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Abstract

Only limited research has been conducted with respect to the use of Virtual Reality for planning of Facilities Management. Through a case study experiment, using only the early stage architectural 3D model of a test building, a Virtual Environment was generated allowing test persons' evaluation of the usability of Virtual Reality as a Facilities Management planning tool. Facilities Management, Building Information Model, Modelling and Management and Virtual Reality are individually widely researched. However, this paper contributes to great amount of scientific literature existing with respect to Facilities Management, by studying the topics in unison. The evaluation of Virtual Reality for Facilities Management planning was divided into a qualitative phase involving interviewing of test persons and a quantitative phase allowing test persons to rate their experience in Virtual Reality in a questionnaire.

The study revealed that 82 per cent of the test persons found Virtual Reality usable as a planning tool for Facilities Management. The experiment evaluation however also showed a wide range of the degree to which the test persons found the tool usable.

Keywords: Virtual Reality (VR), Facilities Management (FM), FM-planning, Building Maintenance

1. Introduction

Facilities Management (FM), Building Information Management (BIM) and Virtual Reality (VR) are topics presently receiving increasing focus in the architectural, engineering and operation industry. FM is by the International Facilities Management Association (IFMA) defined as: *a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating: people, place, processes and technology* (IFMA, 2019). This is also definition used in this paper.

Today, multiple Information and Communication Technology (ICT) tools are used in the FM industry to facilitate management as well as communication and process, people, place and technology integration (Aziz, Nawawi, & Ariff, 2016; IFMA, 2019; Olapade & Ekemode, 2018), and capturing of knowledge through a building's life cycle (Arayici, Onyenobi, & Egbu, 2012; Kymmell, 2008).

Since the introduction of e-mails in the 1970s various types of ICT tools have been developed and introduced to the FM industry such as: Maintenance Management Software, Computer Aided Facilities Management (CAFM) software and Building Information Management (BIM) (Aziz, Nawawi, & Ariff, 2016; Donaldson, 1991; Elmualim & Pelumi-Johnson, 2009; Harrison & Leaman, 1986).

One of the primary motivators for stakeholders in Facilities Management when implementing new technology is the opportunity for direct gains and benefits in their operations (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012). Expanding use of ICT must therefore consider the benefits such can provide the stakeholders.

BIM is defined as either: Building Information Model, Modelling and/ or Management. In this paper we define it as Building Information Management, including both the 3D model, the manipulation of the model and the management/ handling of the model with respect to FM.

Using BIM can provide a way of storing FM data supporting the Facilities Manager during operation (Farghaly, Abanda, Vidalakis, & Wood, 2018; Olapade & Ekemode, 2018) as well as Architectural, Engineering and Construction (AEC) personnel in the early stages of design. Use of BIM

additionally allows Facilities Managers to specify what they really need, at early stages of a project development (McAuley, Hore, & West, 2013; Tucker & Masuri, 2018). BIM based FM is sometimes also defined as 6D BIM (Nicał & Wodyński, 2016).

Building Information Management can be beneficial for a variety of FM practices such as commissioning, quality control and assurance, energy maintenance, repair and space management. The model must however be accurate and updated to be usable for FM (Kassem, Kelly, Dawood, Serginson, & Lockley, 2015). Increased control of BIM during design and operation may lead to heightened cost in early project stages, but can potentially reduce the owner's operation and maintenance cost (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012). Facilities Managers are nevertheless hardly involved in BIM (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012; Volk, Stengel, & Schultmann, 2014) or a building's planning process, making maintenance strategies based on "as built" conditions when a building is delivered (Olapade & Ekemode, 2018). FM planning can however, potentially begin before the FM organisation receives an "as built" model, using 3D models from earlier design stages.

VR development has, in recent years, led to increased utilization of the technology (Shi, Du, Lavy, & Zhao, 2016) in many domains (Du, Zou, Shi, & Zhao, 2018; Goulding, Rahimian, & Wang, 2014), as an interactive design platform, supporting collaborative design and co- creation (Petrova, Romanska, Stamenov, Svidt & Lund Jensen, 2017; Rasmussen, Gade, & Jensen, 2017; Svidt & Sørensen, 2012). A tool for simplified communication between building users and designers (Sørensen & Svidt, 2017). Real time audio- visual simulation (Wyke, Christensen, Svidt, & Lund Jensen, 2019). Building evaluation (Kuliga, Thrash, Dalton, & Hölscher, 2015). Simulation of dangerous situations (Wang, Li, Rezgui, Bradley, & Ong, 2014) and user experience testing in a more cost effective way than real life mock- ups (Andrée, Nilsson, & Eriksson, 2016; Zou, Li, & Cao, 2017), with increased control over the tested environment (Kinateder, Müller, Jost, Mühlberger, & Pauli, 2014; Pitt, Goyal, Holt, Ritchie, Day, Simmons, Robinson, Russell, 2005; Wiederhold & Wiederhold, 2010).

Using vendor neutral formats like the industry foundation classes (IFC) allows importing BIM models into CAFM platforms overcoming lack of interoperability between CAFM tolls and the growing number of commercially available BIM packages (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012; Farghaly, K., Abanda, F. H., Vidalakis, C., & Wood, G. 2018). It furthermore allows conversion of geometric data into Virtual Environments (Bille, Smith, Maund, & Brewer, 2014; Rüppel & Schatz, 2011)

To understand how VR can be used by Facilities managers with respect to operation and maintenance, a research study was conducted, using an early stage architectural 3D model (BIM) to generate a Virtual Environment for testing of the usability of VR as a tool for FM- planning.

2. Methodology

In this section, the methods for the qualitative and quantitative data collection are introduced. The description of the technological experimental development is additionally presented and explained.

2.1 Empirical data collection

Empirical data were collected in two phases, using the contextual design method as described by Beyer & Holtzblatt (1997). The first phase involved interviewing facilities management (FM) personnel at Aalborg University's Campus Service (FM-organisation), to attain knowledge of which systems they use in building operation and FM. The second phase involved interviewing test persons, after their participation in a Virtual Reality (VR) experiment. This stage additionally included test persons responding to a questionnaire of six questions, rateable on a scale from 0 to 10.

Eleven test persons participated in the experiment. After immersion into VR for 3-5 minutes, they were asked to evaluate the usability of VR for FM-planning, focussing on building maintenance. The test persons thereafter responded to a questionnaire and an oral interview, documented through audio recording.

Responses from the test persons presented in section: "3. Results" are based on the calculated mean, variance, spread and range of the responses to the questionnaire.

2.2 Technological experimental development

The VR used in the experiment was based on the architectural building model of a selected test building, converted from the .RVT (Autodesk Revit) format into .FBX for generating the Virtual Environment (VE) in 3dSMAX. The generated VE was then exported in .FBX and imported into the Unity Game Engine. The full architectural model was converted into VR; however only a limited area of the building was accessible to the test person in VR during the test, as shown in figure 1. No steps were taken to optimize the VR model to make it more realistic or improved graphically. Only the "raw" architectural model was used, to test if such a model, with low Level of Development (LOD) and lack of technical installations can be used as a FM-planning tool.

The Oculus Developments Kit 2, Head- Mounted Display (HMD) was used in the experiment.

3. Results and Discussion

In this section, the case study and the results from the experiment are presented. All results are discussed promptly after introduction.

3.1 Case study

Aalborg University Campus Service (FM-organisation) is responsible of operating 243.200 square meters of educational facilities in Aalborg, Denmark, owned by the Danish Building and Property Agency (Bygningsstyrelsen), whom in addition to owning the buildings also finance their operation. The FM-organisation is furthermore the primary stakeholders with respect to implementation of new technology (Bygningstyrelsen, 2015), such as VR for FM.

In order to operate and do FM at Aalborg University campus, multiple systems have been implemented, as a combined building operation and FM system, as shown in figure 2. Even though only 2D drawings are used directly as part of the FM-organisations' workflow, 3D models are used as data repositories (Building information management). These models are updated every time changes are made to the facilities portfolio operated by the FM-organisation, in order to be able to generate 2D drawings, which are used in the FM-system.
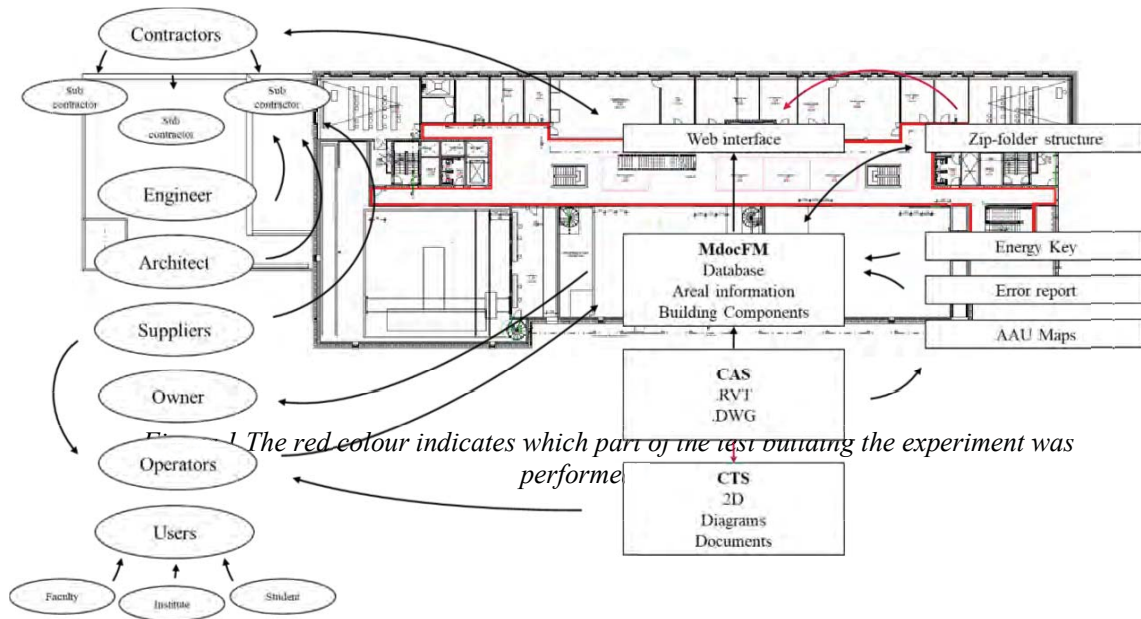
Figure 2 The FM-organization's systems and their interaction with stakeholders. Red arrows indicate manual exchanges.

Since 2011 AAU Campus Service have demanded to receive "as-built models" in the industry foundation classes (IFC) format (AAU Campus Service, 2011), when new buildings are handed over to them for operation. Upon receiving the IFC "as-built" model at building handover the FM-organisation usually re-do the model, to ensure a fitting quality and LOD, as the received models often presents with multiple errors and issues due to an inadequate modelling discipline.

According to a FM-operator: "*One reason for why some models are less usable, is that some building construction projects runs for a very long time, and therefore has many different persons modelling the 3D during the design and construction phase. This change of personnel is displayed in the variation of quality in the models we receive*".

Up to seven different systems are used to fulfil specific purposes, for specific segments of the stakeholders or building users, which is also the case for many other FM-organisations also relying on numerous different systems (Wong, Ge, & He, 2018). The implementation of the seven tools is a result of implementation happening over decades, beginning in the 1970s, as results of new needs arising. Even though combining some of the systems is possible, no efforts are being made in that regard.

One of the primary issues with the workflow the FM-organisation has, is the limited interoperability between systems, which in most situations only allow one-way communication. Even though the use of multiple systems in some cases create internal issues regarding interoperability and difficulties in data exchanges with external partners, the system used by the FM-organisation is capable of providing the data needed to generate and use Virtual Reality.

The FM-organisation only uses 3D model to generate 2D drawings which they use in their building operation and FM. They do however update their 3D models continuously, whenever changes are made to the buildings they operate, allowing for a potential wider use of the models, thus allowing use of VR, without cost involved in modelling the virtual environments.

Adding VR to the system portfolio will undoubtedly increase the complexity of the overall workflow of the FM-organisation By studying if VR can provide benefits in form of heightened understanding and better basis for decision making with respect to FM-planning, it can however be discussed if the increased complexity is overshadowed by the benefits VR can provide.

3.2 Virtual Reality experiment

The Virtual Reality (VR) experiment was designed to asses both common understanding of

facilities management (FM) of the test persons and evaluate the usability of VR as a planning tool in FM, using an initial architectural model received from the FM-organisation participating in the case-study to generate the Virtual Environment.

All the participating test persons rated themselves with an average knowledge of facilities management of 4.09 on a scale from 0 to 10, with a spread of the responses of 2.96. As all test persons were professionals in the building industry, the low knowledge average might indicate that there is a need for ways to communicate FM issues generally in the industry. The responses ranged from 3 to 8, indicating that no one was completely unknowing, and that none of the test persons would be considered experts in FM.

When asked how the test persons estimated VR's ability to heighten the understanding of FM needs in the test building, the mean of the responses was calculated as 3.27 with a spread of 2.04. The experiment results showed that use of VR might improve the understanding of the FM needs in a building. However, as the responses ranged from 1 to 5 it was revealed that the test persons only found VR use as what can be interpreted as limited or mediocre at best.

One of the test persons commented on the usability of VR as a FM-planning tool, by stating: *"Maintenance of the high glass areas, is as for my opinion the biggest FM-problem. The inability to clean the windows is clearly visible in the VR model"* - test person A.

For other test persons the limited usability of VR as a FM-planning tool was described as due to low LOD and lack of realism - *"It is a limited model with respect to LOD, but what I noticed is that it is hard to see what is what in the model. It gives a nice overview of the geometry of the building, but that is it. To me it is just a grey model with limited information"* - test person B.

The comment from test person B was elaborated on by test person C stating: *"HVAC and other technical installations would be a nice addition to the model. Except for building geometry, the visibility of FM-issues is limited"* - test person C.

When using initial architectural models of a building for FM-planning, the limitations seem to be the lack of graphic representation of visual capabilities of the building, as well as a lack of technical installations.

Use of HMD to allow immersion into VR, compared to the use of monitor observation of VR, was rated with a mean of 5, however, with a range of the test person responses going from 0 to 9. This indicates that it is highly person depended how HMD enhances perception and tangibleness, making it hard to quantify when HMD-viewed VR can be used beneficially for FM-planning generally.

In the experiment, 82 per cent of test person answered that VR is usable in FM-planning. With respect to VR and the degree of which it be used for FM-planning the mean of the responses was calculated to be 4.09, ranging from 0 to 8. This finding reveals that most people in the experiment saw VR as usable in some way, but without a significant impact as a planning tool. Based on the qualitative responses from the test persons it is however clear that, a more realistic VR regarding colouring and inclusion of technical installations would improve the usability of VR as a FM-planning tool.

Another interesting result from the experiment was the test persons' reaction to the HMD-viewed VR. In the experiment the test persons, rated their experience of VR sickness, with responses ranging from 0 to 10, showing a wide range of reactions to VR. The ratings however showed that 50 per cent of the test persons only had little or no reaction to the HMD-viewed VR, arguing both for and against using the tool as a planning tool.

4. Limitations

- The field of view in a Head- Mounted Display (HMD) is only 100º (Rift info, 2019), compared to the 210º horizontal and 150º vertical view human eyes have (Traquair, 1938), limiting the realism of the experiment.
- Eleven test persons participated in the experiment. All of whom were construction architects, and all participants were male, limiting the generalisability of the experiment results.
- VR sickness is a common consequence in using VR (Feng, González, Amor, Lovreglio, & Cabrera-Guerrero, 2018; Sharples, Cobb, Moody, & Wilson, 2008; Shi, Du, Lavy, & Zhao, 2016; Svidt & Sørensen, 2016), as also indicated in the results from the case study. This limits the use of VR as a FM-planning tool, and the testing of it, as some might not have experienced

the potential of the tool due to feeling uncomfortable.
- Only one FM-organisation participated in this study, and only one scenario was tested in the experiment, making the conclusion on the experiment based on the needs of only one organisation.

5. Conclusion

The case study uncovered that even though architectural models are handed over to an FM-organisation, they are not necessarily used to improve understanding of issues or included in the planning of Facilities Management. They can nevertheless be converted into Virtual Reality (VR), and provide benefits without any significant financial impact on the FM-organisation, with respect to generating the Virtual Environment.

The study revealed that using the initial architectural design model for Facilities Management planning can provide a better understanding, when presented in VR. The improvement of understanding is however highly depended on:

1) The visual representation of the building in VR.
2) The Level of Development of the model used for generating VR.
3) Who are using VR?

50 per cent of the test persons experienced no or limited VR sickness during the experiment, making it hard to conclude to what degree VR sickness limits the use of VR viewed through a Head Mounted Display (HMD) when used for Facilities Management planning.

Future work

Future work will include testing the use of Virtual Reality with a bigger group of test persons allowing a more generalizable foundation for conclusion with respect to usability in Facilities Management planning.

Future work will additionally include testing of multiple scenarios and test buildings, from different stages of the building design, including "as built" models. This will make it possible to conclude when in the design phase 3D models have the best degree of information and visual development for planning of Facilities Management.

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