Modellen kan vise hva den vil, men det er tegningen som gjelder.»

> « It's probably the drawing I trust. Because that is the one that applies. The model may have been updated, but it is still the drawings that is the official [document]. The model can show whatever it wants, but it is the drawing that counts.»

Informant 5

«Nei, som sagt så... jeg kjenner jo ikke alle verktøyene der. Jeg har jo ikke brukt alle. Jeg har kanskje ikke følt at jeg trenger de. Men så er det jo noe med det at det er ikke alltid du skjønner hva du trenger for du vet egentlig ikke fordelene med det.»

«… I am not familiar with all the applications [on the tablet], I haven't tried them all. I may not have felt that I need them. But then there is something about it. You don't always understand what you need because you don't know the benefits of it.»

«Den er såpass grov sånn at jeg klarer ikke å kjenne meg igjen i felt bare ved å ha studert modellen. Det er mer motsatt. Etter å ha studert virkeligheten så klarer jeg å forstå modellen.»

« It [the model] is too rough, so that I cannot recognise my surroundings in the field just by studying the model. It works the opposite way. After studying reality, I can understand the model.»

«Det er jo ikke alt som er tegnet inn i -- [visualiseringsverktøyet], av sånne veldig små ting da. Men det har stemt veldig bra til nå. Jeg er egentlig imponert over hvor godt det har stemt.»

«After all, not everything is drawn in [the digital twin], especially smaller things. But it has matched very well so far. I'm really impressed with how well it has matched.»

«De verktøyene de er jo ikke gode nok da, for du klarer ikke å se... du ser litt og så kutter den bort det som ikke er i umiddelbar nærhet. Men det gjør at du ikke klarer å orientere deg da.»

« The tools are not really good enough because you're not able to see… you see a small section, and then it cuts off whatever is not in your immediate proximity. However, that makes you unable to orient yourself.»

«Hvis det er et system du skal forstå da og du går ut og ser så ser du bare masse rør, og da klarer du ikke å skjønne hva som egentlig skjer her. Men så har du en indre forestilling om hvordan denne prosessen må fungere da. For hvis du for eksempel har en tank og så går den videre til en ventil og så har du en regulering. Så vet jeg inni hodet mitt hvordan en sånn type regulering må fungere. Jeg har liksom en modell da, så kan jeg liksom connecte den med rørene jeg ser og skjønne ganske kjapt hvordan ting henger sammen da.»

« If there's a system you need to understand and you go out [in the field] to look at it and only see a lot of pipes, you can't understand what is really happening there. But then you have an internal representation of how this process must work. If there is a tank that connects to a valve that continues to a regulation, then I know how this type of regulation must work. I sort of have a model that allows me to identify the pipes I see and can understand pretty quickly how thing are connected.»

«For hvis du ser noe i virkeligheten som ikke stemmer med modellen din, så ja da må du oppdatere modellen din i hodet ditt, så du har rett modell. Så kan du bli veldig effektiv da.»

« If you see something in reality that doesn't match your model, then you need to update the model in your head so you have the correct model. This way, you can become very efficient.»

«Du har jo noen teknikker[filter], du kan vise kun et system for eksempel et rørsystem ... du kan ta bort alt og vise kun oljerørene og det ser jo ut som et spindelvev, for det er jo komplekst. Men det kan jo være nyttig i noen tilfeller å vite hvor rørene går.»

> «There are some techniques [filters]. You can show just one system, for example, a pipe system... You can remove everything and only show oil pipes, and it looks like a spider web because it is so complex. But it can be helpful in some cases to know where the pipes are going.»

Informant 6

«Det er ofte det som er problemet at det er vanskelig å bruke og da vil ikke folk bruke det. Så det må være enkelt, og så må det finne noen arbeidsoppgaver som stemmer overens med deres jobbsituasjon, at de får noe de har nytte av.»

> «The problem is often that it's difficult to use, and then people won't use it. It has to be simple, and there has to be some work tasks [it applies to] that match their job situation so that they benefit from it [the digital twin].»

«Ja, altså det går jo på større ting. Stort utstyr, formen på rommet, større komponenter i området, de store veiene rundt omkring på plattformen. Men på enkelte ting er det kanskje mer småkomponenter som jeg vet hvor skal stå, hvor de bør stå i forhold til hvordan systemet er bygget opp.»

> « Well, it works on larger things. Big equipment, the shape of the room, larger components in the area, the big walkways around the platform. On specific things, however, there may be smaller components that I know where should be, where they should be based on how the system is built.»

«Før hadde jeg en viss oppfatning av hvordan ting skulle se ut, basert på 3D-modellen ... Nå har jeg gått og trakket på plattformen i to år fra første stålbit til den var ferdig, og da er det jo hukommelsen over hvordan ting ser ut og hvor utstyr står, jeg husker jo ganske mye. Så da er det mer den hukommelsen som sitter etter det da, som er det jeg bruker i arbeidet i dag.»

> « Earlier, I had an idea of how things would look based on the 3D model... Now, after I have walked around the platform for more than two years, from the first piece of steel until it was finished, then it's my memory of how things look and where equipment is placed. I remember quite a lot. It's the memory of all of that I use in my work today.»

Informant 7

«Nei, jeg er jo egentlig veldig trygg. For jeg ser det er veldig basic bygget opp, så har du en grei knowledge på data så...»

> «No, I am actually really confident. Because I see that it is built very basic, so if you have a decent knowledge about computers then …»

«Du vil få oversikt mye raskere, for det vil si du tar jo bare med deg hjelmen i bagen og stikker ned.»

> «You'll get an overview much faster, because you just bring the helmet [AR glasses] in your bag and go down there [to the build site].»

«Vi stiller oss opp på en plass hvor vi egentlig klarer å sjekke veldig mye på en gang. Så skal vi flytte oss så tar vi den av og på med den andre hjelmen på og så flytter vi oss og så tar vi den på oss igjen»

> «We stand in a place where we manage to check a lot at once. Then when we move, we take it off and put the other [protection] helmet on, and then we move and put it [helmet with AR glasses] on again.»

Informant 8

«Så det er nok et verktøy som er kommet for å bli det tror jeg, og det blir nok mer som jeg etterlyser da, i vekt og mer brukervennlig og mer sikkerhet, lettere å aligne, det er litt tungvint med den aligningen da.»

> «I think it's probably a tool that's here to stay, and it'll probably become more like I want it to, regarding weight and user-friendliness and safety, easier to align. However, it might prove difficult with the alignment, though.»

«Men det er litt sånn, du blir litt sånn god på å slurve blir det rett å si? Men du ser at det er innafor og ok, eller skal vi si "godt nok" da.»

> «But it's a bit like that you get less strict, is that the correct way to say? You see that it's acceptable and okay, or shall we say, "good enough".»