Emerald Facilities

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Introduction

High quality data and information created from advanced Information Systems (IS), such as Building Information Modelling (BIM), are considered valuable assets for the management of today's sophisticated facilities (Becerik-Gerber et al. 2011, Rundell 2006, Teicholz 2013). Consequently, an increasing number of building owners and operators prioritize BIM utilization in design, construction, and facilities management (McGraw-Hill 2012). The term computer-integrated facilities management refers to the reuse of digital project information created throughout design and construction in facilities management (Yu et al. 2000). Despite an increasing BIM technology uptake in project planning, limited consideration is given to operation, maintenance, and end of life disposal of buildings (Shen et al. 2010). Thus, few BIM models are developed with the purpose to provide the accurate data, information, and knowledge required for facilities management (FM) (Rui and Issa 2014, Teicholz 2013). As a result, FM struggles to reap the benefits of BIM technology (Arayici et al. 2012).

A recent survey study reporting on important FM research trends in the Nordic countries, argues that information technology continues to be an important theme in further developing the sector (Jensen et al. 2014). This is echoed by research reviews calling for further work expanding BIM's utility for management and maintenance of built structures, facilities, and infrastructure (Merschbrock and Munkvold 2012, Shen et al. 2010). In line with this, we explore how BIM's utility for FM can be enhanced. The BIM application area focussed in this article is relocation management in FM. As organizations respond to their business 'climate', their facilities change to provide best support for core operations and processes (Alexander 1996). Change scenarios such as the relocation of organizations to new facilities or refurbishments of existing facilities need to be carefully managed to prevent inefficiencies and downtime (Airo et al. 2012, Bull and Brown 2012).

Preparing a workforce well ahead of starting-up can curb inefficient downtime and improve services delivered to clients and customers, which are core priorities for FM (Jensen 2010). A recent example of what can go seriously wrong when healthcare personnel are not trained well enough before relocating, is the new Akershus University Hospital in Norway, where the police is investigating eleven suspicious patient deaths related to the moving-in process (Lerø 2012). By focusing on BIM use in staff training prior to workplace change, the employees' familiarity with a new facility can be increased (Arayici et al. 2012, Raju et al. 2011). Despite BIM being a powerful tool for visualization in building design it has not been built for educational purposes. Thus, scholars have suggested utilizing BIM models as graphical environments in digital game-based learning (DGBL) (Raju et al. 2011). DGBL is the newest trend in e-learning and has become an important part of the global education and training market (Prensky 2007, Susi et al. 2007). DGBL can be defined as the use of computer/video games for educational purposes such as professional training (Breuer and Bente 2010). In this article, we study a digital learning system which we from here on refer to as a 'serious game', a more widely used term for DGBL (Susi et al. 2007).

Digital games and their motivating features are widely perceived as useful and attractive new methods of delivering educational content (Boyle et al. 2011, Charsky 2010, Connolly et al. 2012, De Freitas 2006, Sward et al. 2008). This is echoed by serious games becoming increasingly diffused in businesses, industry, marketing, healthcare, education and governments (Sawyer and Smith 2008). The success of serious games in the educational market has been ascribed to "learning which can be more engaging with the induction of an underlying game, and the current generation of learners who have grown up in a digital environment" (Yusoff et al. 2009, p. 21). While the adoption of serious games is a well-developed research area, the link to BIM in the context of architecture, engineering, construction, and facilities management (AEC/FM) is less well studied (Liu et al. 2015). Joining BIM and gaming technology offers several benefits for the AEC/FM disciplines, including "3D walkthroughs, interactive visualisation, virtual collaboration, design and planning to education,

[1] An early version of this article has been presented for an audience of gaming researchers at the 21st *Norwegian Symposium on Information Technology and Organizations* (Merschbrock et al. 2014).

training and simulation" (Raju et al. 2011, p. 2). BIM's geometric data also aids the generation of levels and maps in games (Yan et al. 2011). Moreover, object-oriented programming in BIM tools and games supports their integration (ibid.). So far there is "limited research focused on using BIM as […] 3D virtual environment for collaboration, learning and/or training" (Shen et al. 2012, p. 1212).

In this article we contribute to the discourse on integrating BIM and gaming by reporting on the development of a 3D role-play serious game used to prepare professionals for relocating to a new, yet unbuilt, hospital facility. In doing so, we draw attention to BIM-based gaming as a novel approach to prepare the relocation of a workforce to a new facility, and we illustrate some of the challenges this involves. Against the background that downtime can be reduced and even lives can be saved, considering BIM-gaming integration in the context of healthcare FM is worthwhile. The research question addressed in this article is: *How can BIM and gaming be integrated to support professionals in their learning about the spatial layout of a new building?*

We present the results of a case study conducted in a hospital construction project in Norway. The case constitutes Norway's first BIM and gaming integration with the purpose of building operation testing. Moreover, the project has been awarded BuildingSMART's 2015 award for 'outstanding open BIM practice', making it Norway's role model for BIM practice. The project entailed the development of "the Ward", a serious game intended to familiarize healthcare professionals with their new work environment. The new hospital ward differs from those in older hospitals by its architectural layout, the building automation systems used, and its medical equipment. We present the findings of a series of interviews conducted with several of the key persons involved in the development and testing of the game. Task-Technology Fit (TTF) theory (Goodhue and Thompson 1995) serves as a starting point for our analysis of the actions undertaken throughout the development process to integrate BIM and gaming, and to ensure that the game would fit its purpose.

Related research

Combining BIM and gaming is a relatively new discourse in the field of construction informatics (Liu et al, 2015). Triggered by the recent evolution of both technologies, construction informatics researchers begin to explore the potential that lies within combining them (Raju et al. 2011). Early examples of this stream of research can be found in the 2011 special issue on "BIM and serious gaming" published in the Journal of Information Technology in Construction. Topics discussed in this release include: BIM-based games for construction site safety training (Lin et al. 2011), education of fork lift drivers working in the future facility (Juang et al. 2011), and the use of games to optimize a building's design (Shiratuddin and Thabet 2011). This work indicates that construction researchers find a range of prospective application areas and benefits of this combinatorial innovation. More recent examples of trying to apply the new technology include BIM-based games combined with sensor technology as a means for assessing a building's state, including temperature and energy consumption (Chiang et al. 2015, Fürst et al. 2014). Others suggest using these technologies for elderly care and related building automation (Wu 2015). Moreover, there is growing interest to apply BIM-based games for building design review by users (Edwards et al. 2015). Some research suggests using BIM-based games displayed on handheld devices for fire emergency evacuations (Wang et al. 2014). Thus, there is a wide array of thinkable application areas of the new technology and construction researchers are just beginning to understand its implications.

While there appears to be wide agreement that integrating BIM and gaming is worthwhile, it is all but easy and researchers report a number of challenges, especially when large, data heavy BIM models are to be incorporated in game engines (Dalton and Parfitt 2013, Edwards et al. 2015). There is a focus on overcoming challenges related to the technological integration of BIM and gaming as the following quote illustrates: "importing the Revit model into Unity via the FBX file format will lose some parameter information, e.g. the material color or texture" (Chiang et al. 2015). Consequently, scholars begin to suggest workflows and IT solutions assisting the technological integration (ibid.). Since the technology is still in its infancy, most of the practical 'use cases' presented in literature are based on laboratory experiments run in universities (Chiang et al. 2015, Edwards et al. 2015, Fürst et al. 2014). Perhaps due to the novelty of BIM-based games, their application in the industry is rare.

Norway's construction industry is a global leader in BIM adoption and use (Smith 2014). This article presents an early case of an industrial BIM-based gaming application in Norway. Moreover, the end to which the system is used can be seen as a novel application area of this technology. BIM-based gaming can assist in preparing organizations for workplace change in projects where communication and spatial information is essential (Bull and Brown 2012). Thus, this article contributes to the body of literature by (1) studying a novel application area of BIM-based games, namely relocation training in FM, and (2) providing an early case of an industrial application of the technology.

Theoretical lens

The application of a technology in a novel area can be investigated based on theoretical models explaining software use and linking it to work performance. The model chosen for this study is the so-called Task Technology Fit (TTF) model, which facilitates the investigation of how well a new system (e.g. BIM-based game) supports work performance (e.g. knowledge of the new hospital's spatial layout). Goodhue and Thomson (1995) proposed the concept of Task-Technology Fit (TTF) to "better understand the linkage between the information systems and individual performance" (p. 213). The TTF construct is intended to serve as an indicator for evaluating the extent to which a new system will be useful to assist its future users in doing their jobs. Since its inception, TTF has been applied to the study of a wide range of information systems, including group support systems (Zigurs and Buckland 1998), e-procurement systems (Gebauer and Shaw 2004), and electronic knowledge repositories (Kankanhalli et al. 2005).

Early TTF models were criticised for their technological imperative perspective, where improved job performance depends solely on technology and task characteristics (Goodhue and Thompson 1995). However, newer versions of the theoretical model include the characteristics of the individuals involved (Goodhue 1998). Similar as with other theories used in information systems research, TTF has undergone a shift from what was a techno-centric focus to a better balanced socio-technical focus. For instance, Goodhue's (1998) research model suggests that task, individual, and technological characteristics all influence TTF. Based on a research review, Nan (2011) found that current TTF research mainly focuses the correspondence between (1) task requirements or characteristics; (2) individual abilities, and (3) the functionality of an IT system. Tasks are broadly defined as "the actions carried out by individuals in turning inputs into outputs. Task characteristics of interest include those that might move a user to rely more heavily on certain aspects of information technology […]. Characteristics of the individual (training, computer experience, motivation) could affect how easily and well he or she will utilize the technology. […] Technologies are viewed as tools used by individuals in carrying out their tasks. In the context of information systems research, technology refers to computer systems (hardware, software, and data) and user support services (training, help lines etc.)" (Goodhue and Thompson, 1995, p.216).

TTF highlights the importance of aligning the three aforementioned constructs for inducing positive IT-enabled task performance, or in other words a task-technology fit situation. A graphical illustration of the constructs important in TTF is presented in Figure 1. The TTF model has guided the analysis in this article. Rooting the article in TTF and Information Systems theory aids the systematic assessment of the utility of a BIM-based game for FM (Junghans & Olsen, 2014).

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Method

The research strategy chosen to guide the inquiry is a case study approach reporting on game prototyping done by software developers. Data were collected through a combination of semi-structured interviews, a focus group interview, and document analysis which allowed for data triangulation. The game development process was executed in three sequential stages: (1) development of an alpha version to demonstrate feasibility; (2) development of a full version; and (3) game testing sessions. In the case study the developers created their BIM-game by transferring a BIM model (Revit) via a rendering software (3DS Max) to the game engine (Unity3D).

There are several reasons for why a case study was considered a good fit for the purpose of this research. A case study approach enables an in-depth understanding of 'sticky' practice-based problems where experience and the context of the action are important (Benbasat et al. 1987, Orlikowski and Baroudi 1991, Yin 2009). The research question pursued in this study - "How can BIM and gaming be integrated to support professionals in their learning about the spatial layout of a new building?" - is an exploratory "how" question, and the case study method is perceived as well suited for studying this type of questions (Yin 2009).

The data were collected over the time span from April 2013 to May 2014 through nine semi-structured interviews and one focus group interview, involving altogether twelve interviewees. We complemented our data collection by document analysis where we studied for instance trade press articles (https://www.buildingsmart.no) or public announcements related to our case (https://www.doffin.no). The interviewees were selected either for their active involvement in creating the BIM-based game or for participating in testing. The interviewees were one client representative responsible for BIM, one client representative responsible for making the game, four game developers, a healthcare expert involved in making the game, and a group of five healthcare professionals testing the game. This approach ensured that both developer and user perspectives were taken into account.

Two individuals were interviewed twice, namely the client's BIM manager and one of the developers. A first early interview with the client's BIM manager was undertaken in April 2013 while construction design was underway. This allowed for an understanding of how the game development process would be arranged. The follow-up interview in March 2014 was undertaken to attain an understanding of the construction design teams' involvement in the BIM-game development. The game developer was interviewed twice for confirming and complementing some statements made in the earlier interview. This improved our work by filling "holes" in our data. These interviews took place, when possible, at the interviewees' offices mostly located in the wider capital area of Norway. In two cases, due to the tight schedules of the interviewees, the interviews were undertaken via the video conferencing tool Skype. The focus group interview took place at the hospital agency's IT training centre in Sarpsborg, Norway. An overview of the interview details such as the interviewees' professional roles, interview durations, techniques and interview dates can be found in Table 1. All interviewees were informed about the modalities of the interviews and gave their informed consent for the process.

<< Please insert Table 1 here >>

The following work procedure was followed to analyse the data: recording all interview and focus group data and writing it down to produce textual accounts; uploading the full-text transcriptions to the qualitative data analysis software NVivo10, reading and analysing the acquired material sentence by sentence, creating thematic nodes for task requirements or characteristics, individual abilities, the functionality of the IT system, and task technology fit; coding all textual accounts by assigning nodes to notions related to the aforementioned TTF constructs; developing overview reports showing all text fragments assigned to a specific node; exploring differences and similarities between the various data sources and making "sense" of them; writing up initial findings, and discussing them with the co-authors and colleagues.

The hospital case

The setting of our case study is a major health-care construction project in the Østfold region of Norway, built by the Southern and Eastern Norway Regional Health Authority (Helse Sør-Øst) and operated by the county's hospital agency (Østfold Sykehus). The project is part of a large program of investments in the Norwegian healthcare sector. The target is to change and improve the way healthcare services are provided to the patients by building better caring environments. Operating brand new hospital facilities fitted with the latest technology involves significant changes for healthcare personnel. Careful change management and intensive preparation are required for safe and effective operation of new hospital facilities. This entails significant changes to users' well established processes and ways of working.

The project comprises the construction of several facilities, including buildings for emergency, surgery and intensive care, patient rooms, psychiatric care, and services such as a laundry and central sterilization. Altogether the buildings comprise a gross floor area of 85082 square meters, and the project costs are estimated at € 670 million. Helse Sør-Øst and Østfold Sykehus decided to prioritize BIM technology use in design, construction, and operation. Serious games were developed as part of the effort to extend the employment of digital modelling data beyond building design and make it available for operation. The game development process was executed in three sequential stages, namely: (1) development of an alpha version to demonstrate feasibility; (2) development of a full-version; and (3) game testing sessions.

According to the client's BIM manager it is "…an important part of the strategy [for a building owner] to have building models that can be used […] and the intention is to save money in the operation phase" (Client, regional health authority). To ensure that the outcome of the model-based design would be of sufficient detail for facilities management, the client made clear that the BIM model was to be an: "acceptable [virtual] prototype of the building". Moreover, the desired outcome of the BIM work was to create "[the] biggest, most complete and best digital model in the world" (BIM manager client). BIM was deployed as the 3D virtual environment for the serious game used in staff training. Figure 2 presents two screenshots from the Ward game, one of a surgery room (left) and one of a hospital corridor (right), to provide a visual impression of the serious game.

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Analysis

The analysis of our results is based on the TTF constructs suggested by Nan 2011, namely: (1) task requirements, (2) functionality of the IT system, (3) individual abilities, and (4) user evaluations of task technology fit. The factors discussed have been identified based on interview statements that could be related to the TTF of the serious game.

Task requirements

The game was developed to "ease the [workforce's] transition to the new hospital facility and the new work environment" (Client, hospital). Achieving this, required "teach[ing] and train[ing] people who are going to work in the new hospital" and familiarizing them with "the [architectural] features of the buildings" (Client, hospital). The workforce needing training comprised nurses, physicians, and other health-care professionals. Getting the visual impression right was a priority: "The most important thing is to get the details in their place so that it is as realistic as possible" (Health care professional #1). Entering the new hospital after having played the game should give users an impression of "having been here before" (Client, regional health authority). The virtual space needed to provide a close resemblance to the physical space found in the as yet unbuilt hospital:

> "[We make the game] because when we move, then that will be a radical change in a very brief period of time. We will have new equipment, new spaces in which we move, and I think when you come to the new hospital it is crucial to know where the things are and that you can avoid having to look for things. If you have patients with serious health conditions then it is important to know where things are. I think that gaming technology can support us very much to get to know the building." (Healthcare professional #1)

Rooting the game in architectural BIM data was prioritized to ensure that dimensions, proportions, and materiality of the 'real' hospital were accurately represented in the game. Thus, the game developers had to incorporate the architectural BIM model in the game engine. Moreover, rendering details like surfaces, lighting, and fittings with a high level of accuracy received priority. In addition to providing a close resemblance of the physical hospital the game had to be self-explanatory and easy to use:

> "[The game has to be] accessible and intuitive, [and] there should be no manuals […]. It should teach you everything you need to play and you should not even know that you are being taught. The simulation should be rewarding and motivating and the game needs to give you feedback on what you're doing." (Client, hospital)

The desired outcome was to motivate users to play the game not only during office hours but also in their spare time. To enable use of the game at will, various versions were developed which can be run on tablets, laptops, and stationary PCs. The game was also intended to serve as a 'virtual training ground' for health-care professionals, simulating typical work processes taking place in a hospital ward. Accomplishing this required infusing the gameplay with health-care expertise, presenting users with a 'true' reflection of real work situations. This required simulating different work procedures like handling patient complaints, disinfecting hands before entering a room, and finding the required medication. To enable building operation testing and providing users with a good understanding of the new building, the game had to fulfil the following task requirements: realistic resemblance of the physical space; self-explanatory and easy to use interface; and simulation of typical healthcare work processes.

Individual abilities

Creating a functional serious game required collaboration among different expert groups. The users' individual abilities mattered for game development. The groups involved were architects, health-care professionals (the game users), game developers, and script editors. Consequently, hospital management established the role of a "knowledge broker", having the responsibility to facilitate knowledge exchange among the different disciplines involved in the game design. The senior manager entrusted with this job was a computer scientist having extensive prior experience from working as a 3D artist in game design since 1994. An experienced nurse having worked since 1995 in professional healthcare represented the user perspective in game development. Her job encompassed close collaboration with the developers to ensure the game would reflect the realities of hospital work. She met with the game developers in a series of five workshops in which she helped developing dialogues and explained work tasks. The following quote describes why involving a senior health-care professional was of crucial importance for the game design:

> "It is of course a lot of information you have to give [the game developers] because they have no experience from before, and it would have been an advantage if they would have known something about hospitals and how a hospital is run from before. What we have also done [to mitigate for this] is that one game developer has taken an internship in one of our hospital wards to see how [for example] dialogues happen." (Health-care professional #1)

The architects' involvement was limited to handing over a BIM model which was consecutively used by the organisations developing the game. Thus, rendering the model and creating an accurate representation of the building's physical space was left to the game developers who had no prior experience from architectural design. The health professionals' computer skills, professional backgrounds, age, and educational background differed. While young health-care professionals were quite acquainted with using games in private, many of their older peers had no gaming experience from before.

Functionality of the IT system

There is currently no "easy way" for importing and exporting geometry from CAD and/or BIM into a game engine (Lehtinen 2002, Yan et al. 2011). While the challenges are known and researchers suggest developing software easing the integration of data between BIM and game engines, no such software is yet commercially available (Yan et al. 2011). The findings from our case study showcased how practitioners struggle to accomplish such "crossovers". The Autodesk©Revit design software was used to create the BIM design and the Unity3D engine was used in game development. Unity3D allows for running large models in real time and can be used to add physics to objects such as opening and closing doors, creating sunlight simulation, and incorporating acoustics (Dalton and Parfitt 2013). However, translating Revit models into Unity3D is challenging, since several of Autodesk's textures cannot be interpreted by Unity (ibid.). Thus, transferring Revit files into Unity cannot be done without additional intermediary steps, such as using Autodesk's rendering software 3DS®Max as an intermediary system between Revit and Unity (Kreutzberg 2011). Despite the technical obstacles, the developers succeeded in importing the Revit file into Unity via 3DS®Max based on the fbx file format. However, they deemed the quality of the resulting model in Unity as unfit to serve as a 3D environment for their game:

> "It is bad, really bad. […] the problem is that the BIM model is built in a totally different way and with a totally different focus. [This is not] what a game engine really needs" (Developer #4)

From this quote it follows that the different focus with which the architects drew their model posed the real challenge for the game developers. According to the project's BIM manager the game designers received an unaltered construction design model, developed to serve as blueprint for construction design and work – in other words, a single-disciplinary architectural BIM model which had been coordinated with structural, mechanical, electrical, and plumbing design data. The model was semantically rich, featuring specifications of building components, materiality, and precise measurements. While such an architectural BIM model works for engineers and other construction professionals it had not been prepared for use in a game engine:

> "The thing is that a BIM model represents a physical building and is loaded with information. Insulation found in a wall, nuts and bolts, and all that. That is way too much information for a game engine. A game engine would need only the visible surfaces and not what's below." (Developer #1)

A technological issue occurring in Revit to Unity import, beyond the aforementioned, is that deleted Revit objects have a tendency of reoccurring in Unity. While deleted objects disappear from the architects' Revit user interface, they remain as hidden objects in the system. This indicates that the game developer was not familiar with how data can be filtered when it is exported from Revit. These objects then reappear once models are imported into Unity:

> "In the BIM data there was a lot of – let's call it "trash" data, for example, windows floating in mid-air or a room without a door, or window. Probably leftovers from the construction design process where some stuff is deleted in the architect's software remaining flagged as hidden. When we import this data into the game it doesn't read as flagged and so it is put back in the model." (Client, hospital)

Increasing the architects' awareness of import related issues and especially improving the use of layering in the architectural model would have eased Revit data import. According to the client, layering would then have to be done "right" and procedures for building up the architectural design model would have to be put in place. How improved layering could improve the process of importing BIM models is illustrated by the following quote:

> "If the engine has to draw thousands of pipes and wires in the walls, everything that you don't see, the game will be slow. What I suggest is layering – that you can better segment things. You could put all the pipes and wiring in one box, and all which is actually visible while in the building, in a different box, and then you could turn these things off quickly." (Client, hospital)

This could have been achieved by using filters within Revit. The game developers found that a crucial aspect for getting the game right is strengthening communication among those building BIM models and those building the game:

> "There must be a good process setup in advance before attempting a BIM model import into Unity. The BIM model was unnecessarily heavy, a lot of clutter, there were double surfaces, the object naming was inconsistent, a lot of unnecessary objects that you do not need because they are anyhow invisible in the game. We should have had a proper dialogue with those building the BIM model from day one. This would have helped clarifying the naming, the materiality of objects, we would have known which objects were supposed to be static and which objects needed dynamic functionality. These things need to be resolved before attempting to put BIM into Unity." (Developer #2)

Consequently, the data import was prefaced by a lengthy process of "cleansing" the architectural BIM model of all unnecessary data. This took the form of reducing the BIM model and even drawing anew in Unity. After remodelling the geometries, the models were re-rendered, lighting and shading simulated, and the digital hospital was furnished. Thus, turning the BIM model into a realistic 3D game environment was labour intensive and tedious work. Nonetheless, as can be seen in Figure 3, the availability of the architectural BIM model and data allowed for creating a realistic virtual prototype of the building. Details such as the wall signs in hospital corridors, the stainless steel cladding on the walls, the display of colours, and the furnishing of patient rooms were all depicted based on the architectural knowledge conveyed by the BIM model. Additionally, several new electronic tools like electronic patient curves on tablet computers, large wall-mounted touch panels (to maintain an overview of the patients, the logistics, and the personnel resources), and the new electronic tube post system, were simulated in the game. These electronic 'gadgets' also had a simulated in-game functionality. One more issue is that current Revit Unity import can be characterized as a "static" process where a model is only imported once. This leads to a situation where changes in an architectural Revit model after import into Unity are not depicted in the game:

> "If the architect were, in five years' time, to move the door, then you would have to move that door in the game. There's two ways of approaching that. There is a static way, if you move this door you have to update the model, you have to get a new model from the architect etc., and there is a delay here. But if you know you are going to have to move things, you can set up the game engine so that it is instant. Like Sims – you could actually click the door and drag it. In the game, if you want. And the light and everything would change. And you can even build in rules that if you try to move that door it will stop at the window."(Developer #3)

Players of the Ward game are offered a gameplay in which they take on the role of a nurse working in a ward. Gameplay is defined in this article as 'that which lies at the heart of a game', it describes what happens and what players do. The game places players into the new hospital where they start a shift and take care of patients in the new ward. Players engage in a series of scenarios supporting them in learning the concepts of being a nurse in this new hospital. The following quote illustrates how the features of the gameplay resemble real world tasks typically found in a hospital environment:

> "You arrive at your job and then you go to your work station where you sit down with a PC and then you read a report about the patients you have to take care of on this day. The alarms will go off and you have to respond. That is when the patients call [patient alarm system], then a new job will appear on the screen at your workstation for the respective patient room. Then you will go to that room and start a dialogue with the patient." (Health-care professional #1)

Figure 3 (top right) shows a game situation where a patient having a certain health condition needs to be cared for in an appropriate way. A patient is a Non Player Character (NPC) randomly occurring throughout the gameplay. There are twenty different types of patients all having different health conditions requiring a certain response by the players. For example, one patient type complains about a pain in the chest, while another is confused or dement. Taking care of a patient requires locating the right patient room, engaging in a dialogue and resolving the problem situation. Involving the senior health-care professional in the making of the game ensured that realistic "business as usual" in a hospital was depicted in the game. In a series of workshops this expert told the game developers where hospital staff go when starting a shift, where patient reports are read, how staff disinfect their hands before entering a patient room, how to preferably address patients, the kind of feedback given to patients, where to pick up drinks, where to get the medication, and other daily activities. Figure 3 (top left) shows a game situation where a player engages in a dialogue with a colleague in the staff room. Figure 3 (bottom) shows an in-game plan view of the hospital ward aiding the orientation of players.

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Task-technology Fit

To attain an initial understanding of the game's task-technology fit, a group of healthcare experts tested and evaluated the game before it was rolled out operation wide. Twenty individuals were randomly selected from the total population of potential users, and five of these were interviewed after the test session. A test-player who had visited the hospital construction site prior to playing the game reported that the game certainly captured some of the building's feel: "I have been to [the hospital construction site], and seen how it looks so far. I was there in March and I recognized it" (Health care professional #2). Naturally, the user perception of the game 'being similar' to the construction site can just offer an initial idea of whether the game works for representing the finalized building. Nonetheless, not only was the game recognizable for people having visited the construction site, but the virtual environment also gave newcomers a sense of "being there": "It [the new ward] was different from what I thought it would be, I thought the wards were arranged differently. One could see how the rooms were grouped […], that was good" (Health-care professional #3).

Users felt that the game provided a superior understanding of the new workplace: "We did get more of an impression [of the new building] than from those sheets with drawings that we have seen" (Health care professional #3). However, there were some critical voices as to how well gaming could provide a solid understanding of the dimensions of the new space: "How far is it from one end of the hallway to the other?

That's rather interesting. We didn't really get an impression of that. We do not know how many meters we cover while pushing a button." (Health-care professional #5). Moreover, one user argued that: "it's only me running around in the corridors" (Health care professional #6), indicating that there should be more non-player-characters in the game making corridors look more realistic (compare figure 3).

How the game was perceived as a useful means of learning is illustrated by the following quote: "one becomes more focused by doing it yourself [playing a game] instead of being served a power point presentation, which is not interactive" (Health-care professional #4). However, several test users reported feeling "dizzy, sea sick, and even driven crazy", indicating that not all of them were accustomed to using computers in general, and/or 3D games in particular. On the other hand some users were motivated and considered using the game at home to train some more, or to show friends what they do at work.

Discussion

The early results of integrating BIM and gaming are encouraging and show the potential this technology yields for building operation. However, the case project also shows that there is significant work remaining in this field. One fundamental issue is currently the technological integration of BIM models and games. In line with earlier research (Dalton and Parfitt 2013), our results show that design systems like Autodesk®Revit and game engines like Unity3D are not interoperable. Since all developers in the case worked based on Unity3D we cannot say whether other game engines would have performed better.

The interoperability challenges have to do with Revit encrypting its exported materials, making it unreadable for Unity (ibid.). This requires practitioners to conduct workarounds via other systems, when importing BIM data into game engines (CIC 2014). However, the textures and renderings would still need to be manually applied in Unity. Thus, there appears to be room for improvement which is echoed by researchers calling for the development of crossover modules for BIM import (Yan et al. 2011). These crossover modules would then have to be designed to support different BIM solutions (i.e. Autodesk, Bentley, Graphisoft, Nemetschek), as well as different game engines (i.e. Unreal® Engine or the CryEngine®), which complicates matters. While early prototypes for direct import from Revit to Unity are emerging, they are not yet commercially available and they support neither other BIM software nor other game engines (Edwards et al. 2015). A thinkable solution would be to develop software using non-proprietary file exchange formats like the Industry Foundation Class (IFC) format. However, at the moment no game engine is able to build a virtual environment based on IFC descriptions (Pauwels 2014). Thus, there remain unsolved technological integration issues requiring further research.

Nonetheless, the game designers in the case project succeeded in overcoming software related interoperability issues by manually redrafting and rendering the game's 3D graphical environment. However, this manual work was redundant, unnecessary and often error-prone. One possible way to achieve higher levels of integration between BIM and gaming is to develop both BIM and gaming systems further into better interoperable systems. This would then lead to a reduction in unnecessary rework.

A similarly important issue was the differing focus of architectural design and game design. Architects and game designers have different information needs. While the architectural design model needed to be detailed and semantically rich, the game developers only had need for simpler surface data. Moreover, as pointed out by Dalton and Parfitt (2013), data-heavy, complex, and large BIM models need to be reduced to prevent a reduction in run-time and overcome texture translation issues in games. BIM models would thus ideally need to have a 'lighter body' to best facilitate BIM and gaming integration. However, simplifying a large architectural design model and reducing its polygon counts requires a significant amount of work (ibid.). Several commercial and freeware solutions designed for reducing BIM model polygon count are available.

A swift transition from architectural BIM models into a computer game would thus require game developers to clearly define and express their information needs. Doing so could facilitate a mutual understanding between architects and game developers of how to best generate BIM-based games. Moreover, it is thinkable to make the production of 'lighter body' BIM models part of the contractual arrangements for BIM delivery. This would be an initial step for easing the creation of BIM-based games. It follows from our results that the absence of contractual arrangements and specifications, in conjunction with architects being pressured for time, led to limited involvement of the architects in making the game. In fact, the handover of BIM models from architects to game developers happened without any form of coordination and an ordinary construction BIM model was used in game design.

Despite the apparent shortcomings in current practice of integrating BIM and gaming, the responses by the game's test users were promising. An overview of the task-technology fit of the Ward game can be found in Figure 4. Most test players found the Ward game to provide them with a realistic representation of the future hospital. Moreover, by infusing game design with health-care knowledge, the gameplay, in-game dialogues, and representation were perceived as realistic by most of the test users. However, a limitation of gaming technology surfaced in that the game did not provide a good understanding of the walking distances that would need to be covered between the rooms in the hospital. This limitation could perhaps be overcome by having an avatar/user move through the distance between the rooms and let this 'take some time', or by indicating the number of steps needed, similar to how this is solved in Second®Life.

<< Please insert Figure 4 here >>

In addition, players not accustomed to playing computer games reported feeling unwell or dizzy during play. The fact that some players even considered playing the game in their spare time, and/or share it with their friends, shows that the developers succeeded in creating a motivating gaming experience. However, the group interview with the game's test users provided only an initial understanding of the game's utility for building operation. Given that the hospital has not yet started up its operation, the results presented here do not allow for claiming that the game provided performance gains in operation. Rather, this presents an intriguing area for further research. Research into the value of BIM games for operation could for instance draw from existing FM literature on post occupancy evaluation (POE), similar to what has been suggested by Zimmerman and Martin (2001).

This article contributes to the emerging discourse on the application of BIM-based games in building operation in general, and in the context of healthcare projects in particular (Juang et al. 2011, Lin et al. 2011, Raju et al. 2011, Yan et al. 2011). Based on our findings, we argue that BIM-based gaming yields a range of opportunities for improving staff training in healthcare projects, including training in work processes and learning about a new work facility. Yan et al. (2011) argued that "[…] building operation may benefit from the educational potential of games" (p. 446), and the initial responses by the test users in our case indicate that this may be true. BIM-based games appear as a promising tool for aiding facilities management by making workplace changes apparent for users. Gaming could also open up opportunities for feeding user experiences back to the construction design process similar to what has been argued by Shiratuddin and Thabet (2011).

Our work could be extended by research inquiring into how collaboration and information exchange between architects, game developers, and subject matter experts could be further improved. Moreover, an intriguing area for further research is to study the business value of BIM-based games for building operation. How user experiences could inform construction design represents an interesting avenue for further research. Last, the technological interoperability between BIM and gaming is an area in need of further work.

The main contribution of our work is in drawing further attention to the potential of digital game-based learning for building operation. In addition, the paper explains some of the challenges in BIM and gaming integration and suggests improvements in this. BIM and gaming research is still in its infancy and we just begin to understand the implications of this technology for industrial practice. Based on early stage feasibility studies run in university settings, it has been claimed that BIM-based games support "the simulation of aspects of the use of a completed building" (Bille et al. 2014, p7). We extend this prior work by exploring, based on an early industrial application of this novel technology, whether and how these claims are supported in industrial practice.

Conclusion

Our study shows how the Task-Technology Fit concept is useful to analyse, explain, and understand how BIM and gaming could be integrated to support staff training prior to starting up the operation of a new facility. The case analysis identified that integration between BIM and gaming could be further improved by (1) using crossover modules in data exchange, (2) increasing collaboration between architects and game developers, (3) formulating clear information needs, and (4) defining contractual arrangements for the integration of BIM and gaming. Process simulation based on gaming technology informed by 3D building design data is just in its infancy and current commercially available solutions do not support an integrated way of working. Despite the experienced challenges, the test users perceived the BIM-based game as a useful tool for increasing their knowledge of the building's architectural layout. Still, there is a need for further research exploring the benefits of BIM-based games for building operation, facilitating stronger collaboration among architects and game designers, and improving the technical interoperability between BIM and gaming technology.

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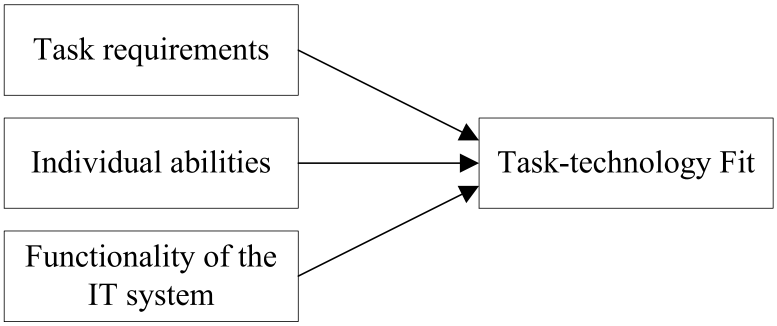

Figure 1. Task-technology fit model (adopted from Nan 2011)

Table 1. Interviews conducted

Affiliation	**Services provided**	**Interview duration**	**Interview technique**	**Date**
Client (regional health authority)	Responsible BIM manager (architecture, engineering, and construction expert)	60 min	Face-to face	April 2013
		10 min	Skype	March 2014
Client (hospital)	Responsible gaming manager	80 min	Face-to face	March 2014
Developer #1 (alpha-version)	3D artist in game design	30 min	Face-to face	March 2014
Developer #2 (alpha-version)	CEO and game developer	30 min	Face-to face	March 2014
Developer #3 (alpha-version)	CEO and game developer	30 min	Face-to face	March 2014
Developer #4 (full-version)	CEO	35 min	Face-to face	March 2014
		45 min	Face-to face	April 2014
Health-care professional # 1	Counsellor game design and script, experienced expert	50 min	Skype	March 2014
Health-care professional # 2, #3, #4, #5, #6	Game testers, experienced expert	30 min	Focus group	May 2014

Figure 2. *Screenshots of the serious game 'Ward' showing (a) a surgery room, and (b) a hospital corridor [(a,b) courtesy Jarl Schjerverud, Sykehuset Østfold HF]*

(a) Surgery room	(b) Corridor

Figure 3. *Screenshots of (a) hospital staff room, (b) patient room, and (c) a floor plan view of the 'Ward' [courtesy of Jarl Schjerverud, Sykehuset Østfold HF]*

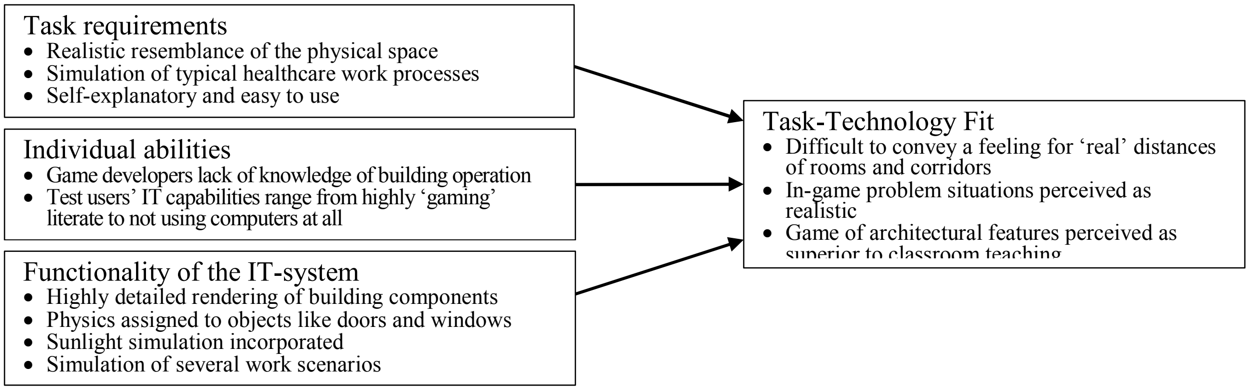

Figure 4. Key factors of the 'Ward' game's task technology fit

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