SUPERIMPOSING BUILDING INFORMATION MODELS IN AUGMENTED REALITY

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ABSTRACT: *Augmented Reality (AR) can enhance Building Information Modelling (BIM) by allowing architecture, engineering, and construction (AEC) professionals to visualise and refine building models. The possibility of integrating BIM model in AR environment provides an effective solution to all phases of a building's lifecycle. To visualise digital information in the actual physical environment, BIM models are superimposed to the structure. The techniques used to superimpose the BIM models are either based on reference markers or QR codes, which are occasionally inaccurate. This paper reviews and analyses the BIM model superimposing techniques in AR. To describe and discuss different methods, a BIM model of an office room was generated in Revit and superimposed to the actual physical space using two different AR devices and four different AR applications. From the results obtained, it can be concluded that presented superimposing methods allow for overlaying of digital information, but model positioning can be slightly inaccurate depending on the superimposing method used and AR device. Any inaccuracy while positioning the BIM model reference markers or QR code can lead to inaccurate superimposing of the model. The recommended process and method for superimposing BIM in AR environment is documented.*

1. INTRODUCTION

During construction, "omission errors" are often committed due to the lack of information available on hand (Love et al., 2009). Team members do not consistently and enthusiastically spend time and effort to get access to the required information, which is stored remotely or distantly, requiring them to be physically away from the task that they are performing. Wearing a head-mounted AR device that includes all of the building information in the form of a BIM model can mitigate this issue as the worker would not have to be detached from their task and the information can be made directly relevant to the task. The integration of BIM and AR can also enhance the visualisation of different phases of a project lifecycle and eventually improve the final product (Wang et al., 2014). The use of a 3D BIM model in architecture, engineering, and construction has already shown its numerous benefits. It allows designers to virtually test the proposed alternative designs and identify any possible problems at an early stage of the construction process. Using AR, BIM information can be visualised in real time and in the actual physical setting, particularly during the construction, maintenance, and operational stages of a building (Yan, Culp & Graf, 2011). This can improve decision making, eventually allowing tasks to be efficiently and effectively executed.

The construction process consists of a large number of tasks and subtasks classified into three main categories: input, output, and processing (Bernold & Abourizk, 2010). The input mainly consists of material, labour and time; the output mainly includes waste, cost, quality and schedule overrun; and the processing consists of preparation, transformation, monitoring and cleaning. Such construction processes can be reclassified and connected in terms of product, process, and resources.

To fully benefit from the integration of BIM and AR, the 3D BIM model of the building needs to be precisely superimposed to the actual physical environment in AR. At the moment, the superimposing techniques that are used to overlay the 3D BIM model on the actual physical environment mainly use reference points (Mahmood, Han, & Lee, 2020). The accuracy of the reference point techniques depends on various factors such as the user's knowledge of the pre-set reference point and the ability to set the reference points at the same location in the physical AR environment. This paper describes and analyses the various superimposing techniques that are being used in current BIM-AR applications. The limitations of those superimposing techniques are discussed, and a new automated superimposing approach is proposed.

2. TRACKING AND IMPOSING

2.1   Tracking

Tracking is a technique used by extended reality (XR) equipment such as head-mounted displays (HMD) to determine the position of an object in the virtual or augmented real-world environment (Sherman & Craig, 2019; Pearlman et al., 2019). Outside-in and inside-out tracking can be distinguished. The difference between outside-in tracking and inside-out tracking lies in the location of the cameras and sensors that define the object's position in the space (Ribo, Pinz, & Fuhrmann, 2001). For inside-out tracking, the camera and sensors are located on the HMD, whereas for outside-in tracking, a stationary tracking device is mounted to a fixed location in the scene. While using the inside-out tracking method, the camera incorporated in the HMD determines the changes of the equipment's position in relation to the external environment. To create an illusion of walking through the virtual environment in real-time, sensors adjusts the user's spatial position when the headset moves (Keil, Edler, & Dickmann, 2019). Such tracking method can be used both for marker-based tracking, where markers are used as reference points, and markerless inside-out tracking, which uses natural features to determine its positions. Markerless inside-out tracking is a technique that identifies specific shapes and images that are already present in the physical environment to calculate and determine the position and orientation of an AR device in physical space. Such positional tracking system uses data from accelerometers and gyroscopes to enhance precision. In marker-based tracking, fiducial markers, positional markers, or infrared markers are used to allow the tracking system to easily detect and position the HMD in the specific environment (Borrego et al., 2016). The fiducial markers are in the form of primitive shapes such as points, circles, or squares. Quick Response (QR) codes are commonly used positional markers placed in the physical environment as reference points. Infra-red (IR) markers and cameras sensitive to different types of light can also be used. The marker-based tracking is effective only if the markers are within the field of view of the HMD and can be clearly detected.

2.2   Model Imposing

To provide a realistic and accurate AR experience, digital information must be aligned with the elements of the real physical space (Montero et al., 2019). Digital models can be superimposed in an AR space in two ways: (1) through tapping the digital model into the physical environment's surface, or (2) by snapping the model to a QR code, which physically represents the origin of the model, or a reference point (Hashimoto, 2020). Measuring placement of the QR code can facilitate accurate positioning of the model in the physical environment. Alternatively, model placement and adjustment in the AR environment is possible using the X, Y, and Z plane if high accuracy is not required. Snapping digital objects in an augmented reality setting is inherently more challenging than snapping in a virtual reality because of physical constraints such as sensor noise, environmental complexity, and hardware limitations (Nuernberger et al., 2016). In an AR environment, the likelihood of extracting the wrong constraints is higher and can negatively affect the snapping performance. An ideal AR system creates the illusion that the real and virtual components coexist in the space (Montero et al., 2019). However, most AR applications require much work before they will be capable of creating this impression. Although AR technology has advanced, most software applications still cannot imitate the experience of virtual objects being part of the real physical setting.

3.   METHODS

To analyse the different superimposing techniques used to superimpose a 3D BIM model in AR environment and evaluate the methods' effectiveness, a BIM model of an office room located in the Phoenix Building at Teesside University's Middlesbrough campus was created. The two pieces of AR equipment used in this experimentation were Microsoft HoloLens 1 Development Edition, which is the first mixed reality head-mounted headset developed and manufactured by Microsoft Corporation, and Daqri Smart Glasses, which was created for use in a variety of areas, including technical visualisation with BIM. The Microsoft HoloLens runs the Windows mixed reality platform in the Windows 10 operating system and can run third party applications. The Daqri Smart Glasses consists of a wired control box that provides the required computing power and the device operates on an internally-built Visual Operating System (VOS). Testing examined four different BIM-AR applications: 3D Viewer Beta (Microsoft, 2016), BIM Holoview (Revit-Holoview, 2017), HoloLive (VisualLive, 2018) and Model-BIM (Daqri, 2018). The Microsoft HoloLens has a wider range of software available that allow visualisation of digital models in AR compared to Daqri which is limited to its inbuilt application Model-BIM. The applications chosen for Microsoft HoloLens were based on compatibility with BIM models and availability.

3.1 BIM 3D Model

Room P1.09 is an office on the first floor of Phoenix Building. The room was selected to perform the test being easily accessible and available. A model of the room was generated in Revit (Autodesk, 2019) version 2019.2 based on available information and observation. Available 3D CAD model and 2D plans allowed positioning of the MEP components in the room model. Being an office, the Room consisted of electrical and mechanical (heating, ventilation, and air-conditioning) system components. As the exact designs and information on some of the room elements, such as the doors, windows, and electrical trays were not available, similar components' designs were used keeping the size and properties as close as possible to reality.
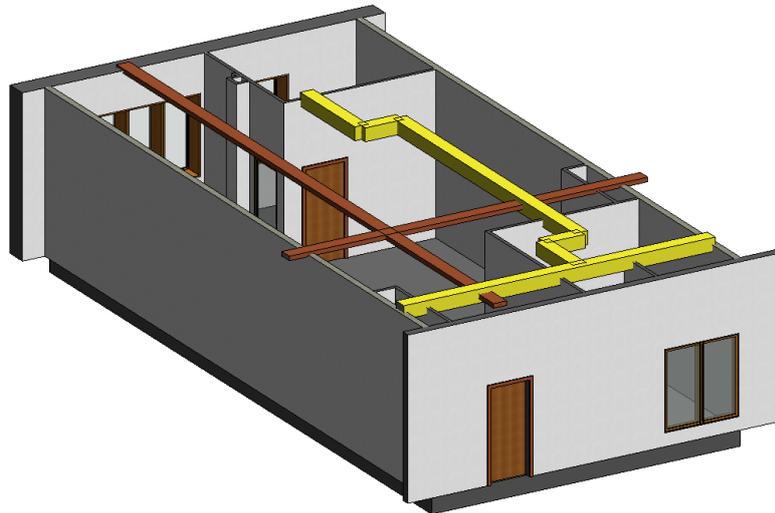

Fig. 1: Created BIM model in Revit file format (RVT)

The room's BIM model is shown in Fig. 1. Due to the limited textures available as default in Revit, assigning the desired colours to the different components was challenging. The heating system of the room is highlighted in yellow, the electrical cable trays in brown, the walls in white and the doors and windows in a darker brown wooden texture in order to differentiate different components in the room.

3.2 Superimposing Model

The superimposing test used the 3D viewer software 3D Viewer Beta, BIM Holoview and HoloLive on Microsoft HoloLens and Model-BIM on DAQRI Smart Glasses. The 3D viewers descaled the model to a reasonable size fitting the HoloLens display so that positioning, moving, and rotating the model were easier. To superimpose the model into the actual building, the model was first placed at a correct position and then scaled accordingly. After an inbuilt room scan, the software added a grid on the bottom level to guide and increase the precision while positioning the model on the floor or table. The software scaled the model in terms of percentages rather than using ratios. Therefore, the scaling process relied on trial and error, personal judgement, and consideration of reference points such as walls, roof and other various components. As the model scaled up, minor adjustments using rotation and moving options were frequently made to secure the model in the correct position. The scaling, rotating, and moving process repeated until the model was superimposed on the actual building.

The BIM Holoview, HoloLive and Model-BIM were designed with the BIM model in mind. The Holoview and HoloLive software included a variety of options for superimposing the BIM model in a physical environment. Before sending the model to the AR equipment, reference points were added to specific locations in the model. Two or more reference points were required to position the model in the AR environment. The same reference points were then identified and selected in the physical environment to fit the model to the right place and orientation. In case of any misalignment, the application provided various options to adjust the model to the physical environment. Daqri has a set procedure of accessing and visualising a BIM model in AR which includes the use of BIM 360 Docs and Daqri BIM 360 Viewer. Model-BIM uses QR codes and landmarks set on the model and on the actual physical environment. Using this system, once the equipment scans the QR code or landmark, the model is automatically imposed into the environment.

3.3   Analysis and evaluation

Validation included visual inspection of the superimposed model in the actual office room. The model was first validated by ensuring the reference points were at the predicted locations and that the model's layout was perfectly matching the physical building's layout. Then, the alignments of the model's electrical and mechanical components were checked in comparison to the actual room lighting, ventilation openings and plumbing.

4.   RESULTS

The model superimposed in 3D viewer Beta, BIM Holoview, HoloLive and DAQRI's Model-BIM is illustrated in Fig. 2, 3, 4 and 5, respectively. The models were imposed on the actual physical room using different techniques described in Section 3.
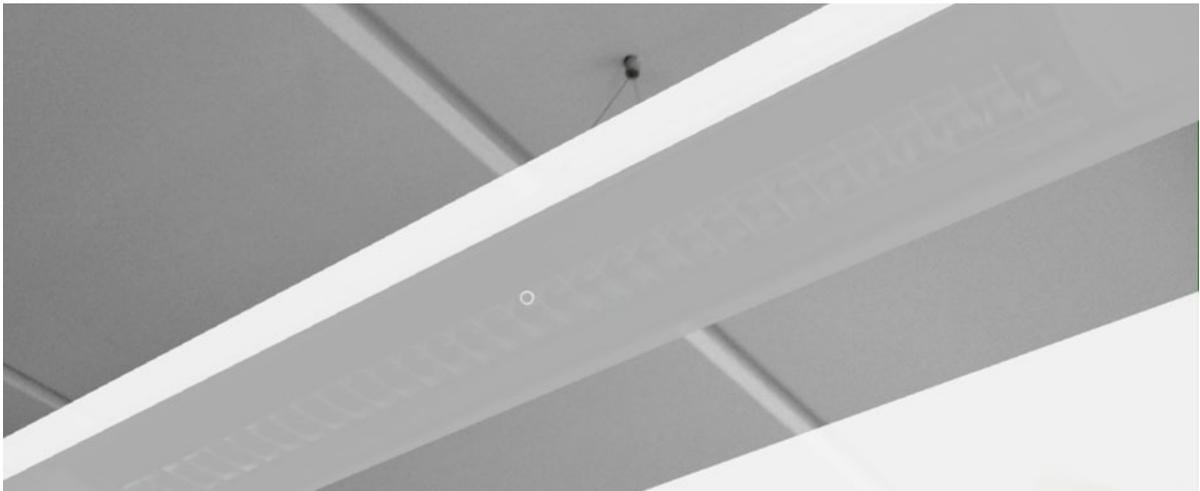

Fig. 2: Room P1.09 lighting fixture superimposed on 3D Viewer Beta

Using the 3D Viewer Beta AR software, the model was superimposed by trial and error. The superimposing process itself was time consuming and took several attempts before it was closely aligned to the physical room. The model needed to be scaled to right size, rotated to the correct position and then aligned to the room using reference points set on the model. During the scaling and aligning process, often the model maintained its original placement and created large misalignments. Such issues would result in restarting the entire superimposing process.

Fig 3: Room P1.09 lighting fixture superimposed on BIM Holoview

Fig. 4: Room P1.09 section superimposed on HoloLive

HoloLive allowed the option to use either reference points or QR codes to superimpose the model into the physical environment, whereas in BIM Holoview only the reference point method was available. The reference point system available on Hololive and BIM Holoview was developed for superimposing specifically BIM models in AR. Therefore, such a system was more accurate than 3D Viewer Beta and relatively easier to use and align the model in AR. Using the reference point system, the BIM model is set in the correct orientation. Model alignment can be finetuned by moving the model but does not require rotation.
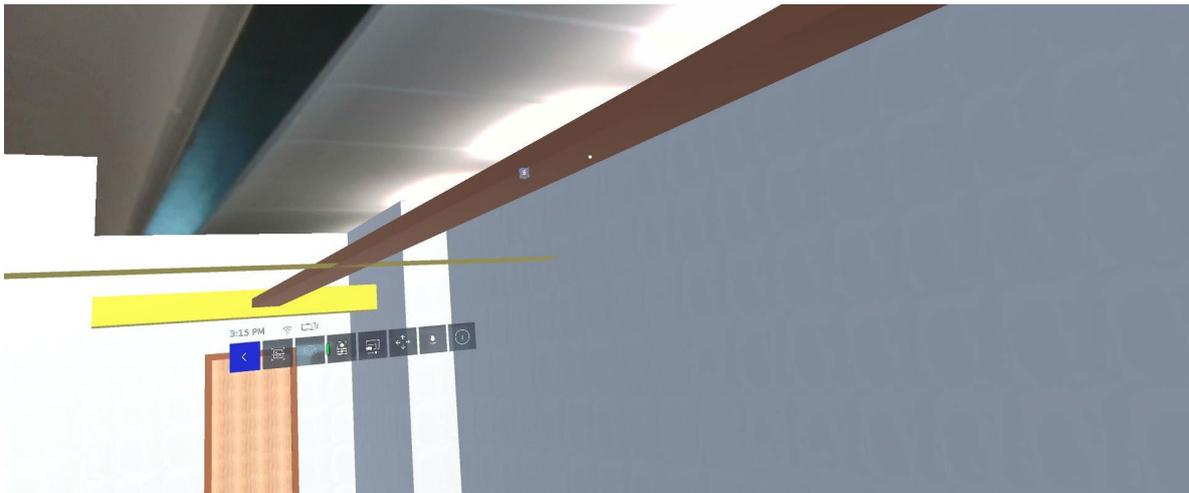

Fig. 5: Room P1.09 cable trays and ductwork superimposed on DAQRI - Model BIM

Daqri Smart Glasses and Model BIM also take into consideration the integration of BIM in AR. Therefore, the superimposing procedure set by Daqri and the available options allow more accurate model alignment to the physical room compared to the other tested software. Using the QR code, the model can be directly accessed and, using the landmark, aligned to the room. After imposing the model, the software allows refining the alignment by moving the model along the three-dimensional Cartesian coordinate axes with a high level of precision.

In terms of the time taken to superimpose the model in the actual physical room, attempting through trial and error took around 10-20 minutes, using the reference points it took between 3-5 mins and using the landmark method it took around 2 mins. The trial and error method was the slowest with the landmark positioning system being around 5-10 times faster. The use of reference points was relatively faster than the trial and error method but slightly slower than the landmark positioning system.

5. DISCUSSION

5.1 Model Superimposing

Models which consist of reference points or landmarks can be superimposed using those reference points. However, models without reference points needed to be superimposed manually by trial and error. There is a high probability when using this technique that the model will take significant time and effort to even come close to superimposing the model accurately. This technique is not always feasible and can introduce alignment errors of the model in the design. The rotation and movement of the model in the AR environment is done by using the scaling system rather than a ratio system, creating inaccuracies.
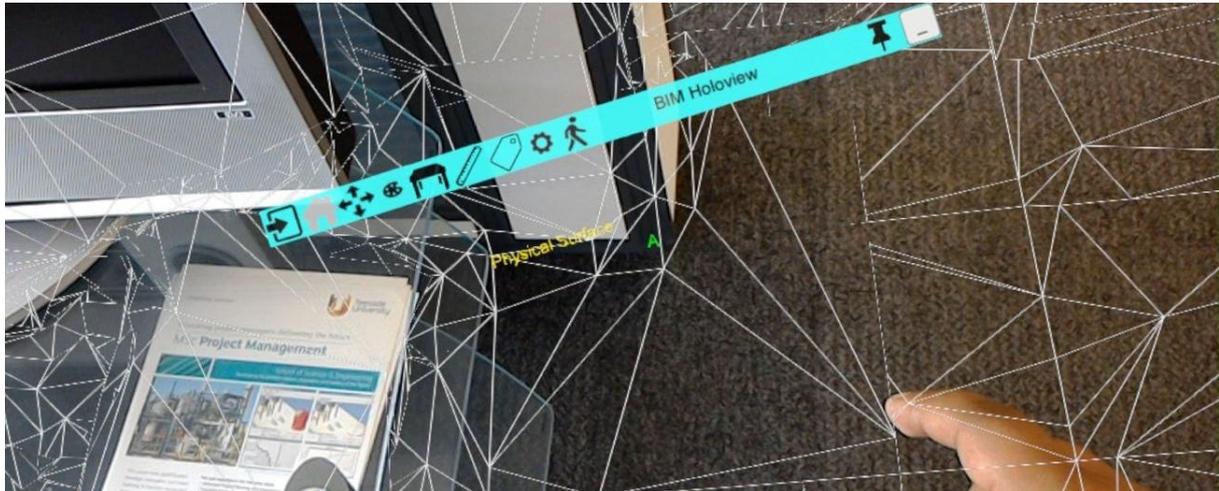

Fig 6: Microsoft HoloLens Mesh Density

Meshes are used to scan and place the model in real surroundings. Microsoft HoloLens had a default mesh density as illustrated in Fig. 6 which could not be reprogrammed in the device. Corners, edges, and other small elements of a building could not be precisely scanned. Therefore, the use of corners and building edges as reference points to superimpose a building model could sometimes cause misalignment. A difference of a millimetre at a reference point can cause the other end of the model to be drastically misaligned as illustrated in Fig. 7.

3D Viewer Beta   BIM Holoview

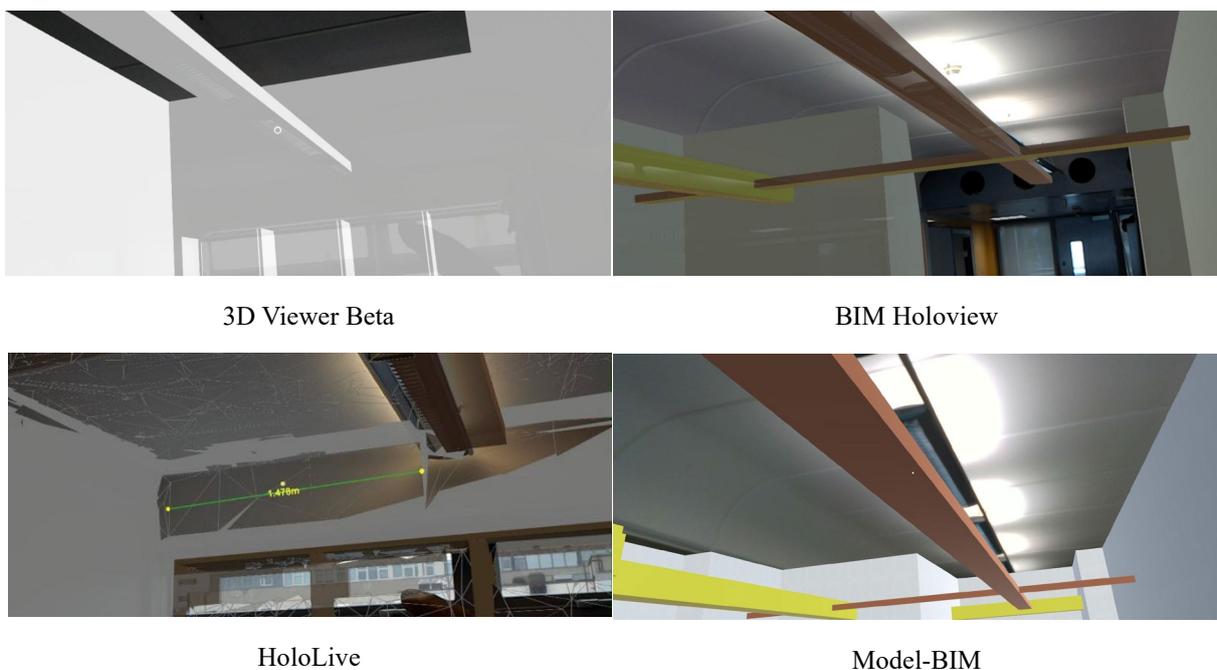HoloLive   Model-BIM

Fig. 7: Room P1.09 superimposed comparison

5.2 Recommended process

Inaccuracies while superimposing BIM models in AR can emerge due to various factors such as the tracking technology, mesh density or the technique and process used. In this experiment, several approaches were compared with respect to alignment accuracy while superimposing the P1.09 office room model. Some of the practices which improved the alignment and accuracy were (1) Avoiding the positioning of reference markers on corners and edges and, instead, positioning the reference markers on a horizontal or vertical open flat surface that has been measured and marked both in the model and in physical space. Scanning elements such as corners and edges can be imprecise compared to open flat surfaces due to the tracking technology and mesh density; therefore, using an open flat surface, the reference points can be accurately placed in the AR environment. (2) While using a fiducial marker, the use of circles or ring shapes can improve the alignment process and act as guide while finetuning the model position.

6. CONCLUSION

Although the model was superimposed to the actual room using pre-set reference points or landmarks, there were some slight misalignments. AR technology is still emerging and rapidly developing. The AR devices used in this study represent the first generation of head-mounted headsets; therefore, their uses are still limited, and the positioning techniques have some inaccuracies. New techniques that do not require manual adjustments should be developed to improve the accuracy of superimposing models into buildings. At this stage, the functions of the AR devices and commercially available BIM-AR applications are limited and still under development. The current scanning technology is insufficiently adequate in terms of efficiency and accuracy. By following the recommended processes, the inaccuracies and the time needed for superimposing BIM models in AR can be reduced by 50%, but the invention of more robust scanning technology may improve the imposing and superimposing accuracy of BIM models in AR.

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