BIM-based Mixed Reality Application for Supervision of Construction

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Abstract

Building Information Modelling (BIM) is an up-and-coming methodology and technology used in the Architecture, Engineering and Construction (AEC) industry, that allows data centralization and stakeholders' collaboration. But to check the accuracy of the work done on the worksite, it is necessary first to go on site and then to modify the BIM model. This paper presents a mixed reality (MR) application based on BIM data and drone videos, allowing off-site construction supervision. It permits to make annotations about differences between what has been planned in BIM and what has been built, using superimposition of the two sources. Then these ones can be transferred to the BIM model for corrections. Finally, we evaluate our work with building construction experts, providing to them a questionnaire to grade the application and to get feedback. Our major result is that as for them the application does really help to do construction supervisions; however, they suggest that the application should provide more interactions with the 3D model and with the videos.

Keywords: BIM, mixed reality, construction, superimposition, drone, videos.

Index Terms: I.2.1[Human-centered computing]: Interaction design—Interaction design process and methods; J.6.4[Computing methodologies]: Computer graphics—Graphics systems and interfaces

1 Introduction

Nowadays, the architecture, construction and engineering (AEC) industry is using more and more technology for assisting the work done by the different stakeholders of a building construction project. Building information modeling (BIM) softwares (the ones that follow the BIM methodology or approach) allow data centralization and stakeholders' collaboration, for all the phases of the building life-cycle. But for some issues these tools are not enough or not the best ones. For example, for providing to the final users of the building a realistic virtual walk-trough, a more adapted tool could be a virtual reality (VR) or mixed reality (MR) application 5. So, it seems that MR technologies could have an added-value (some other previous cases also have shown it 55). Here we want to experiment it on some other study cases (phases and tasks, different from the literature). In collaboration with BIM experts, we found a different case, where mixed reality would have an added-value: the supervision of building constructions by BIM experts. It relies on determining differences between the planned design in BIM and the real current state of the construction. Currently, even with BIM tools, the method consists on going on-site, then to observe the latest changes on the construction work, to identify potential errors or differences between what the person is seeing and the planned design. Note that these differences or errors can be either on the real construction (the workers did not follow the design planned) or on the BIM model (a correction has been made but not been reflected into the BIM model): anyhow the objective is to have uniform twins (real-digital). Our statement is that this method could be improved, because currently it has some shortcomings. For example, the obligation for the expert to go on-site or the difficulties for seeing everything on high buildings. Another issue with this method is the sensation of "double" work since that after having been on-site the expert goes back and makes the corrections on the BIM model reading each annotation and above all searching in the 3D model which elements need a correction.

To resume it, these project reviews are currently facing various issues: accessibility, traceability, efficiency etc. Therefore, based on the MR approach explained above, we propose here a mixed reality application, based both on BIM data (the 3D model for this study case) and videos taken by a drone (unmanned aerial vehicle – UAV) on-site. To facilitate the task of searching differences between planned design and real current state of the construction, we have used superimposition between the two data sources. It also helps for the annotating and localizing process, allowing to select BIM elements and to write localized comments about it (exportable annotations). Then a real added-value is that we provide to the user a way to import these annotations directly to the BIM model, to avoid this sensation of double work and ensure that the annotated corrections written for an element are transferred to it for modification and not to another one.

To summarize, the current method for construction supervision could be improved, but how? Could mixed reality be a solution for this issue? In this paper, we present the approach that we applied on a real study case, for creating a BIM-based and videos-based (from a drone) MR application that allows off-site construction supervision. Then we present the evaluation of it, for determining if it really allows to perform this task and if it has an added-value. To conclude, in the last section we discuss about some remaining issues and improvements for future research.

2 Related work

First, we could remember that Building Information Modeling is, above all, a methodology, supported by some tools such as BIM softwares, to centralize all the data of a building construction project. Note that the data can take multiple forms: 3D models, 2D plans, text documents, etc. As a result, when we talk about a BIM model, it is not just the 3D geometry; in the rest of this paper when we would want to refer only to that, we would use the term 3D model. Note that the BIM model of a building, according to the BIM philosophy, should be updated over all the building life-cycle phases and as a result would be useful at any moment. Here we will focus on the construction phase. Moreover, before presenting some related work and to end with definitions, we want to give a very short reminder about what is mixed reality. Usually, it is a term used for defining all the cases where an alternate reality is created. It

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includes virtual reality, augmented reality and all the intermediate possibilities. In other terms, all the realities, from the real world to a completely virtual world. Another way to define it is to say that a mixed reality should come from a combination between a real and a virtual environment 5.

Furthermore, we could present some studies from the literature that summarize well the current state of the usage of mixed reality in the AEC and BIM context, for helping building project stakeholders to take decisions. T.Sun et al. 5 present a VR application where they combine 3D BIM models and oblique photogrammetry to help the final customers to evaluate whether the price is correct or not for an apartment. But photogrammetry is not the only source of information from the real world that could be coupled to BIM data, for example, drones' videos or data from sensors can be used. A.G. Entrop et al. 5 used infrared drones as data source from the real world about the building thermography. As for them, the classic approaches of the building industry were considering separately UAV and infrared data, so they presented an approach mixing both, describing a new protocol to design building thermography using UAV (drone) procedures. Going nearer to our case, in the literature we easily notice that drones have already been used for scanning existing buildings (or natural environment) to rebuild models 55555. Moreover, in this case (rebuilding models) it is common that the data sources only come from the real environment and that the result is a VR application with the new rebuild 3D model 5.

On the contrary, in our case, thanks to the BIM methodology and its BIM model we already have "virtual data", so we are seeking for real data, leading us to another question: could we make construction supervision, using both drones and BIM data? H.Freimuth et al. 5 have presented an approach where they use the BIM data for calculating the drone trajectory for the inspection of the building, therefore they used these sources but not with the same purpose than us: they focused on how the BIM data can help for planning a good path for the drone inspection (also as M.Erdelj et al. 5), and not how we can mix BIM data and videos coming from the inspection, where mixing has an added-value. On the other side, some researches have a focus on the evaluation of the power of inspection that the drones offer but they do not try to combine these data with BIM data 55. But how can these two data sources be mixed correctly? According to the literature, superimposition is an efficient way. D.Iwai et al. 5 have presented an augmented reality example where they have made the superimposition of infrared thermography pictures (virtual data) on some real environment objects (real data), allowing the user to get the combined result for taking decisions.

Finally, in the literature, in MR applications, what about the usage of BIM and real environment data? One remarkable work about that has been done by G.Riexinger et al. 5. Among all, they have created MR applications that allow visual comparison between virtual models and real on-site situations, but they did not use data from drones. Furthermore, Q.Dupont et al. 5 also asked for this question but they only made a study that says that the question is right and that the two main issues are autonomous indoor flight for UAV and smart integration of the collected data into the BIM software. So, they confirmed that our question is of interest, but they didn't provide answers. That is why we wrote this paper, to provide a concrete example about our approach that allows to create a BIM-based and videos-based (from a drone) MR application for construction supervision. To conclude, S.Meža et al. 55 proposed a way for evaluating their application, comparing it to the traditional way (measuring users' tasks performance). Note that in our paper, the focus about the evaluation has been made on evaluating with the experts the application usability and efficiency, and on getting feedback, and not on the comparison to the traditional method (future work).

3 METHODOLOGY

The current methodology for supervision of construction is to go on-site and write comments about some defects or errors on the construction work or differences with BIM plans (1. in Fig 1.) and then go back to the office, read the annotations, locate the corrections and make them on the BIM model (2. in Fig 1.).

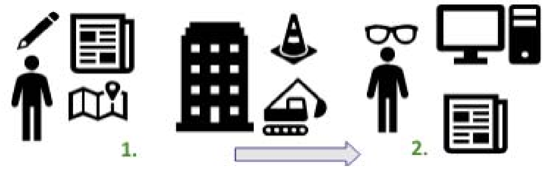

Figure 1: Supervision of construction: current approach

The following picture describes the usage of our mixed-reality application for the supervision of construction work. First the user explores at the same time the BIM design and the construction work in MR, discovers differences and writes annotations (1. in Fig 2.). Then he benefits from his annotations in the BIM software and makes the corrections on the right elements (2. in Fig 2.).

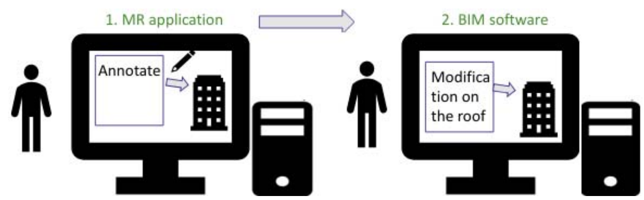

Figure 2: Supervision of construction: our new approach.

In the next paragraphs, we explain the steps of our approach for creating a MR application for the construction supervision. In Fig 3. can observe the concept of our application, which is represented here between two different "data worlds", the engineering (BIM) and the worksite and in Fig 4, the usage of the application, showing that its result is a located feedback in a BIM model.

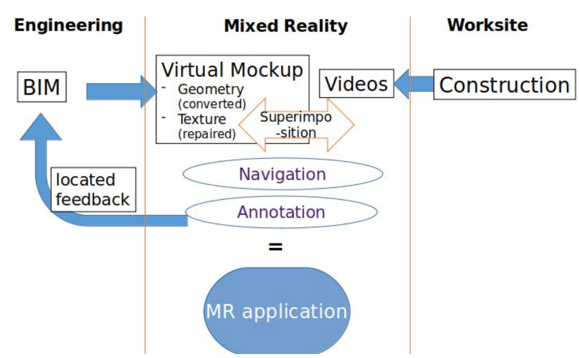

Figure 3: MR application for supervision construction concept

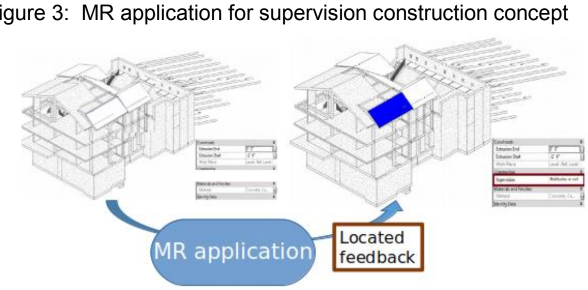

Figure 4: From BIM to annotated BIM thanks to MR application

The first step is to get BIM data about the building: the 3D BIM model for this case. Then we have extracted from it a 3D model usable in 3D game engines, which are used for MR applications. After that, this model has been imported in one of them. Note that we have had to put again the materials on the different elements of the 3D model. To make it more automatic, we have programmatically assigned materials according to the name of the elements. Then we have provided some context around the 3D model of the building by building a "box" around the model that shows photos of the building real environment (see Fig 5.)

At this stage, the mixed reality application only contains a 3D model of a building (no real environment data except the photos). As a result, the next step is the one where real data are collected. Here we have the current 3D BIM planned model, embedded in an immersive space with real world coordinates. So, we can plan and execute a drone flight to get real visual data from the real project. As the aim here is to simulate a project review made by an expert of building construction such as a project manager, he must define the drone flight. In our case, after getting this information, the planned flight was done manually by a pilot to get the video with the required views. After that, we cut it in separated videos. An improvement for future research (work-in-progress) would be to plan the flight thanks to the BIM data, so it would be easier to get a symmetry between the real flight and the MR application.

Then we provide two interactions to the users. The first one is for moving around the 3D model, simulating the drone flight. For this purpose, we have placed around the model some markers (cubes, see Fig 5). By clicking on it, the camera, that simulates a first-person view from the drone, moves. This kind of interaction provides a metaphor of smooth flight, taking the user to the next point of interest without manual camera manipulation. Again, in a future step, using BIM-planned flights, we could take advantage of it for the navigation. The other interaction that we provide is a way to see the drone videos (see Fig 6A), depending on the current point of view. For this purpose, we have placed other visual markers (3D models of cameras), around the building, near the real position of the drone camera in the video. So, before watching it, the user got some context and then he can watch it.

Figure 5: 3D model, context, markers (cubes and cameras)

After these steps, the MR application is using virtual models (from BIM) and real data (from the drone videos). But it is not yet combining them. Here we will explain how we have made this combination (in other terms, how do we combine the video and the geometric model data, using the global coordinate space and the drone planned and real flight data). For this study case, we present a manual way to mix the two sources. In a future research we would like to make it automatic and with more user control (interactions on angle, speed of the video etc.) Currently, at the end of the video (see Fig 6A, the last image of the video), the user sees the last video frame. But, then, as shown in Fig 6B, between the camera and this picture, we have placed some BIM 3D geometric elements that are present or should be present in this zone in the real construction work. We have putted them manually (rotations and translations) in superimposition, with transparency, with the fixed image of the video, in background.

As a result, the application that we proposed here is a mixed reality application. It could be compared to the augmented reality applications that are combining, on-site, real data from a camera that films the current state of a building and virtual data computed on the same device. The difference here is that we make the superimposition off-line and off-site. Another difference is that the device that acquires the real data is not the one that displays the mixed reality, allowing to take videos on zones that may not be accessible for humans. That is why an augmented reality application appears to be less adapted for this kind of review.

The next step consists in providing to the user a way to write his project review directly in our mixed reality application. Thanks to the superimposition (Fig 6B) he can already detect the differences or defects between the 3D model (BIM data) and the construction work (real data from UAV). But how can he make his report, directly, on the BIM elements visible in the application, to get an added-value from it, compared to the traditional way explained in a previous section? For doing that, we provide to the user a way to make annotations, so the user can write a comment about an element after selecting it (see Fig 6C). Once all the annotations done, he can export them. This function is not properly a "mixed reality function", but it is crucial, to allow the users to transfer these annotations to their BIM software.

Figure 6: A) video of the building from UAV; B) superimposition of the video and BIM as a mixed-reality; C) annotation mode

About the mixed reality application, there is no more step, but in the BIM softwares there is an additional step. Many of them allow the users to create their own macros or plugins through programming (visual or classic programming). Yet when we described in the beginning of this section our approach, we said that we wanted that our application and approach had an added-value, in this process of project review, for transferring the comments or annotations to the BIM softwares, for dissipating this sensation of double work, when the user must write again his comments in the BIM software for making the right corrections on the right element. As a result, in this study case, we provide to the users a way to import their annotations to their BIM software, writing each comment on a field dedicated to the supervision of construction, on the corresponding element in the BIM model. Finally, the program highlights where the annotations have been copied and so where the corrections should be done (Fig 7.)

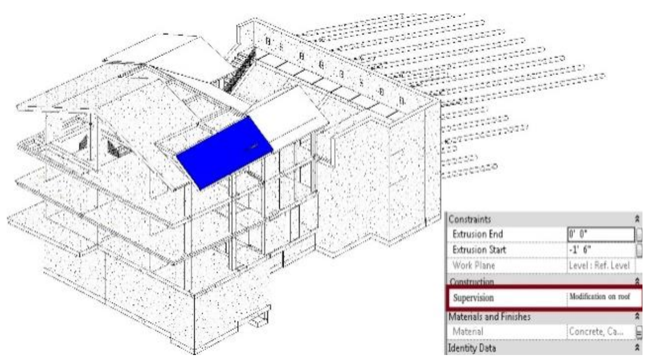

Figure 7: 3D view of the building in a BIM software with the localized comments made in the MR application with highlight

4 EXPERIMENT

For this experiment, we applied our approach on a project that the university leads, allowing us to have full access to the BIM files, to the worksite and to the experts. As our application provides a new way for doing construction supervision, its audience target is the building construction professionals: civil engineers, architects etc. As a result, we have decided to organize an experiment exclusively with these kinds of people. In total, 32 experts have participated to the experiment: around 66% of them were students in civil engineering and around 34% were young civil engineers that are leading building construction projects, including this one. Average age is 22.7 years-old and it goes from 17 to 26; 75% of them were male and 25% female. All of them were building construction experts and BIM experts, or semi-experts, due to their young age. In a future research we would like to repeat the experiment with a more diversified panel of professionals (with people with more experience in construction supervision or BIM).

The duration of the experiment was about 10-15 min for each user. We gave them a story board that described the tasks they had to perform: first, move around the 3D model of the building to get an overview of it (with the cubes) and watch a video on a point of interest (with the camera). Then observe the superimposition of some 3D model elements and the video and write an annotation about one element. You can repeat this process, then export your annotations and open the BIM model in the BIM software and run the program "MR Construction supervision". Note that the elements that you had made an annotation in MR now appear in blue; click on one of them and see your comment in the data field.

Each user made this experiment alone and then he had to fill a questionnaire. Note that, by doing the experiment only with experts, the application evaluation focused on a qualitative evaluation: only experts can determine whether the application allows them to accomplish in a good way a task that currently they are doing in another way (traditional, on-site, with a notebook and making corrections afterwards on a computer). That is why we have chosen to use a questionnaire for evaluating our application, divided into two parts. The first part of the questionnaire is composed by close questions, where the users must attribute a mark, from 1 to 7 (Likert scale): in this part, the users (experts) grade the quality of the application for solving the different tasks or sub-tasks. In the second part, they answer to open questions, to get their feedback on the application and how we should modify it to make it better for performing the different tasks. In the next section, we will discuss about the results.

5 RESULTS AND DISCUSSION

We can observe the questionnaire results (close questions) – Fig 8

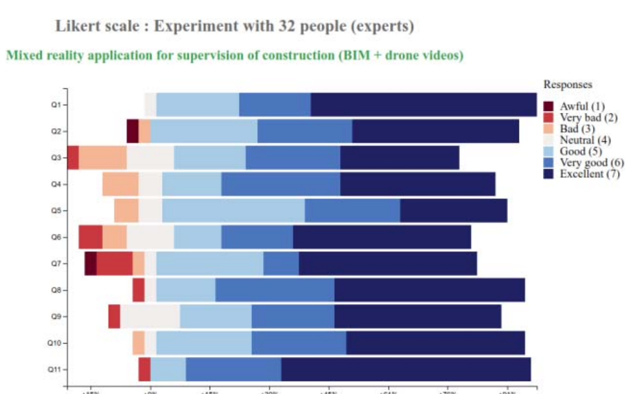

Figure 8: Results of the experience – Likert scale graph

Q1: Is the application useful for supervision of construction?
Q2: Is the application easy to use ?
Q3: Is the application clear enough to interact with it ?
Q4: Could other experts than you easily use this application too?
Q5: Was it clear how to realize and follow the instructions?
Q6: Did the app allow me to get a good overview of the building?
Q7: Was it easy to move around the building in the application?
Q8: Was it easy to watch videos about some building zones?
Q9: Was it easy to detect worksite differences/defects in the app?
Q10: Was it easy to annotate defects/errors in the application?
Q11: As for you, was it easy to transfer and see the annotations made in the application into your BIM software?

First, we can note, reading Q1 answers, that 100% of the users grade the application with 4 or more, and for the other questions, at least 75% of the users grade the application with 4 or more. So, it seems that the application and its approach allow them to perform globally all the tasks, replacing the traditional method.

If we observe the results with more details, we can note that the principal claims are the following ones: first, in Q3, around 20% of the users grade the global usability of the application with a 4 or less ; then, in Q6, around 18% of the users grade the ability of the application to provide to them a global exterior view of the building with a 4 or less and in Q7 around 18% of the users grade the ability of the application to provide to them an easy way to move around the building with a 4 or less. So, we can deduce that around 1 in 5 people would like the application to be more user-friendly, with a better external representation of the building and some improvements about the user interaction for moving. Note that these results are coherent with the open questions section of the questionnaire, because the improvement that appears the most is "I would like to have more interactions with the 3D model of the building (rotations)". About the other questions, the results are very positive: around 85%, up to 90% of the users grade it with a 4 or more, for example for the following questions: Q4, Q5 or Q9.

So, we can deduce that, as for the users, the application allows particularly to perform the tasks of errors detection, annotations and transfer to the BIM software. As for them, they have been able to follow the instructions (story board) and other professionals of building construction could also do it.

To conclude, these results show us that our MR application (and our small program integrated to BIM software) allow the users to perform the construction supervision task, off-site and using BIM data and drone videos. And with this experiment we also get some feedback with the open questions. Indeed, as written above, many users asked for more interaction (not pre-determined points of interest, more points of interest). Another suggestion about interaction is the integration of 360° videos. Some of the users also ask for improvements on the visualization of the 3D model of the building, whereas others put more focus on the necessity to give more feedback to the users when annotating an element. This feedback gives us some ideas for our future work, that we explain in the next section.

6 CONCLUSION AND FUTURE WORK

As the results have shown it, it appears that this kind of approach and of MR application presented in this paper allow the experts to perform the task of supervision of construction. But the results also have shown that improvements and corrections could be done, based on the qualitative evaluation and the users' feedback. Then we could make a new evaluation of the application and compare the results; it would also be interesting to evaluate with qualitative and quantitative criteria the differences between performing this task of supervision of construction with the traditional way and with our approach. Note that, in the literature, J.Chalhoub et al. 5 made this comparison with their mixed reality application (electrical construction design communication), using both BIM and other data sources; Y.Zhou et al 5 also compare their application for inspecting the construction in a tunnel to the traditional way, so it would be interesting to check their methods of comparison (criteria etc.). About the perspectives for this work, our future work will focus on the user interactions with the 3D model of the building, on the other possible different ways for superimposing the elements on the video, on the usage of 360° videos in the mixed reality application and on the automation of the superimposition process in mixed-reality.

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