INTEGRATING BIM AND GAMING TO SUPPORT BUILDING OPERATION: THE CASE OF A NEW HOSPITAL

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Abstract

Moving into a new hospital requires healthcare professionals to adapt to a new work environment. Workflows, processes, and competencies become obsolete and need to be tailored for the new hospital. This paper explores a role-play serious game developed for the purpose of familiarizing professionals with their new work environment. A three-dimensional virtual prototype of the new hospital building created from Building Information Modeling technology, served as the graphical environment in which the game was staged. The game, namely the "Ward", is intended to provide healthcare professionals with a virtual training ground for exercising new work processes. We conducted a series of interviews with the client, healthcare experts, and the software developers involved in developing the games. Our intention of doing so was twofold: attaining an understanding of how Building Information Modeling data has been integrated into the game and exploring how the game's functionalities had been fitted to best support the healthcare professionals in their learning. By exploring the process of the game's development we were able to point out shortcomings in current practice and to suggest areas for improvement. These are (1) use of crossover modules, (2) increased collaboration, (3) clear communication of information needs, and (4) better contractual agreements. The gameplay could be further improved by increasing the amount of non-player characters. Moreover, we just begin to understand how pedagogical concepts for games conveying architectural designs can be built. This indicates that developing such concepts is an intriguing avenue for further research. We argue that the findings are useful for practitioners and researchers interested in integrating BIM and gaming technology.

Keywords: *healthcare, digital game based learning, BIM, Task-Technology Fit, building operation*

1 Introduction

In the past decade Norway's health care sector has seen a large program of investments. The target is to change and improve the way healthcare services are provided to the patients by building better caring environments. In order to meet these targets, two major hospitals, namely St. Olaf's hospital in Trondheim (2012) and Akershus university hospital in Oslo (2008) have recently been completed. Moreover, two additional hospitals, namely Vestfold and Østfold, are currently under construction. These facilities provide new environments of care constituted of surgery rooms, intensive care areas, and the most advanced equipment found. Intensive preparation and staff-training are required to safely and effectively operate brand new hospital facilities fitted with the latest technology (Stichler and Ecoff 2009). By preparing a hospital's workforce well ahead of starting-up, risks such as inefficient downtime resulting in staff and patient complaints, can be mitigated (Norman et al. 2012).

Advanced simulation based learning is believed to provide a means for improving staff performance in high-technology environments like aviation and healthcare (Shapiro et al. 2004). Digital game-based learning (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 'serious game', a more widely used term for DGBL.

While medicine has a long tradition for applying simulation systems to train individual doctors in their clinical skills, systems supporting teamwork have long been neglected in practice (Shapiro et al. 2004). This article reports on the development of a role-play serious game intended to serve as virtual training ground for healthcare professionals. The 3D graphical environment in which the role-play simulation takes place is based on Building Information Models (BIMs) created by architects and engineering consultants. How the BIM models in the hospital project have been developed is reported in depth elsewhere (Merschbrock and Munkvold 2014).

BIM is both a new technology and a new way of working for construction professionals providing a common environment for all information defining a building, facility or asset, together with its common parts and activities (Pittard 2013). Even though many of today's construction projects are designed based on BIM technology, the vast opportunities for virtual analysis and simulation remain unexplored even in BIM projects run by leading design and construction firms (McCuen et al. 2011). Likewise, using BIM models as 3D graphical environments in simulation based learning is still just in its infancy (Raju et al. 2011). Noticing this, journals such as *Information Technology in Construction* have published special issues on the topic area of "BIM and serious gaming" (ibid.). Topics discussed 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). In this article we contribute to this ongoing discussion by reporting on the development of a 3D role-play serious game used to train healthcare professionals in a new, yet unbuilt, work environment. The research question asked in this article is: *How can BIM and gaming be integrated to best support staff-training prior to starting up the operation of a healthcare facility?*

To address this question, we present the results of a case study conducted in a hospital construction project in the Østfold region of Norway. This project constitutes, according to the educational manager of BuildingSMART© Norway, the first application of BIM-based game for professional training in a healthcare construction project in Norway. The project entailed the development of a DGBL game, namely the "Ward", which was intended to familiarize the roughly 2500 healthcare professionals with their new environment. The new hospital ward differs from those found 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 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 (Goodhue and Thompson 1995).

2 Theoretical lens

In this article Task-Technology Fit (TTF) literature serves as a foundation to explore how a set of actors made a serious game to fit its purpose. TTF theory can be traced back to the decision making school of thought and is especially associated with the concepts of 'bounded rationality' (Simon 1957). In their seminal article Goodhue and Thomson (1995) proposed the concept of TTF to "better understand the linkage between the information systems and individual performance" (p. 213). One of the main assumptions is that technology "must match work tasks in order to bring improvements in work effectiveness" (Jarvenpaa 1989) as cited in (DeSanctis and Poole 1994, p. 122). Thus, the theory is deterministic in assuming that technology, once applied, should bring productivity, efficiency, and satisfaction (DeSanctis and Poole 1994). Goodhue and Thomson (1995) found that technology needs to be a good fit with the tasks it supports. Their construct 'Task-Technology Fit' 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. Naturally, before performance impacts can materialize, a system would need to be utilized. 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), or 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). Thus, TTF has in line with other theories used in information systems research, undergone a shift from what was a techno-centric focus to a better balanced socio-technical focus. For instance, the intention of Goodhue's (1998) research was to position TTF as an instrument for information systems policy choices. Therefore this version of the TTF model best reflects the problem situation found in our empirical setting, which is a socio-technical one. We focus our study at the process of readying a serious game for its implementation encompassing (1) the task definition, (2) the development of an alpha-version, (3) the development of the game itself, and finally (4) the quality testing conducted by a group of healthcare experts. The use of the game, once approved by the 'quality testers', was mandatory for 2500 of the 4700 total hospital staff. Goodhue's (1998) TTF model has been built to fit situations where information system utilization is mandatory, which is among the reasons for why we considered it a good fit for our study. TTF is a generic theory which has undergone numerous modifications to suit the purposes of particular studies (Goodhue, 1998). We modified the original TTF concepts based on what has been suggested as typical task and technology characteristics of simulation-based games (Kirkley and Kirkley, 2004). Below, we present the concepts guiding our study based on Goodhue (1998) namely: (1) task characteristics, (2) technology characteristics, (3) individual characteristics, and (4) user evaluations of task technology fit.

- *Task Characteristics*. When creating a digital environment for learning, the tasks would encompass the goals and objectives of the learning itself (Kirkley and Kirkley 2004). Moreover, it has been found important for serious games to be anchored in real-world problems and to provide users with a solid understanding of these (ibid.). Among the tasks in our case was to use a Building Information Model to provide users with a virtual space resembling the physical space, of the hospital under construction.
- *Technology Characteristics.* The technology would need to provide the means to create a match between the physical and the virtual space. Moreover, the technology would need to provide a digital representation, reflecting upon the complexity of the environment in which the learner should be able to function at the end (e.g. the hospital ward) (ibid.). Studying the characteristics of a cognitively complex and learning intensive technology, such as serious games, calls for a research methodology trading "simplicity and generalizability against accuracy" (Lyytinen and Damsgaard 2001, p.14)
- *Individual Characteristics*. We built upon and extended Goodhue's (1998) definition of individuals. Individuals in the context of our study are defined more broadly to include 'individuals using the data provided by the system' and 'individuals having a role in developing the game'. The reason for including the latter group was to understand the role played by the development team in creating a solid user experience for hospital personnel. Individual characteristics studies a person's background in using IT and their familiarity with professional healthcare work (Goodhue 1998).
- *User evaluations of Task-Technology Fit*. TTF is the degree to which a technology does or could meet the task needs. Goodhue (1998) developed a measure of TTF that consists of 12 factors: level-of detail, accuracy, currency, ease of use of hardware, software, presentation, compatibility (across different sources), meaning (of data items), confusion (in file organization), locatability (of needed data), accessibility (of needed data), assistance, systems reliability. The authors however state that, depending on the context, one or more of the measures may be trivial or unnecessary (ibid.).

3 Method

The setting of our case study is a major healthcare construction project in the Østfold region of Norway, built by the Southern and Estern Norway Regional Health Authority (Helse Sør-Øst) and operated by the county's hospital agency (Østfold Sykehus). A case study approach is considered appropriate as it enables understanding 'sticky' practice based problems where experience and the context of the action are important (Benbasat et al. 1987). The project comprises the construction of several facilities, including buildings for emergency, surgery and intensive care, patient rooms, psychiatric care, and for services such as a laundry and central sterilization. Altogether the buildings comprise a gross floor area of 85.082 square meters, and the project costs are estimated at € 670 million. Moreover, prior to starting-up the operation of the hospital roughly 2500 staff have to be trained and familiarized with their new work environment.

The case was chosen based on two main selection criteria. The first was that BIM in conjunction with simulation based gaming technology had been deployed in the project. According to the educational coordinator of the Norwegian branch of the industry-led organization BuildingSMART©, this project constitutes the first application of a BIM-based serious game in a Norwegian healthcare construction project. The second was to choose a project that had neared the completion of the BIM-based serious game. To capture the entire development process our data collection was undertaken just when the game was undergoing a final quality assessment before being released and made available for its users.

Helse Sør-Øst and Østfold Sykehus decided to prioritize BIM technology use in design, construction, and operation. The outcome of the design process was a highly detailed virtual model serving as a digital prototype of the future building. Serious games were developed as part of the efforts to extend the usage of digital modelling data beyond building design and make it available for operation. 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). Accordingly, BIM was deployed as 3D virtual environment for the serious games used in staff-training. Thus, this project where the integration of BIM and gaming was prioritized made a compelling setting for our research.

Our 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 individuals. Moreover, we complemented our work by observing player behaviour in a game testing session. The target was to interview a range of knowledgeable actors having had either hands-on or managerial tasks in developing or testing the serious game. Gaining an in-depth understanding of the phenomenon required interviewing representatives of each stakeholder group involved in making the game. Thus, (1) the clients' managers responsible for both the BIM model and the development of the game, (2) representatives of the four firms involved in developing the games alpha- and full-versions, and (3) a range of healthcare professionals have been interviewed. The organizations subject to our study were either located in the Østfold region of Norway (Sarpsborg etc.) or in the wider capital area of Norway (Oslo, Hamar etc.). 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). An overview of the interview details such as the interviewee's professional roles, interview durations, techniques and interview dates can be found in Table 1.

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

All interviewees were informed about the modalities of the interviews and gave their informed consent for the process. The interviews were recorded, transcribed, and coded according to the concepts relevant in the task-technology fit model. The software used to support the coding of the interviews was NVivo10. The coding was performed by uploading transcripts as documents into NVivo 10, assigning nodes to notions that could be related to the key concepts, and creating reports that related the occurrences across interviews.

4 The 'Ward' game

The analysis in this article is based on the task-technology fit (TTF) concepts introduced in chapter 2. In what follows, we present our aggregated data based on the key constructs relevant in TTF; that is, (1) task characteristics, (2) technology characteristics, (3) individual characteristics, and (4) user evaluations of task

(a) Early-alpha version | **(b) Full-version**

Figure 1. Screenshots of the serious game 'Ward' showing an (a) early-alpha-version and (b) full-version [(a) courtesy Ole Andreas Jordet, Krillbite Studio; (b) courtesy Jarl Schjerverud, Sykehuset Østfold HF]

technology fit (Goodhue 1998). Figure 1 presents two screenshots: one of the game's alpha-version (left) and one of the full-version (right) to provide the reader with a visual impression of the "Ward game".

Task characteristics. The gaming project was initiated jointly by the hospital administration and the regional health authority as part of a wider training program to prepare staff for moving into the new hospital. The serious game was intended to "teach, learn, and train people who are going to work in the new hospital" (client, hospital). The targeted user group for the game comprised 2500 nurses, physicians, and other healthcare professionals out of the total 4700 hospital staff. So-called "training days" were arranged to provide a forum where groups of professionals could play the game. Thus, playing the game was mandatory for hospital staff. In addition, the client appointed the game developers to deliver solutions that could be run on various types of tablets, laptops, and PCs and thereby reach a wide audience. The goal was to make the game available for those employees wanting to learn more and play the game at home. The game was regarded as an essential means to familiarize staff with the new hospital and the new work processes taking place in it.

> "[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 escape looking 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)

> "[The game has to be] accessible and intuitive, [and] there should be no manuals […]. It [the game] 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)

From the quotes above it follows that the games needed to provide users with, (1) a realistic *visual impression* of the future hospital, (2) a good representation of the *real-world problem* that needed to be learned, and (3) the games needed to be *motivating, intuitive and easy to use.*

(1) *Visual impression*. The following quote stresses the importance of getting the visual impression right: "The most important thing is to get the details in their place so that it is as realistic as possible" (Health care professional #1). Creating a gaming experience as identical as possible to the realities of the new building was prioritized by the client. Entering the new hospital after having played the game should leave users with an impression of "having been here before" (Client, regional health authority). To achieve this, the virtual space represented in the game needed to provide a close resemblance to the physical space found in the new and yet unbuilt hospital. The client's idea was to utilize virtual BIM models created as part of the building design process as 3D graphical environments in which the games where to be staged. Rooting the game in data used to engineer the building ensured that dimensions, proportions, and materiality of the 'real' hospital were accurately represented in the game. According to the project's BIM manager, the construction design team had succeeded in creating a sophisticated digital prototype of the new building (Client, regional health authority). Consequently, the task of the game developers entailed embedding their game in a semantically rich architectural design model. The job required importing data created by architects in architectural design software into the engine of the game. Moreover, using building design data signifying building materials used

would also provide gaming developers with the opportunity to render details like surfaces, lighting, and fittings with a high level of accuracy and detail. How the game's "visual impression" has gradually been enhanced from early stage alpha-versions to the final product can be seen in figure 1.

(2) *Real-world problem*. The game was to serve as a 'virtual' training ground for healthcare professionals, simulating typical work processes taking place in a hospital ward. Naturally, accomplishing this required infusing the game with healthcare expertise to present users with a 'true' reflection of work situations found in reality. This required simulating work procedures like handling patient complaints, disinfecting hands before entering a room, or finding the required medication. This is why the clients' organization instilled the role of a gaming responsible manager whose task it was to fuse the two knowledge domains healthcare and gaming. The job of this manager included facilitating the communication among healthcare subject matter experts and game developers. Consequently, healthcare experts had to be appointed to collaborate with game developers to jointly create the gameplay signified in the games. Beyond getting the work situations right, it was important to inform the game's dialogues by the same words, phrases, and language that would be used in a real world situation (Health care professional #1). Thus, collaboration between healthcare experts and text editors was necessary as well.

(3) *Motivating, intuitive and easy to use.* This game was intended to be self-explanatory and easy to use. Further according to the client, the game was to be designed in a way that using it was actually perceived as attractive and enjoyable by its users. Moreover, the game was supposed to provide users with immediate feedback on how well they executed their work tasks and reward them accordingly. The aforementioned measures were perceived as necessary since the game was supposed to mitigate for potential anxiousness felt by hospital staff before moving into the new hospital. The desired outcome of making the game was that hospital staff enjoyed playing the game so much that they would actually play the game in their spare time as opposed to only the few arranged "training days". To enable users to use the game at will various versions were to be developed which could be run on tablets, laptops, and stationary PCs.

Technology characteristics. The process of making the game took place in four sequential stages. First, an architectural BIM model was developed. Second, the client initiated a "proof of concept" study (e.g. game development stage 1) in which an architectural BIM model was handed over to a number of game developers to have them develop a simple version of a playable hospital game. BIM-based gaming is just in its infancy and the early prototype served as means to explore what could be gained by deploying this technology in the context of a hospital construction project. As can be seen in figure 1 the full version of the game took a first-person graphical perspective rendered from the viewpoint of the player, whereas the alpha version took a third-person 'behind the back' perspective. After approval by the hospital's administration, the next game design stage was initiated. The second stage encompassed developing a full version of the game which could be used to train the hospital staff before moving in. This was done in close collaboration with experienced health care staff. Lastly, the game was tested on a "testing day" where 20 randomly selected hospital staff played the game and evaluated it. The sequential game development process is depicted in figure 2.

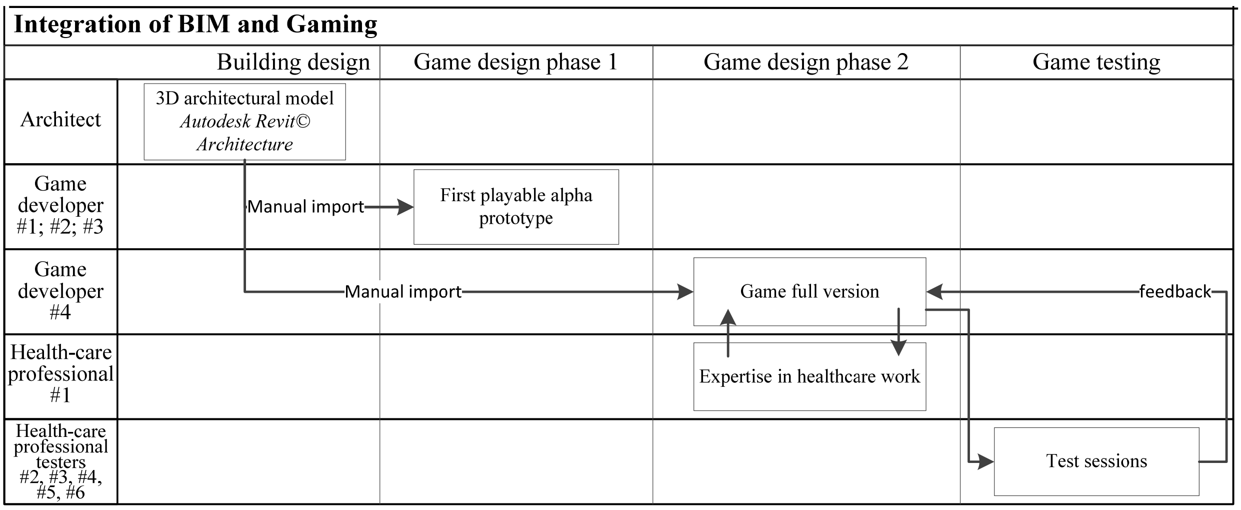

Figure 2. The sequential transition from BIM to gaming

In what follows, the first and second game design stages are focussed and it is explored how the technology was built to best fulfil the three tasks (1) visual impression, (2) real-world problem, and (3) motivating, intuitive and easy to use (see task characteristics).

(1) Visual impression. Creating a realistic visual impression of the building required importing architectural data into the game. Literature reports that there is no "easy way" for importing and exporting geometry from CAD and/or BIM into a game engine (Lehtinen 2002; Yan et al. 2011). Further, it has been suggested that it might be a good idea to develop software modules easing the "crossover" of data between BIM and game engines (Yan et al. 2011). However, in the case project the crossover of data was done manually and developing software to aid this was not focussed. As depicted in figure 2, each of the game developers received a full-fledged digital BIM model created in architectural design software. The following quotes illustrate how much the game developers struggled to manually import BIM design data into their game engines:

> "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)

> "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)

From the quotes above it follows that architectural data could not be used straightforward in gaming. Consequently, the data import was prefaced by a lengthy process of "cleansing" the architectural BIM model of all unnecessary data. Moreover, the developers making the full-version of the game decided not to directly import BIM geometries into their game engine, and instead modelled, inspired by the original design, anew. This was costly, time-consuming, and work-intensive and constituted only the first step on the way towards creating a realistic 3D virtual environment. After importing and remodelling of the geometries the models were manually rendered, lighting and shading simulated, and the digital hospital was furnished. Thus, in this case study, turning the BIM model into a realistic 3D game environment was labour intensive and tedious work. Moreover, design changes undertaken by architects and engineering consultants after the model had been passed on to the game developers, were not accounted for in the game. Nonetheless, as can be seen in figure 3, the outcome of this work was a sophisticated digital prototype of the building, displaying details such as the wall signs in hospital corridors (left) or the furnishing in the patient rooms (right). Additionally, several new electronic tools like electronic patient curves on tablet computers, large wall-mounted touch panels (to maintain an overview over the patients, the logistic, and the personnel resources at the ward), and the new electronic tube post system, were to be simulated in the game. These electronic 'gadgets' were to have an in-game functionality simulated in the game, too.

(2) *Real-world problem*. 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 transports 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 to learn the concepts of being a nurse in this new hospital. The following quote illustrates how the features of the game-play resemble real world problems 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 (left) 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 game play. 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. To ensure that the problem situations depicted in the game would be realistic a senior healthcare professional was involved in the making of 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.

(a) Hospital corridor	(b) Patient room

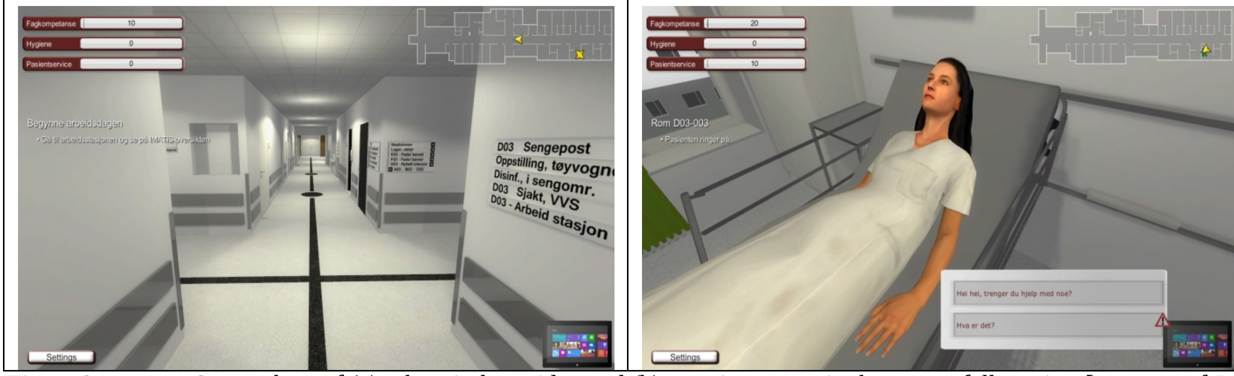

Figure 3. *Screenshots of (a) a hospital corridor and (b) a patient room in the games full version [courtesy of Jarl Schjerverud, Sykehuset Østfold HF]*

(3) *Motivating, intuitive and easy to use.* The game designers decided to put in place a reward system with the intention to drive users' engagement and to provide them with feedback on their performance. The reward system can be seen as a meta-game layered onto the main gameplay. The system rewarded points to achievements in three categories important in healthcare work namely (1) work competency, (2) hygiene, (3) and patient service. Thus, how well players performed in completing in-game tasks in the virtual hospital ward was assessed based on a point based metric. Each point giving category encompassed a range of different healthcare activities. Points for work competency were awarded when players accomplished tasks like finding the right drugs for a patient. The hygiene category encompassed activities like disinfecting ones hands before entering a patient room, or tidying up. Service points were awarded for establishing eye-contact when talking to a patient or addressing patients appropriately in a dialogue. A players' accumulated point score in the three above named categories was displayed on a scoreboard placed at the top left corner of the screen (figure 3). The responsible gaming manager showed how the game reward system worked throughout an interview session:

> "Eye contact, because I looked towards the patient, points for that too […]. [A text box appears on the screen] Now, we talk to him [the patient NPC] and now I answer one of his questions. It is not always clear which answer is appropriate, and you can usually choose between three dialogue options. There can be more than one right or wrong answer. For example: NPC: 'Is it possible to get a juice?' player: 'Sure, hold on a second'." (Client, hospital)

In addition to establishing a reward system, efforts were undertaken to craft an enjoyable game experience. For instance, text editors and senior healthcare professionals worked together towards creating realistic, and at the same time funny dialogues. This was to make most of gaming technology as a method for learning, and to create a "fresh" and captivating learning experience, reaching both inexperienced and experienced professionals. The following quote illustrates how "fun" was made part of the gaming experience:

> "We have for example some funny parts in the dialogues. For example one group of patients is dement and these can say very strange things. When you start the dialogue with a patient then you will have many different choices of how to respond. Some are correct, some are almost correct, and some are totally crazy. There is a patient that is totally lost and does not understand that he is in a hospital and he says repeatedly 'Why am I here? I want to be home and work in the garden'." (Healthcare professional #1)

Individual characteristics. Fulfilling the task of creating a functional, virtual training ground for hospital staff required three different expert groups to share knowledge. These groups were architects, health care professionals and game developers. Achieving active knowledge sharing across these three domains required managerial attention. Consequently, hospital management established the role of a "knowledge-broker", having the responsibility to facilitate knowledge exchange among the different disciplines in 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 game's prospective user group. Her job encompassed close collaboration with the developers to insure the game would reflect the realities of hospital work. She met up with the game developers in a series of five workshops in which she helped developing dialogues, played the game and explained work tasks. The following quote describes why involving a senior health-care professional was of crucial importance in game design:

> "It is of course a lot of information you have to give them [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)

While according to the BIM manager, architects and healthcare professionals collaborated closely throughout the building design phase, the game development took place without active involvement of architects. 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 buildings' physical space was left to the game developers who had no prior experience from architectural design. The twenty individuals testing the game were randomly selected out of the total population of 2500 hospital staff supposed to use the game. Their professional backgrounds and IT capabilities differed along a spectrum from highly computer literate individuals to those hardly using computers. While young nurses were quite acquainted with using games in private, many of their older peers had no gaming experience from before.

User evaluations of task-technology fit. A group of healthcare experts tested and evaluated the game before it was rolled out operation wide. We observed player behaviour during and right after their first encounter with the game. Moreover, five healthcare experts were interviewed with the intention to capture their evaluations of task-technology fit. The evaluation of the technologies fit for the three main tasks (1) visual impression, (2) real-world problems, and (3) motivating, intuitive and easy to use are presented below.

(1) Visual impression. 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, somewhat at least." (Health care professional #2). 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)

(2) Real world problem. While the gameplay itself was perceived as realistic and interesting, it could have been further improved by adding NPC's simulating other colleagues, patients, and visitors. Doing so could have added to a realistic impression of the 'chaos' usually found in hospitals. Players were left with an impression of "it's only me running around in the corridors" which does not capture hospital life (Health care professional #6). At the same time, most test-players found the in-game tasks captured the hectic pace of a busy working day. Some of the new technology used in the hospital and simulated in the game, like the tablet PCs showing patient records, were perceived as realistic. However, some players argued that they had learned only few new procedures and criticised the game for emphasising only basic work processes.

(3) Motivating, intuitive and easy to use. One of the aspects considered when making the game was to motivate users by embedding funny dialogues in the gameplay. In particular, the responses of dement patient NPC's were designed for this purpose. When asked, the testers found the patient NPC's to be a realistic resemblance of their real peers. "Especially the dement lady's [behaviour] was spot on, just like the real thing [laughter]" (Healthcare professional #2). From the quote it follows that the testers were amused, just as intended. When asked what else made the game fun to use the response was: "hard to say, it was fun" (Healthcare professional #4). When specifically asked whether the reward system fulfilled its purpose of motivating players, the response was unanimously positive. How the game was perceived as a useful means of learning is illustrated by the following quote: "one becomes more focussed by doing it yourself [playing a game] instead of being served a power point presentation, which is not active" (Healthcare professional #4). However, several testers reported feeling "dizzy, sea sick, and even driven crazy [nor. huggærn]", indicating that not all of them were accustomed to using computers in general, and/or games in particular. On the other hand some users were motivated and considered using the game at home to train some more, or show friends what they do at work.

5 Discussion

In what follows, we discuss the game's strengths, shortcomings, and potential areas for improvement. By doing so, we provide a useful starting point for practitioners wanting to apply a BIM-based serious game in a healthcare context. An overview of the games task technology fit can be found in figure 3.

Most test players found the ward game to provide them with a realistic representation of the future hospital. However, there is room for improvement, and from our data it appeared that architectural BIM data could not be used straightforward in building the 3D game environment. Reasons can be found in the different information needs of game developers and architects. While the architectural design model needed to be detailed and semantically rich, the game developers had only need for simple surface data. Moreover, the architectural models simply took up too much computing capacity to be directly imported into game engines. This is in line with what has been found by Yan, Culp and Graf (2011) who illustrated that developing a module facilitating the crossover between the two software solutions could be a feasible option to ease this. However, while such programs are presented in literature, they are not yet commercially available (ibid.). Current practice of importing BIM data into game engines is characterized by a large amount of manual labour, redundant work, and unnecessary and error-prone rework. In fact, the handover of BIM models from architects to game developers happened without any form of coordination. This can partially be attributed to the game developers not clearly communicating their information needs to the architects. Improving this could be achieved by a stronger focus on collaboration and a more active involvement of game developers throughout the construction design phase. To provide construction experts with a motivation to partake in such collaboration, it should already be defined in the project contracts. Game project groups could be formed where architects, healthcare experts, developers, and possibly patients all could join forces. Integration of BIM and gaming could be improved by (1) use of crossover modules, (2) increased collaboration, (3) clear communication of information needs and, (4) better contractual arrangements.

The game was developed sequentially, which we argue resembles a mere traditional systems development process. However, the game can be seen as a complex system whose requirements and limitations cannot be known entirely before completion. To account for this, healthcare experts were involved throughout the game development process. In-game dialogues and healthcare scenarios have been developed jointly by a senior healthcare expert and the game developers. By doing so, the developers succeeded in creating a gameplay perceived as realistic by most of the testers. However, there was criticism and especially the relatively low number of patients, staff, and visitor NPC's in the game was perceived as unrealistic and unfit to simulate a busy day in a hospital. Moreover, a limitation of gaming technology surfaced in that a game does not provide a good understanding of the walking distances that would need to be covered between the rooms in the hospital. Thus, the final game had some limitations. In addition, when thinking of future application areas of this technology, it could be a good idea to go beyond simulating standard work scenarios and also develop simulations for extreme or critical situations that may arise in hospitals. A conceivable fire outbreak in a hospital where staff and patients would need to be evacuated, or a crisis situation when a hospital receives a large number of patients after a major incident (i.e. earthquakes or floods), could be such scenarios. Such games could then be used by hospital staff as well as fire-fighters, police, and local authorities. These games could be further developed into multiplayer solutions used simultaneously by a range of players. This would then also enable a gameplay where multiple actors can train coordinated actions. The gameplay could thus be further improved by: (1) more NPC's, (2) simulation of crisis and emergency scenarios, and (3) multi-player solutions.

Most of the testers found the game easy to use, however some players not accustomed to computer games reported feeling unwell or dizzy when starting up. In terms of player motivation, the developers managed to create a captivating gaming experience. Though they were encouraged to just take it easy, look around and become familiar with the place, the testers soon found themselves performing the in-game tasks. Both the reward system and the 'funny' parts of the gameplay triggered them to find the game enjoyable and motivating. Moreover, the facts that 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. While people like to share, we argue that the motivation to voluntarily play the game at home can partially be attributed to the intriguing and funny dialogues and the reward system. While the game was "serious" and its main focus was not pure entertainment, fun was found to play an important role in creating a captivating learning experience which is in line with what has been found elsewhere (Kirkley and Kirkley 2004). Thus, when creating role play games for hospital settings, developers should aim at providing a gameplay having elements of fun.

Table 2. Overview of the ‘Ward’ game’s task technology fit

TTF concept	Key factors
Task characteristics	• Realistic virtual visual impression of the physical hospital • Gameplay reflecting real-world problems and everyday-life in the hospital • Gameplay motivating, intuitive, and easy
Technology characteristics	• Sequential game development process in four phases • Architectural data could not be used ‘straightforward’ in a game engine • Simulation of healthcare scenarios in which patients need to be cared for • 20 patient NPC’s having different healthcare conditions simulated in the game • Point based in-game reward system for competency, hygiene, and patient service • Dialogues and gameplay infused by healthcare language and professional knowledge
Game developers characteristics	• Experienced gaming expert worked as clients gaming manger and champion • Game developers not having prior experience from healthcare work • Senior health care expert collaborated with script editor, and game developers • Architects had no active role in game development
Test-user characteristics	• 20 randomly picked healthcare professionals out of the 2500 future users • Varying IT capabilities, age, and jobs
User evaluation of task - technology fit	• In-game problem situations widely perceived to be realistic • Dialogues with dement patient NPC’s considered funny • Most test-players found the reward system motivating • Some users felt “dizzy, sea sick, and even driven crazy” when playing the game • The games ending has been criticized by some for being too abrupt • Users found that there were too few staff, patient, and visitor NPC’s • Users found it difficult to get a feel for the ‘real’ dimensions and distances of hospital corridors • Users felt game based learning superior to chalk, talk, and PowerPoint classroom teaching • Overall positive evaluation of the game and its value for education

This article builds on the emerging discourse on the application of BIM-based games in building operation in general and in the context of health care projects in particular (Juang et al. 2011; Lin, Son, and Rojas 2011; Raju, Anumba, and Ahmed, 2011; Yan, Culp, and Graf 2011). Based on our findings, we argue that BIM-based gaming yields a range of opportunities for improving staff training in health care projects including: training work processes, getting to know a new facility, and training emergency scenarios. Yan, Culp, and Graf (2011) argued that “[…] building operation may benefit from the educational potential of games” (p. 446) and our data shows that users found BIM-based games to provide them with a far better understanding of the new building than traditional talk, chalk, and PowerPoint classroom teaching could have done. 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 explore the value of BIM-based games for training emergency situations in hospitals or elsewhere.

The main contribution of our work is that we draw further attention to the potential of digital game based learning as a means to familiarize future users of a facility with their new work environment. The game presented in this article shows that gaming technology yields a range of potential advantages over traditional classroom teaching. In spite of the advantages, the case study highlights the difficulties revolving around developing a gameplay fit for conveying the architectural layout of an unbuilt facility. To illustrate this, user questions like: How far do I need to walk? or, In which direction am I walking? remain unaccounted for by current games. Scholars have pointed out that the pedagogical principles underlying the gameplay are essential for the games’ success in terms of learning provided (Rilling et al. 2010). The case showed that no professional pedagogues have been involved, leaving the impression that the game could have been ‘better’ once infused by pedagogical knowledge. An important implication for research, aside from improving technology, is that we need work inquiring into pedagogical concepts for digital games familiarizing users with architectural layout.

6 Conclusion

We have shown the usefulness of the Task Technology Fit concept to analyse, explain, and understand how BIM and gaming could be integrated to best support staff-training prior to starting up the operation of a healthcare facility. The game studied in this article can be in many aspects seen as a success, since most of its test users found it to provide superior learning when compared to traditional classroom teaching. Moreover, the BIM-based game gave its users the opportunity to get acquainted with a new working place before it was actually built. However, throughout our analysis it became apparent 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. Much of the gameplay was perceived as realistic by its users. However, there is still room for improvement, such as increasing the amount of non-player characters representing patients, visitors, and staff or turning it into multi-player solutions. Moreover, a future application area for BIM based games for hospitals is the simulation of emergency situations. In addition, it has been found that the game's reward systems and 'funny' dialogues infused with healthcare knowledge were perceived by players as motivating. One area in need of further research would be exploring the value of BIM-based serious games for training emergency situations. In addition, an important implication for research, aside from improving technology, is that we need work inquiring into pedagogical concepts for digital games involving with architectural features. This, combined with the potential of BIM-based serious games for starting up facilities, leads us to conclude that BIM-based games are an exciting area for further research.

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