

IN REAL LIFE: INSTANTANEOUS SYNCHRONISATION FROM THE BUILT STRUCTURE TO THE BUILDING INFORMATION MODEL USING AUGMENTED REALITY APPLICATIONS

M. GREEN,

*University of New South Wales, Sydney, Australia
montannagreen97@gmail.com*

Abstract. Building Information Models (BIM) have become one of the most significant collaborative tools since 2003 in the Architecture, Engineering, and Construction (AEC) industry (Holzer, 2016). The ability to update information dynamically and accurately is crucial to the successful use of BIM, however BIM lacks seamless and real-time interaction between the virtual and real world (Wang et al., 2014). This limitation contributes to discrepancy issues between 'as-built' and 'as-designed' data. Site verification aims to connect the physical world to the BIM through reporting and documentation, this is rarely completed as it is a time consuming and manual task, which can be completed inaccurately. The research project adopts an action research approach to develop an integrated augmented reality (AR) application and workflow that interacts with a BIM to mitigate against extensive manual activities for site verification, and provide a visualisation tool for viewing discrepancies between 'as-built' and 'as-designed' data. The AR application aims to allow the user to move the model to match on site conditions and synchronize this data to the BIM using cloud computing, resulting in a more accurate 'real time' development of models and buildings.

Keywords. Apple Augmented Reality, BIM, Cloud Computing, Synchronisation, Site Verification

1. Introduction: Research Aims and Motivations

Innovative digital modelling and visualisation technologies are gradually entering the AEC industry in ways that aim to improve the interoperability of building models and data through immersive virtual environments. AR is currently being used as a visualisation tool in the AEC industry as it enables users to visualise digital models in a ‘real life’ environment by overlaying virtual models onto the physical world. Additionally, cloud computing, which enables data to be transferred efficiently over the internet, and offers ways to improve collaboration and efficiency between project stakeholders, is fast becoming a more viable option. This research project argues that by synthesising AR and cloud computing, the collation of data can be represented in three dimensions on a standard user interface as well as being synchronised with a complex BIM.

BIM is a significant collaborative tool in the AEC industry due to its success in digitally representing a building’s “...physical and functional characteristics” (Wang et al., 2013). Critical to the effective use of BIM, is the ability to update information dynamically and accurately. Although BIM is effective in documentation from correlating between 3D models to 2D drawings, it lacks synthesis between the digital and physical world (Wang et al., 2014). This in turn, can create communication issues between ‘as-built’ and ‘as-designed’ data. For example, service plans (e.g. piping, ductwork, etc.) can be modified to suit on-site conditions (Abe et al., 2017), however, the manual process of communicating these changes to the collaborative BIM is often not a high priority.

While there are existing tools that allow users to send accurate data from the physical world to the digital world (Abe et al., 2017) such as, 3D scanning with LIDAR technologies, they often require specialist software skills and can be prohibitive for smaller companies (Sato et al., 2016). A promising alternative to address these problems is through the use of AR technologies, and more specifically mainstream consumer-based technologies, those such as the Apple AR Kit, which requires minimal expenditure.

Without efficient methods of site verification, communication of the physical ‘as-built’ site conditions in comparison to the ‘as-designed’ digital model remain difficult to achieve. Currently, where site verification is required, manual activities such as measuring, obtaining information, aligning, recording, and reporting are implemented. However, all of these roles can be performed more efficiently and accurately with the implementation of AR technologies (Dunston and Wang, 2011). For a BIM

to reach its full potential and remain useful for a buildings lifecycle, this research argues that changes from ‘as-designed’ to ‘as-built’ need to be fully taken into account and facilitated into a new workflow.

2. Research Observations and Objectives

This research proposes a new workflow to integrate AR, BIM technologies and cloud computing in order to mitigate against extensive manual activities required for site verification. Additionally, this research aims to provide a visualisation and communication tool for documenting and adjusting discrepancies between ‘as-built’ and ‘as-designed’ data in real time. The proposed AR workflow intends to remove the potential for misinterpretations among project team’s stakeholders by providing simplified visual information, to improve efficiency and productivity. The system also intends to give the user the ability to change the data in the AR interface, to instantaneously synchronise to the BIM using cloud computing, thus; removing the need for extensive, labour-intensive, manual processes. This research argues that by integrating an online data platform, consumer-based AR applications and BIM, an accurate virtual model of as-built conditions can be achieved.

3. Research Questions

Based on the aforementioned research observations and current problems in relation to the use of BIM in the AEC industry, this research aims to address the following research questions.

1. How can synchronous communication of data between the as-built and the as-designed BIM be achieved?
2. How can as-designed data be communicated effectively in a multi-disciplinary project context that often involves multiple skills levels?

4. Methodology

In a discussion with the academic partner, BIM Consulting, it was highlighted that there is no acceptable solution to address the lack of communication between the physical world and the BIM, therefore, this research project aims to understand the problem and create an adequate solution. Accordingly, this research project adopts an action research based approach to iteratively design and develop a technology-led solution to an industry identified problem. Action based research is characterized by continual cycles of planning, acting, observing, and reflecting (Hearn and Foth, 2005). This research further aligns to the key objectives of action based research as it seeks to improve the conditions for BIM users through proposing ways to change and augment existing workflows and practices.

The specific methods this project adopted include:

1. Problem Analysis
2. Critical review of existing technology and applications
3. Review of technologies being utilised
4. Iterative design of new workflow
 - i. Design
 - ii. Reflect
 - iii. Improve
 - iv. Repeat
5. Analyses of results from experimentations

5. Background Research

To understand this research field, it is necessary to outline definitions of key concepts, as well as analyse the success of past and similar projects. By doing so, a greater knowledge is gained about the problem, the technologies used, and the process of similar projects, resulting in a more defined and effective solution that covers all aspects of the problem. The topics being investigated are BIM, AR, cloud computing, and existing technologies and applications.

5.1. LITERATURE REVIEW

Wang et al. (2013), states that a BIM “provides a shared knowledge resource for information ... throughout the project's life cycle” (p.g.37). A BIM enables users to synchronize numerous services to a central 3D model, and is seen as a highly-efficient collaboration tool for AEC professionals. Although this tool is extremely useful, Wang et al. (2014) argues that BIM's have a lack of interaction between the virtual and real world, that is exacerbated when changes to the initial design occurs on site. For a BIM to be valuable, it needs to be accurate and continually updated, however, because of the lack of real-time communication, on-site changes are often not reported or updated to the BIM. With the implementation of AR technologies, Wang et al., 2013 believes that an efficient system could be generated to send ‘as-built’ data to the ‘as-designed’ model. Dunston and Wang (2011) argue that manual activities such as measuring, obtaining information, aligning, recording, and reporting, which are common tasks for site verification, could be performed more efficiently and accurately with the implementation of AR technologies. The proposed application that this research explores aims to integrate AR with cloud-based modelling to remove manual activities used for site verification, and enable communication between as built and as planned data.

The research project is intended to be used by all AEC industry professionals, however Danker and Jones, (2014), highlight that there is a problematic generation gap between ‘digital immigrants (born before technology drive) and digital natives (born during technology drive)’, and discuss how barriers for adaptation and integration of technology are created from attitudes and lack of skill from digital immigrants. GU, Singh and Wang, 2010, conveys the importance of an intuitive interface, as it needs to facilitate the different levels of skill for interdisciplinary collaboration. This project aims to remove barriers towards AR technologies, as it relies on a simple and intuitive user interface on a consumer-based device to visualise data. Similarly, the ARUDesigner created by Wang and Chen, 2009, uses a head mounted display (HMD) with AR to visually communicate to team members. The AR system removed misinterpretations among team members by providing detailed visual information, improving efficiency and productivity (Wang and Chen, 2009). Furthermore, Wang et al. 2013 suggest that AR could be used to visualise discrepancies and make accurate decisions, by mapping ‘as-built’ and ‘as-designed’ data into the same environment. The proposed application aims to achieve this, however, it intends to give the user the ability to change the data in the AR interface, which then instantaneously synchronises to the BIM model using cloud computing; removing all manual processes.

Cloud computing is concerned with “moving computation and data away from the desktop and portable PCs and into large online data centres” (Jadeja and Modi, 2012). Within the AEC industry, Flux.io is a popular cloud computing tool, as it enables interoperability between design platforms, allowing users to develop models online, and store large amounts of raw data. The integration of cloud computing and BIM is seen as a second generation of BIM development by Afsari, Eastman and Shelden, 2016, as it results in major improvements in performance at a relatively low cost. Afsari, Eastman and Shelden, 2016, state that ‘compatible and efficient data representation in the Cloud is a critical aspect for Cloud-BIM interoperability’. Flux.io achieves this, as it allows the AR application to send numerical data, and Dynamo to receive geometry without the user interfering. GU, Singh and Wang, 2010, discuss how significant the implementation of a BIM server is for a collaboration, as the platform enables users to view and modify models online. Within the paper, GU, Singh and Wang suggest that integrating AR technologies with a BIM server would enhance information exchange, and state that multiple attempts have been made but not achieved.

5.2. EXISTING TECHNOLOGIES

Though there are multiple existing applications that use AR, BIM, and cloud computing independently, there are few that aim to view and remove discrepancies on-site and communicate the updated data to the BIM. Those that do, require a certain skill set, and/or are still quite a manual process.

5.2.1. Lidar

Light Detection and Ranging (LIDAR) is a powerful tool used in the AEC industry to accurately construct 3D models of existing site conditions using point clouds (example shown in figure 1). Often, it is used to determine the progress of the build, however, it has been known to be used to map existing terrain, and to “juxtapose existing content with newly generated designs” (Holzer, 2016, pg. 93).

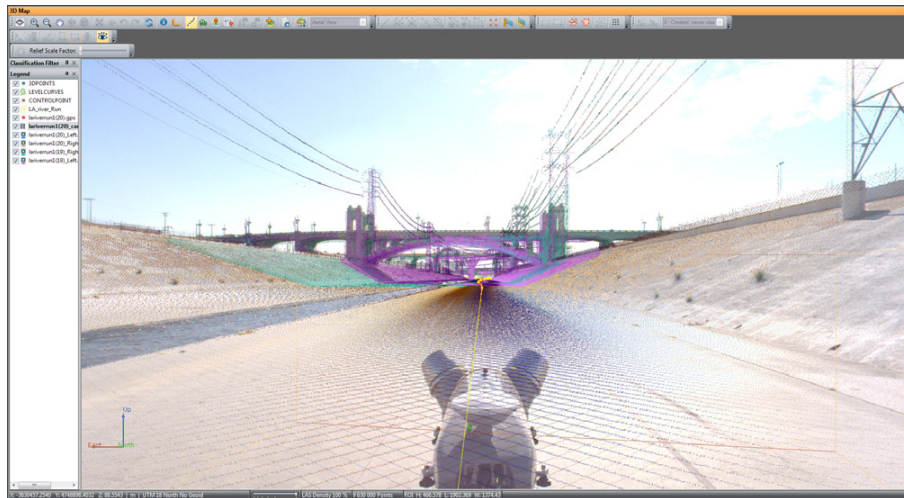


Figure 1. Gehry Partners using a LIDAR to create a 3-D model of the L.A. River (Wainwright, 2015)

5.2.2. GAMMA

GAMMA is an application that uses the depth-sensing AR tablet, google tango, to overlay a BIM onto site to detect errors. The application allows the user to ‘send notes, pictures and audio commentaries directly from the construction site to the office’ (GAMMA, 2017), whilst tracking the user's location on site in real time. These comments and images are assigned to the building element that were selected in the AR application, so the model manager can view them and update the model to match on site

conditions



Figure 2. GAMMA - Viewing services on-site (GAMMA, 2017)

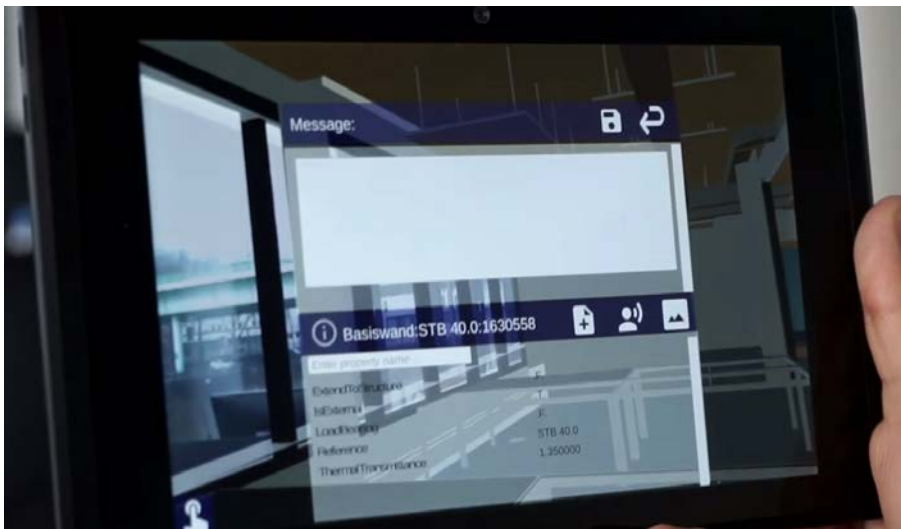


Figure 3. GAMMA - Sending notes to BIM (GAMMA, 2017)

5.2.3. Shape Trace

Similar to GAMMA, Shape Trace uses the google tango tablet and has the ability to track the user's location in real time. The application uses mixed reality to 'prevent errors and build right the first time' (Shapetrace, 2017). Images and notes can be taken, which then are automatically mapped onto the BIM. 3D tags are left in the AR environment so other users can see what has already been reported. Further, Shape trace allows operators to 3D scan

the building to measure progress, which then is exported to the BIM for comparison between as-built and as-designed.



Figure 4. Shape Trace - Viewing services on-site (Shapetrace, 2017)



Figure 5. Shape Trace - 3D Scanning buildings progress (Shapetrace, 2017)

5.3. TECHNOLOGY REVIEW

From previous experience with many of the technologies listed below, it was determined that they would be suitable to utilise for the proposed workflow.

5.3.1. AR Technologies

Currently there are numerous AR technologies being used for architectural and construction purposes. These technologies all provide a different quality and feature and it was important to decipher which tool would be suitable for the research project. Due to the amount of technologies available, a criteria

was set and an analysis was undertaken. The results are shown in the table below:

TABLE 1. AR Technologies Review

	Markers Needed?	Expensive?	Easily Accessible	Consumer Based Technology?
Google Tango		✓		Google Tango Smart Device
Apple AR Kit			✓	IOS Smart Device
HoloLens		✓		Microsoft Head Mounted Display
ARToolKit	✓		✓	Android Smart Device
Vuforia	✓		✓	Android Smart Device

The Apple AR kit has been selected for this research project as it fits all requirements. This technology tracks surfaces in real-time and places the model upon them, meaning no markers are required. The development technology is free, however, it needs to be constructed on an apple device. The application will work on the following devices if IOS 11 is installed:

- iPhone 6s or higher
- iPad Pro
- iPad 2017

5.3.2. Unity

Unity is a closed source gaming engine that is used throughout the AEC industry to make virtual reality (VR) and AR environments for visualisation purposes. Unity Technologies developed a plug-in for the Apple AR Kit once Apple released the technology to developers. The plug-in contains all the components needed to get a basic AR application running.

5.3.3. Google Forms/Sheets

Google forms is an online survey platform that can instantly receive data from unity. This data is then automatically synchronized to google sheets. Both google forms and google sheets are stored on google drive, which is an online file storage platform that is continuously synchronized. This project will utilise these platforms, as once the forms and sheets are set up correctly, no human interference will be needed, everything will synchronize automatically.

5.3.4. Flux.io

Flux.io enables a 'seamless exchange of data' (Flux.io, 2015) between multiple stakeholders by sending a 3D model's data through the web which can be stored, manipulated for understanding and sent to synchronise the same information on another user's model. The manipulation of data can be done on Flux Flow, their online scripting platform, to extract specific values and translate them onto a data table. This project aims to incorporate their tools to enhance the synchronous exchange of data.

5.3.5. Dynamo

“Dynamo extends BIM with the data and logic environment of a graphical algorithm editor” (Dynamobim.org, 2017). It is a plug-in for the wildly popular BIM tool, Revit, and has the capability to manipulate models based on flux.io outputs. This tool will be utilised for this project as it will be able to report and highlight incorrect geometry, whilst also replacing it with the correct geometry brought in through flux.io.

6. Case Study

This research has investigated how to improve the current site verification process by using newly developed AR technologies, along with BIM and cloud computing. It is proposed that this would be achieved through establishing a new workflow. From reviewing the aforementioned programs, a process was developed.

6.1. BUILDING THE AR APPLICATION

6.1.1. Exporting Files

The BIM was originally sourced from BIM consulting, as their ceiling had exposed services and the project was able to be safely tested at their office location. The model firstly needed to be detached from the shared model, which was done by checking ‘Detach from Central’ when opening Revit.

Once the model had been detached, it was exported to an FBX and brought into Rhinoceros, a 3D modelling program. To prepare the model to be brought into unity, the following steps were completed:

1. Remove unnecessary geometry
2. Reduce polygon mesh, as the original BIM was too large
3. Set positioning to 0,0,0
4. Export to FBX

6.1.2. Developing the AR Application

The unity AR plug-in was used to set up the application as it had all components required to make a basic AR application. This process must be completed on an Apple product (MacBook, iMac) and the user must have an apple developer account.

This is the method used:

1. Drag the model onto the 'HitCubeParent' located in the hierarchy tab. The HitCubeParent is used to determine which surface the user has selected when using the iPad.
2. Select the model that is now underneath the HitCubeParent, and add the script 'UnityARHitTestExample' by selecting 'Add Component' in the inspector tab.
3. Drag and drop the 'HitCubeParent' located in the hierarchy, into the Hit Transform in the inspector. This script will link the geometry to the HitCubeParent and move the geometry to the selected surface in the AR application.

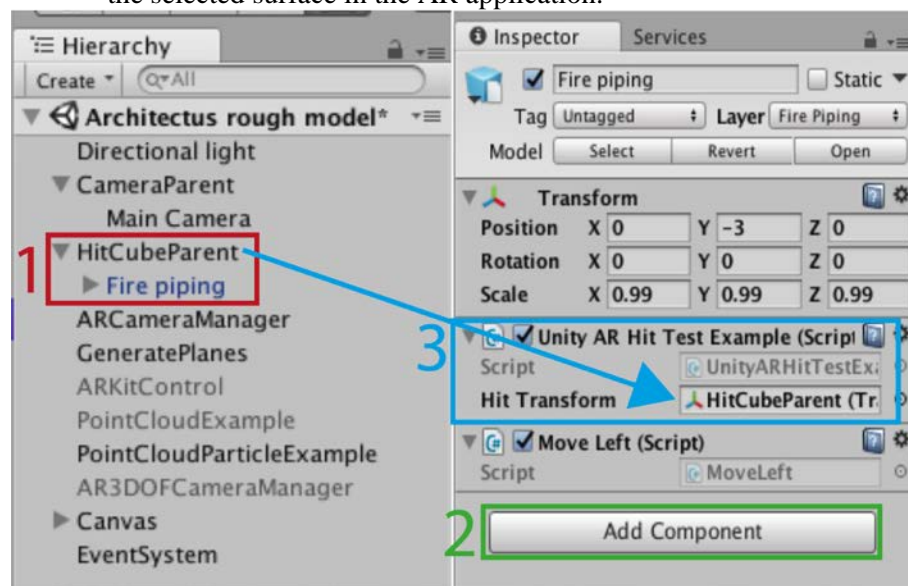


Figure 6. Steps 1-3

4. All models are loaded with a camera which needs to be turned off. To do so, drop down the geometry in the hierarchy, select the camera and untick it in the inspector. If this is not completed, the AR camera will not work, and the app will be a blue screen.

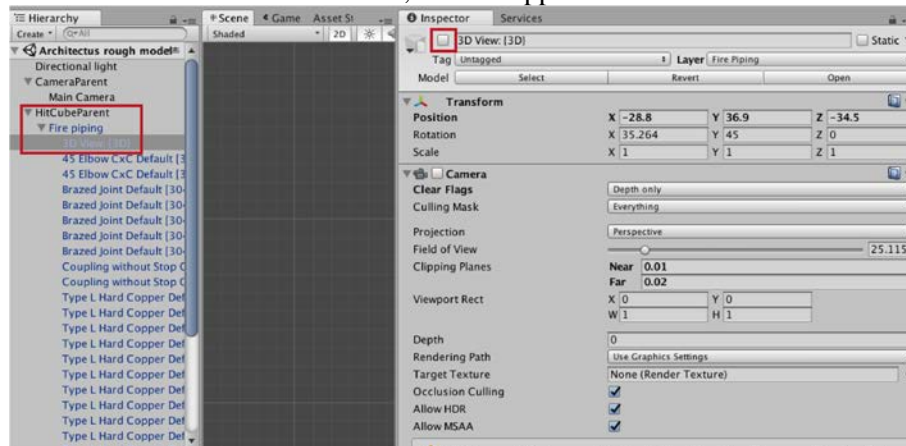


Figure 7. Step 4

5. To build the application for IOS, go to file, build settings. 'Add Open Scenes', ensuring the correct scene is selected, and the platform is set to IOS. From here select 'Build and run.'
6. XCode, the coding platform for IOS, will open after the application has be built out from unity. The user must enter a display name and bundle identifier. The user must then add their team name to sign the product.
7. Plug the device in, select the device name, and select play. The app will then load onto the device.

Test 1: Once the application was built, it was noticed that the model would not move to the selected surface and it would float in the air. Another problem established was the poor quality of the model, this was a result of the polygons being reduced.

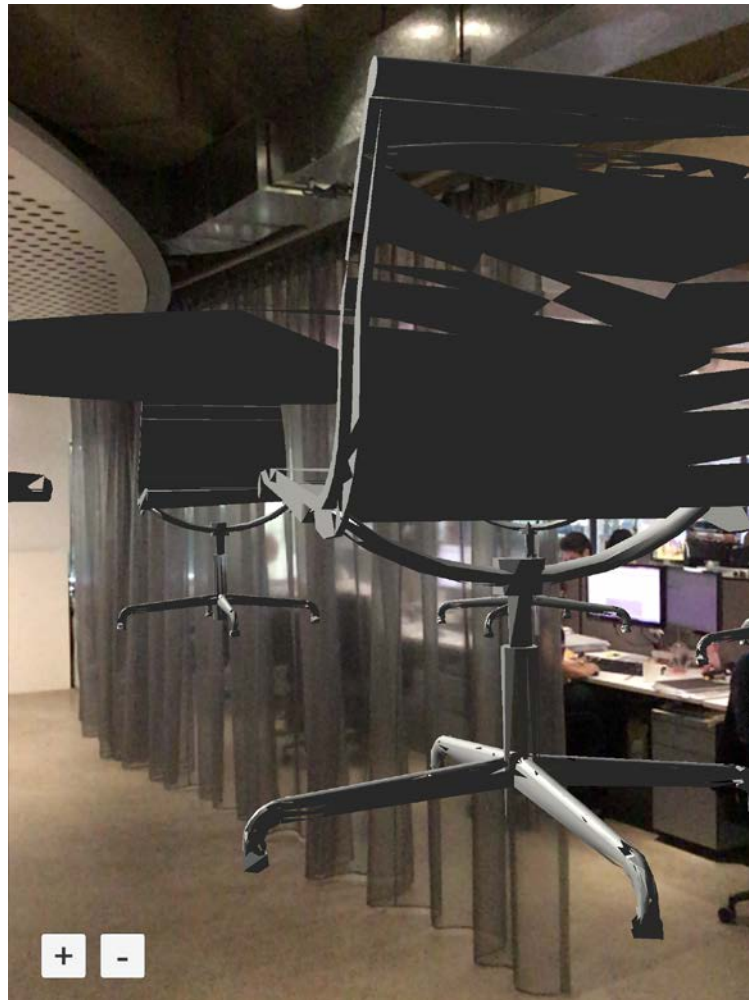


Figure 8. Test 1

To test whether it was the BIM or the method at fault, a different 3D model of a house was put into the AR application. This model was scaled at 1:1, and would move to the selected surface in the AR application.

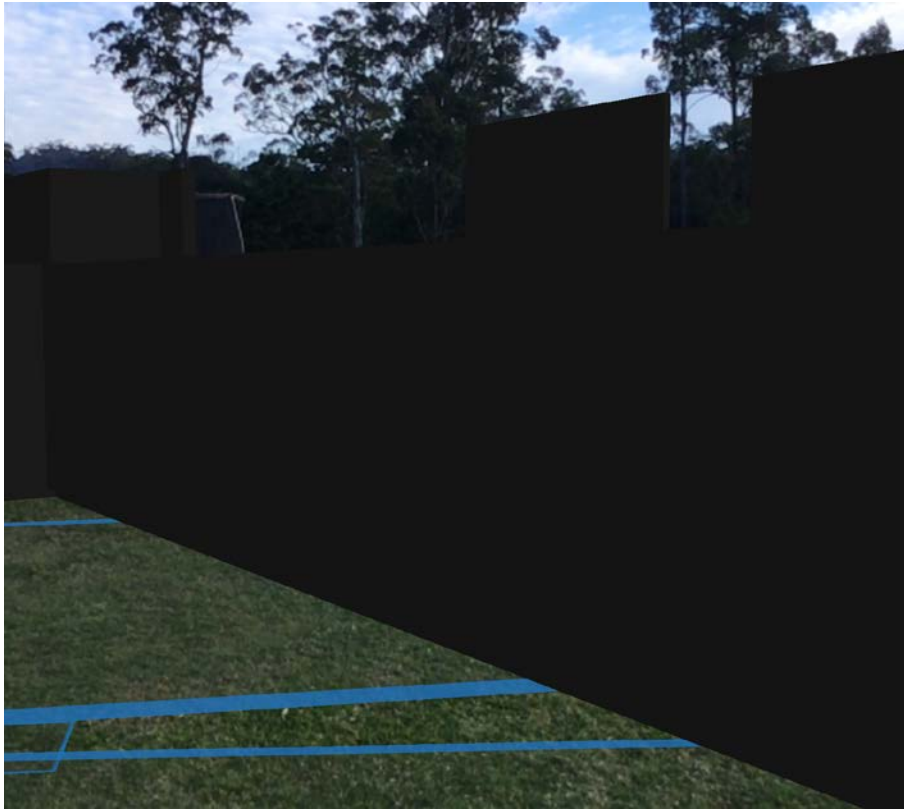


Figure 9. 3D 1:1 house model

Multiple attempts to fix the original BIM failed, and it was determined that a similar, yet simpler model would be constructed and tested.

From using the AR application at 1:1 with the 3D house model, it was identified that placing the model in a specific location may become difficult. The application originally aimed to allow the user to view the discrepancies between ‘as built’ data and ‘as designed’, meaning the AR application would be accurately placed at 1:1 scale. The house model opened at the camera's positioning determined within unity. The hit transform script allowed the model to move along the selected plane, however this was not accurate. It was discussed with BIM consulting and determined that the model would be used at 1:20 scale for testing and this problem would be investigated in the future.

Test 2: The same method was executed, however, a basic 1:20 model was used to develop the second iteration.

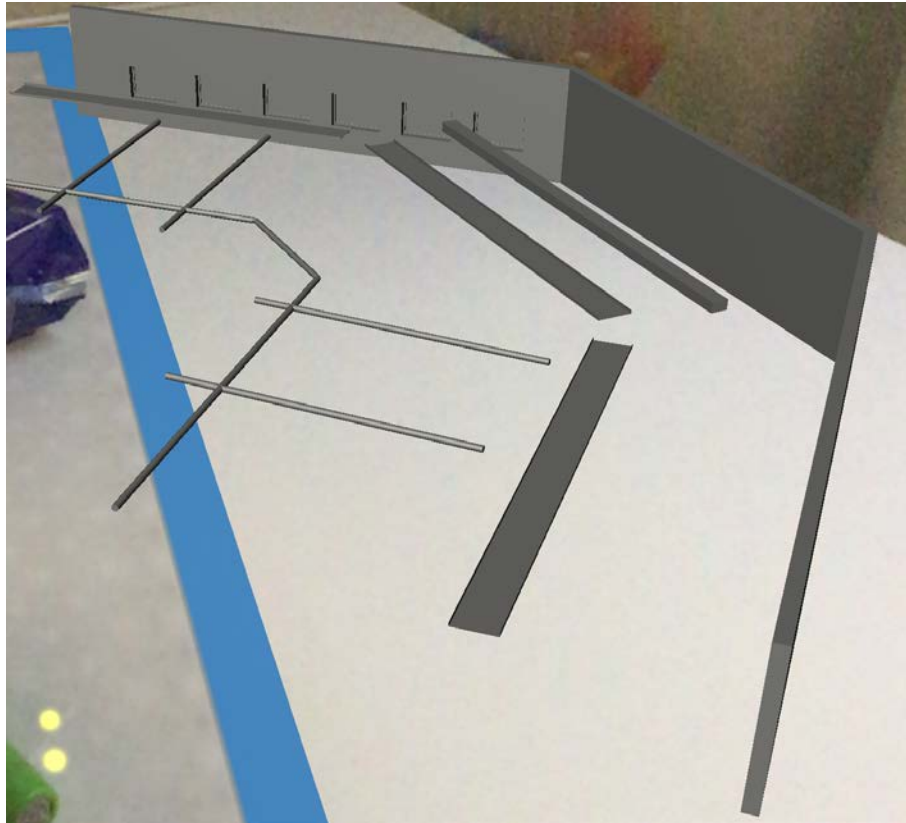


Figure 10. Test 2

Initially, the user interface was to be constructed with minimal buttons, and users would be able to drag the services into place on the selected axis. This iteration highlighted that the hit transform script moved the model once the screen was touched, which would result in the whole model moving position if the user attempted to touch and drag. After reflecting upon this approach, it was decided that controller buttons would be more practicable for the current application. For future iterations, it was requested the scaling of the model be changed to 1:2, and more detailing be added to the model.

6.1.3. Controllers

The buttons translating the services is scripted in C-Sharp and was adapted from the tutorial 'Apple AR Kit Augmented Reality App' written by Matthew Hallberg. The tutorial demonstrated how to transform the local scale, and the script was adjusted to transform the positioning on the X and Y axis.

The user interface (UI) was created using unity's UI functions, which allows developers to apply certain functions or custom coding to the buttons. To create a functioning button:

1. Right click in the hierarchy, select UI and then button.
2. Select the newly created button, go to on click in inspector.
3. Drop down menu and select the geometry translation script (MoveLeft), then select the direction (Left).
4. Drag and drop the object you wish to move into the object box.
5. Change colours and text

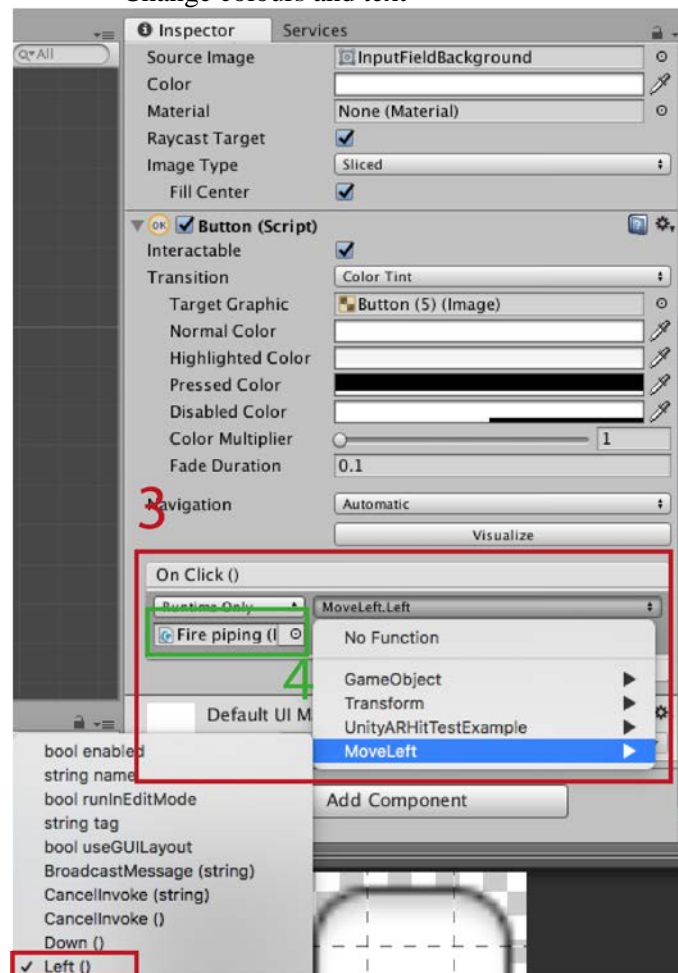


Figure 11. Steps 3 and 4

Three iterations of the interface were developed before an intuitive interface was designed.

Iteration 1: The interface had two control panels which were separately linked to the services. The button colours matched the service colours so user could determine which set of controllers to use, however, this was deemed impracticable.



Figure 12. UI Iteration 1

Iteration 2: A new drop-down menu was created, giving the user the ability to select which element they want to move. The buttons to translate geometry were moved to the top of the screen and changed from arrows to the text N, E, S, W.

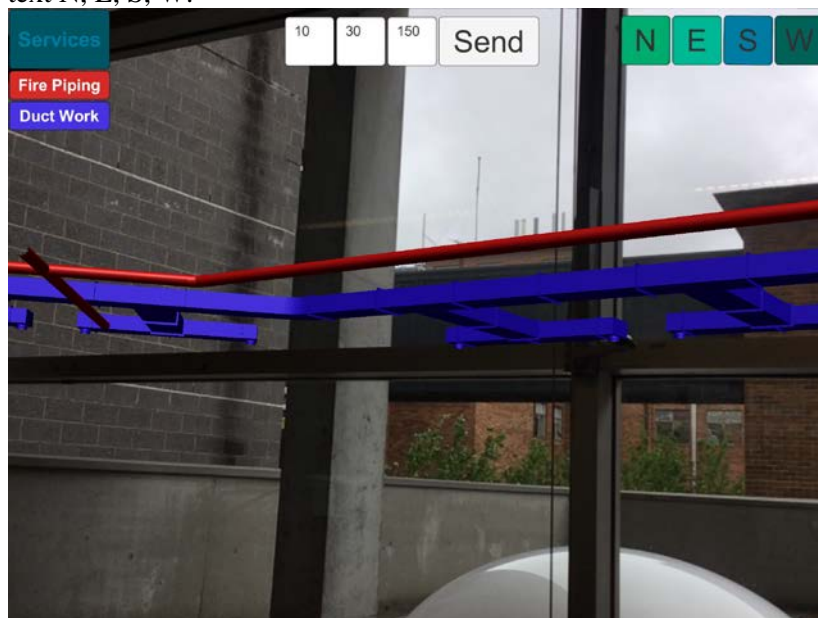


Figure 13. UI Iteration 2

Final Iteration: The colours were changed to BIM consulting branding guidelines and N, E, S, W was changed to Y, X, -Y, -X.

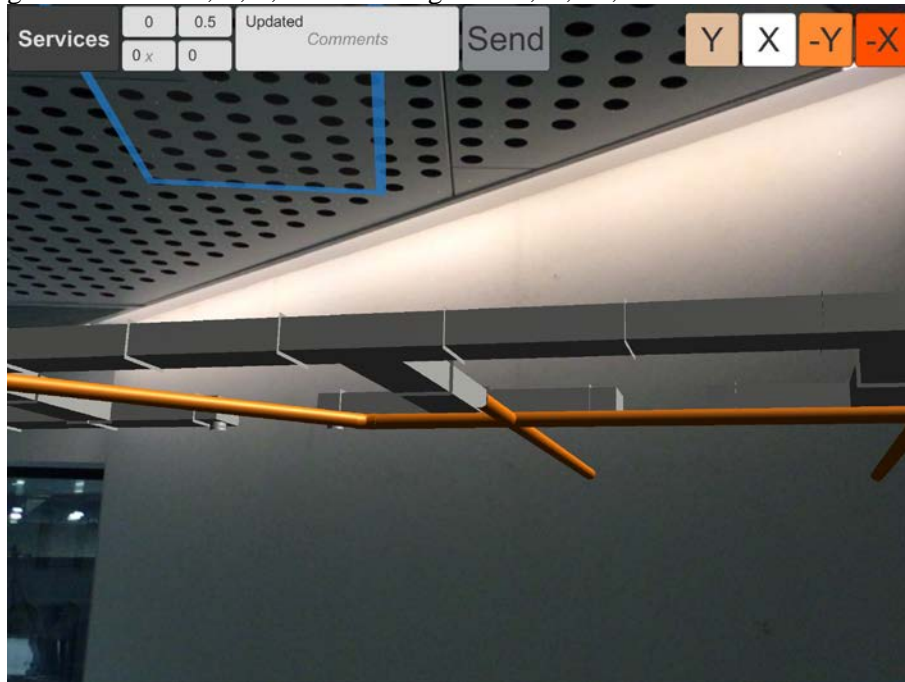


Figure 14. UI Iteration 3

A problem discovered when testing was that the UI buttons wouldn't detect the change in rotation from the user. A temporary solution was suggested which put reference points on the roof, so users knew which direction they were translating the geometry. Another canvas with the 'UnityARHitTestExample' script was created and attached to the HitCubeParent. The positioning was set to 0,0,0 and 4 buttons matching the direction of the UI controllers were added. This guided the users as to which button to press in order to move it in their desired direction.

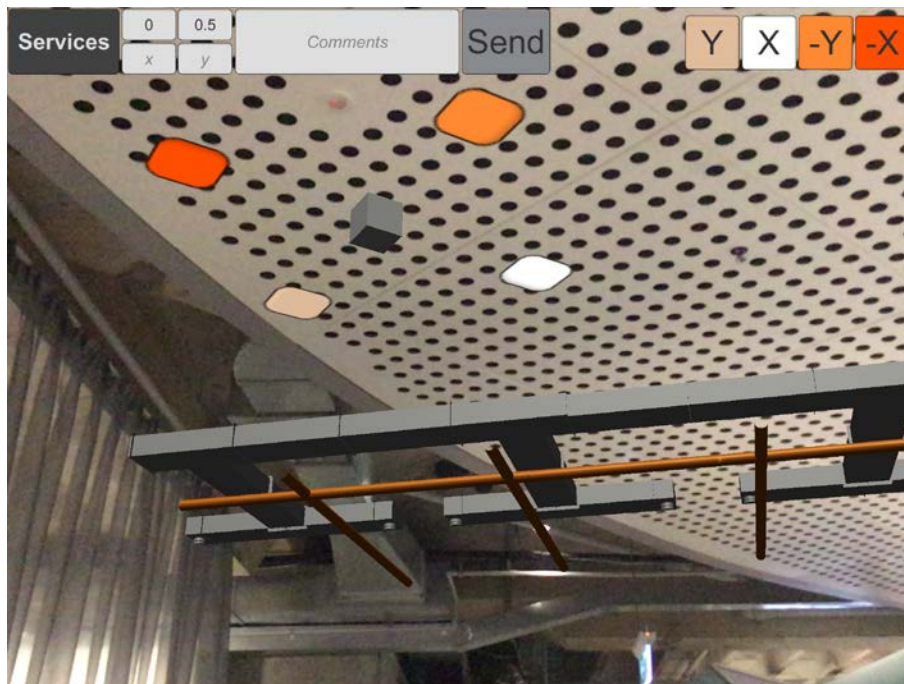


Figure 15. Reference Points

6.1.4. Sending Data

The AR application needed to be able to communicate to an online server or database instantly for the proposed workflow to be successful. Luzan Baral's tutorial of sending data between unity and google sheets (Baral, 2017) was implemented as it demonstrated how to provide convenient data transfer. This was done with the use of google forms, as unity was able to send data to the specific text fields repeatedly. This data could then be sent to google sheets in real time.

The script built in the tutorial (send to google) required three inputs which would gather the data to send to google forms. To do this:

1. Add three UI input fields (x, y, comments) to the canvas.
2. Add the send to google script to the canvas
3. Drag and drop each input field into the corresponding game object box

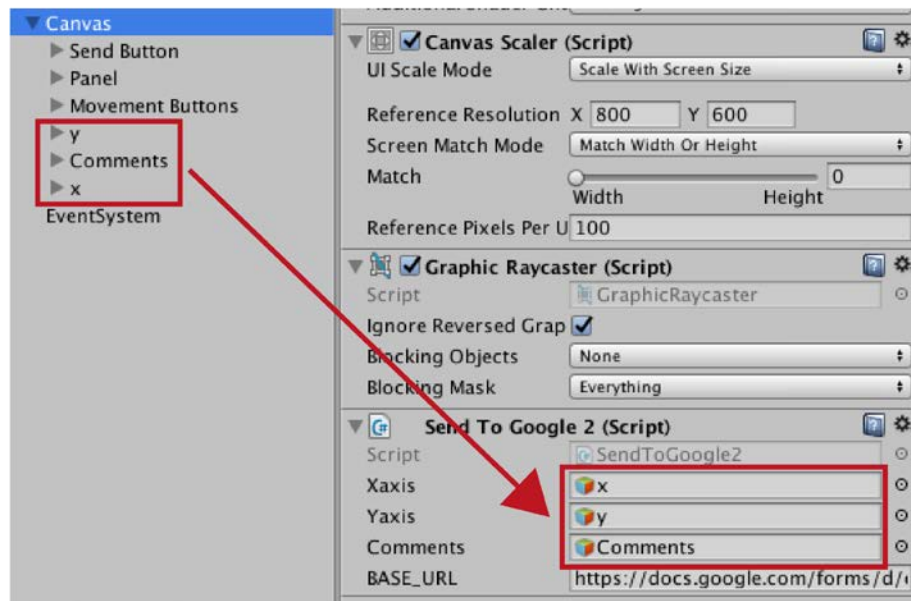


Figure 16. Step 3

4. Add new button in the canvas
5. Select the button and in inspector drop down the 'On Click' menu and select 'send to google' and then 'send'.
6. Drag and drop the canvas into the game object box

This aspect of sending the data was successful, however, the user would have to estimate how far the model had been moved. From following unity forums posts (Unity Community, 2015), a script was developed that enabled the distance to be calculated between objects on both the X and Y axis. A block was generated and put into the HitCubeParent. The script firstly finds the base object (the block) and continuously measures the distance between that and the moving geometry (services), the distance is then displayed in the application. To do this:

1. Add the distance script to the cube inside the HitCubeParent
2. Drag and drop the service to the player box
3. Create a new input field in the canvas
4. Drag the text input into the label box

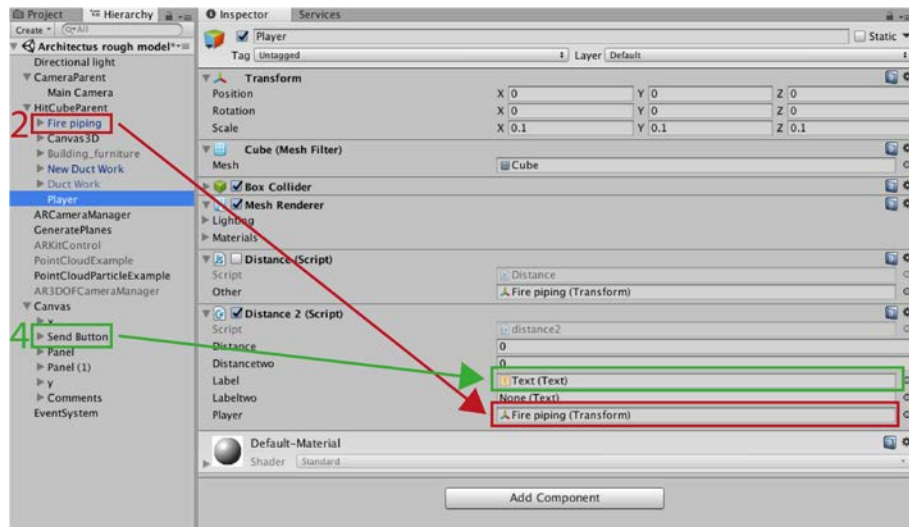


Figure 17. Steps 2 and 4

The user can then input the distance calculated into the text field and send it to google sheets.

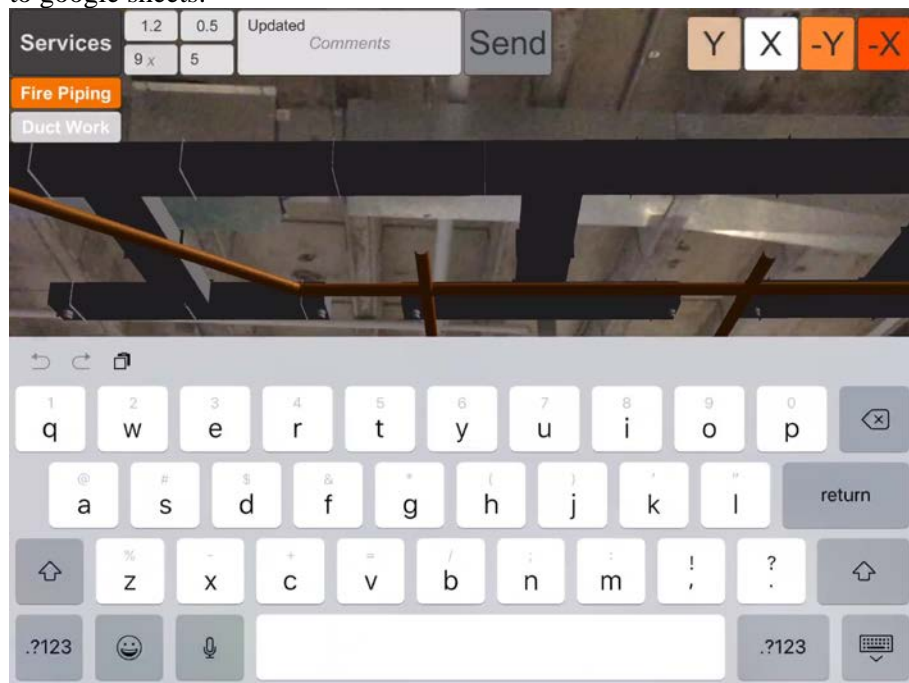


Figure 18. Measuring distance and sending to google sheets

6.2. FLUX.IO TO DYNAMO

6.2.1 Receiving the original data from Revit

In order for flux.io to update the incorrect geometry, the BIM needed to be brought into flux.io. This was done using Dynamo and the flux.io plugin.

1. 'Select Model Elements' node in dynamo allows the user to select multiple elements and bring the geometry into Dynamo.
2. Using the flux.io nodes, the user can then select which project and key to send this geometry too.

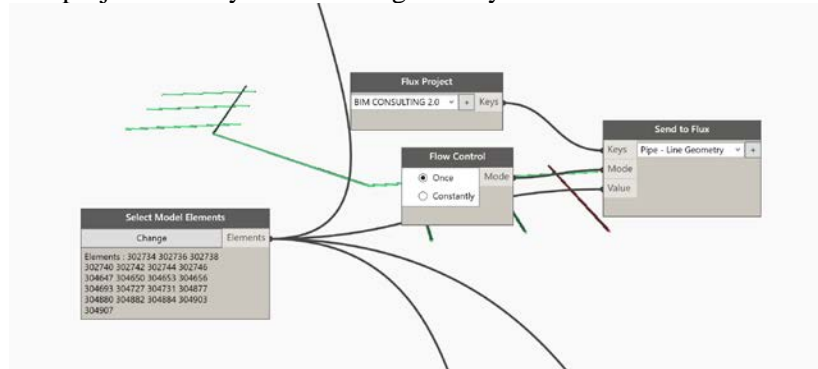


Figure 19. Sending Revit data to flux.io

3. The geometry will then show on the flux.io 'projects' platform and can now be manipulated.

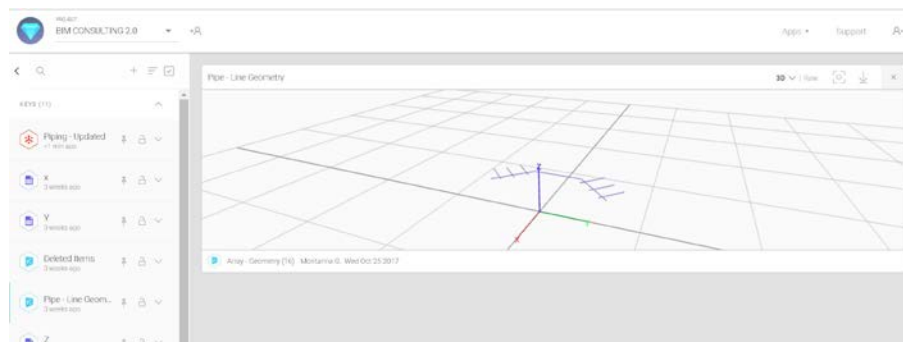


Figure 20. Geometry in flux.io

6.2.2. Receiving the data from google sheets

The data from the application is sent to google sheets through google forms. Flux.io has a beta plugin that allows cell data to be attached to keys. In preliminary experimentations, only one key was assigned to a cell, however, once the connection between unity and google sheets was established, it became apparent that google forms doesn't replace previous entered data, meaning the cell assigned to the key would need to be updated each time a number was added. This was deemed as impractical, and a full column was attached to the flux keys.

Initial testing was undertaken in excel spreadsheets which allowed for constant data transfer. The transition from excel to Revit took place in under 10 seconds, meaning this aspect of the project was instantaneous without the need for human interaction.

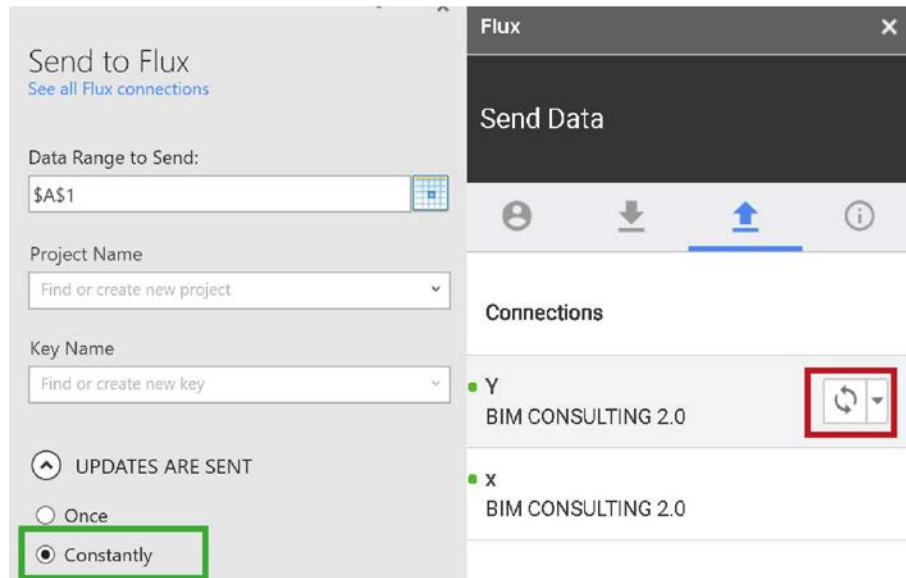


Figure 21. Comparison of flux.io in excel and google sheets

The image to the left demonstrate the flux.io interface on excel, and the right shows it on google sheets. As shown, there is an option for the data to be constantly streamed in excel (green), but not google sheets. The communication between unity and google sheets was achieved with the use of google forms, meaning that the application data would be sent to google sheets. As a result, the data in google sheets needs to be manually synchronized (red) and the application is no longer automatic.

6.2.3. Flux flow

Originally, the flux.io flow script was designed to translate the geometry brought in from dynamo, using single cells. The individual cells were inputted into a translate node, which would move the geometry each time the cells were updated. This script was successful in translating the geometry and sending it back to flux using single cells, however, as discussed earlier, flux.io needed to be able to read multiple cells in case the user updated the positioning of the geometry multiple times.

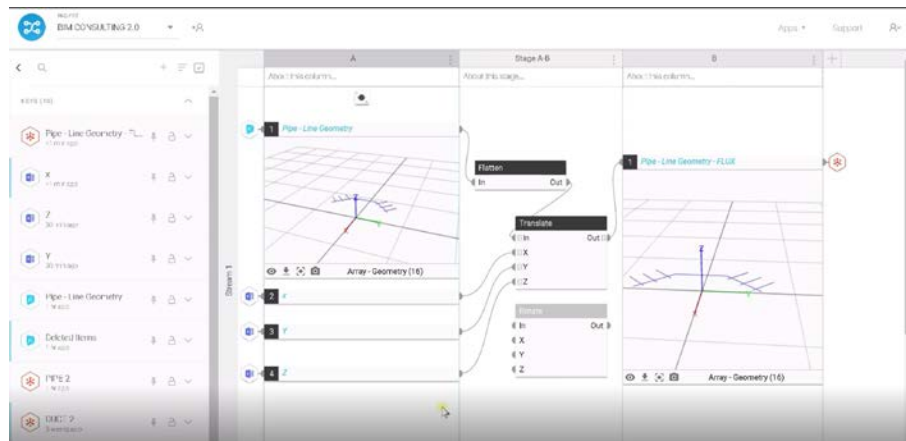


Figure 22. Iteration 1 of Flux flow

Figure 23, 24 and 25 demonstrate the updated script. Using a data node, null is inputted into the equal2 node, along with the flattened google sheet data. This is used to find the cells with a nothing inside. The 'not' node is used to extract all the null cells, and the filter removes them from the spreadsheet. The 'Last' node then finds the last number in the table.

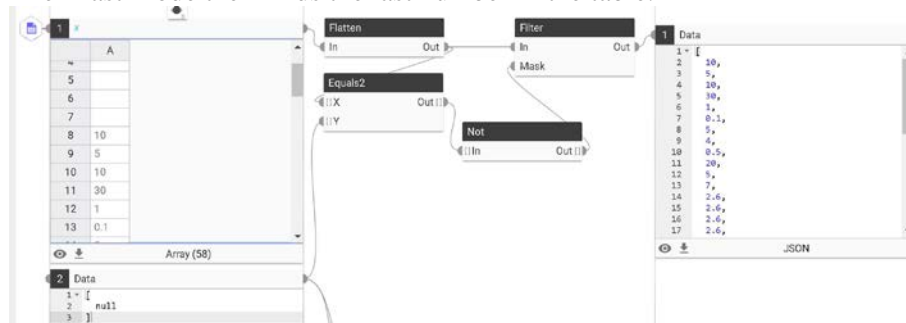


Figure 23. Iteration 2 flux flow.1

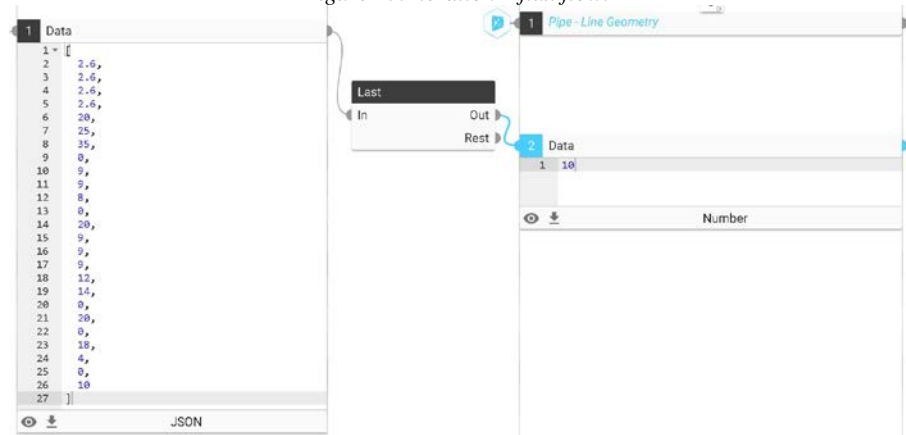


Figure 24. Iteration 2 flux flow.2

Similar to the original script, the last number is then inputted into the translate node, and moves the geometry.

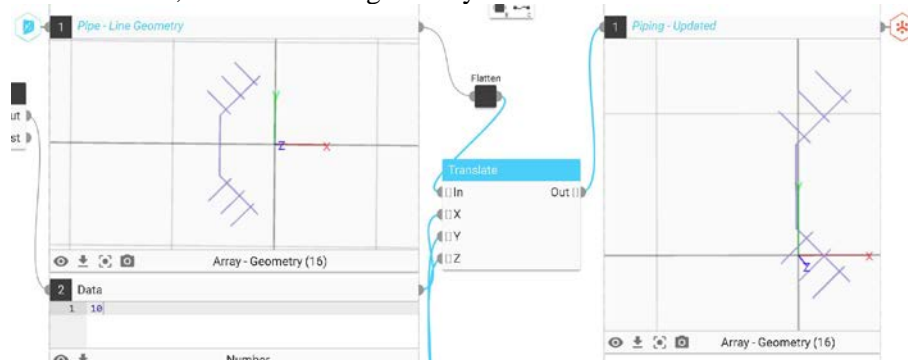


Figure 25. Iteration 2 flux flow.3

6.2.4. Bringing data into Dyanmo

The translated geometry was now a new key in flux. Similar to sending the data to flux, Dynamo has nodes that enables the geometry to be brought back in. Using the 'receive from flux' node, the updated geometry is pulled into Dynamo.

6.3. DYNAMO

6.3.1. Displaying Incorrect Data

For visualisation purposes, the dynamo script shows the incorrect geometry in red, and correct in green. This is achieved through the node 'Display.ByGeometryColor', which needs a colour input to work. In doing this, the user can easily visualise the incorrect geometry in the BIM.

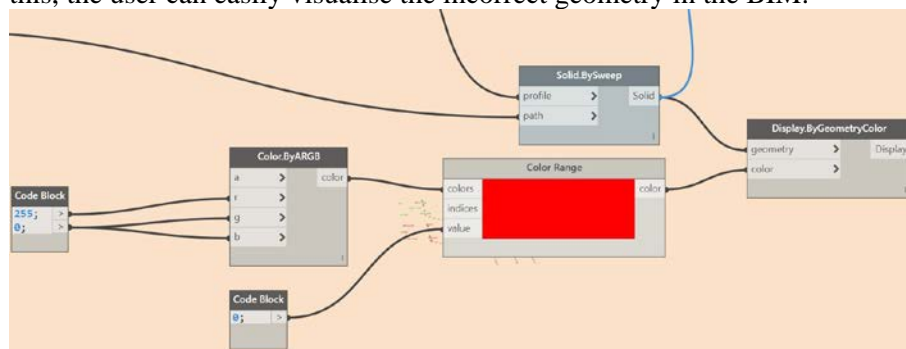


Figure 26. Script for displaying incorrect geometry

6.3.2. Removing the incorrect geometry

Once the incorrect data has been established and confirmed, the user can then report and delete this geometry using a true/false Boolean.

Firstly, the script says that if the Boolean is set to true, then:

- Get the element ID's and create a list
- Write 'deleted' in another list for each element
- Merge these lists
- Put this into a table format
- Send this table to flux.io for reporting

If the Boolean is set to false, then this script will do nothing. In flux.io, the element ID and what has happened (deleted) is stored in a table. This is timestamped with the user's name for reporting purposes.

Deleted Items

Deleted Items

1

302734

Deleted

2

302736

Deleted

3

302738

Deleted

4

302740

Deleted

5

302742

Deleted

6

302744

Deleted

7

302746

Deleted

8

304647

Deleted

9

304650

Deleted

10

304653

Deleted

Showing last 12 writes (of 38 total) spanning the last 20 days, and read activity for each write.

During this time, Montana G. has written to this key.

WRITE AUTHOR	DATE & TIME	SIZE	TOTAL READS & READERS
M Montana G. (Escribto, Dynamo.d	193022	4000	2 M
	192935	110	1 M
	192951	110	1 M
	190027	110	1 M
	171024	110	1 M
	Oct 25, 2017 16:44:31	110	1 M
	Oct 25, 2017 11:02:07	110	1 M

Figure 27. Time stamp and Element ID in flux.io

From here, the Dynamo script allows the user to delete the incorrect elements. Similar to the previous script, it reads:

If the Boolean is set to true, then:

- Delete elements

If the Boolean is set to false, nothing will happen. This completes the workflow from the AR application to the BIM.

6.4. WHERE IT FITS INTO THE BIM CYCLE?

In the near future, it is likely that BIM will be an integral aspect of project design, delivery and operation of building assets. It will never be a linear process, as it is an 'ever moving target' with multiple stakeholders (Holzer, 2016). The workflow generated from this research project has been designed to be useful throughout the perpetual BIM process. Although it would be of most use during the 'build' process (see figure 28), the use of AR technologies allows it to be functional throughout the 'operate' process, as facilities managers (FM) are able to find services for maintenance/renovations efficiently.



Figure 28. BIM Cycle (Advanced Solutions, 2016)

7. Significance of Research

This research paper argues that it is possible for a BIM to accurately match on-site conditions through the implementation of a synchronous workflow that integrates AR, BIM and cloud computing. Providing an as-built BIM to external stakeholders is one of the most important aspects in the BIM process, and the current method for site verification is a manual, inaccurate and time-consuming task. The workflow and application developed throughout this research project has shown potential for efficiently delivering accurate BIM, which removes the previously manual process for communicating discrepancies between as-built and as-designed. With future development, the implementation of the workflow could allow for efficient and accurate site verification, saving time and cost. Additionally, the use of AR technologies has allowed for complex data to be displayed in a real-life environment, giving all project stakeholders the opportunity to view and

manipulate the data. This may result in the removal of misinterpretations among stakeholders, and improved collaboration and communication in the AEC industry.

8. Evaluation of research project

By adopting an action based research method, this project has been able to continuously improve throughout experimentations and as a result, it has successfully integrated AR, BIM and cloud computing into a synchronous workflow. The research has established a solution for the disconnect between real-life and BIM, however, further research is required if it is to be used in a consumer context.

The research project has successfully explored how as-designed data can be communicated effectively in a multi-disciplinary project context though implementing AR technologies for visualization. By providing an intuitive user interface on a consumer-based technology, most project stakeholders will be able to view and share this data, which could potentially result in enhanced communication and collaboration between disciplines. Further, the research project has established a workflow that highlights how synchronous communication of data between the as-built and as-design BIM can be achieved. From experimentations with platforms, it has been determined that the translation of data can be achieved with Cloud Computing and AR technologies. Though this workflow has proven to be successful, there were limitations with the research project.

A prominent objective communicated throughout this paper was to create a synchronous workflow that required a minimal amount of human interaction, however, there is a disconnect in the workflow between google sheets and flux.io. The user must manually synchronize the data received from the AR application to flux.io. This was an unanticipated limitation which would require further development into the flux.io plug-in to be resolved. A more critical issue presented earlier in the research was concerned with tracking in real-time and accurately placing the BIM in the real-world, which is an essential aspect to the workflow. This topic is extremely complex and requires in-depth research and on-site testing, therefore it was not addressed in this research project. Though these constraints existed in this project, the knowledge gained will benefit the AEC industry as it provides a beginning platform for a new method of communication between disciplines.

9. Conclusion

Initial investigations into prominent issues within the AEC industry found a lack of communication between physical buildings compared to its BIM.

Therefore, this research explored and established a possible solution to remove this disconnect by integrating AR technologies, Cloud Computing, and BIM into one synchronous workflow. Though this workflow still requires manual human interaction due to software limitations and is unable to be scaled accurately on-site, it has provided a basic method for developing a successful solution in comparison to current site verification methods. With further development, this research project has the potential to be used in a consumer context for on-site verification and further, aid in effectively managing a building's lifecycle. Additionally, extra development on the interface for the AR application has the potential to allow all stakeholders to have access to the information as well as understanding the critical data. The successful workflow derived from this project provides a step closer towards research into 1:1 scale, real-time communication between as-built data to the BIM.

Acknowledgements

This research project was completed in partnership with BIM Consulting and the University of New South Wales.

References

- Advanced Solutions.: 2016. *BIM Yields Significant Benefits*. [image] Available at: <http://www.advancedsolutions.com/design/services/lifecycle-bim.html> [Accessed 27 Oct. 2017].
- Afsari, K., Eastman, C. and Shelden, D.: 2016. *Data Transmission Opportunities for Collaborative Cloud-Based Building Information Modelling*. In: SIGraDi. [online] SIGraDi, pp.907-913. Available at: http://papers.cumincad.org/cgi-bin/works/Show?_id=sigradi2016_448&sort=DEFAULT&search=Kereshmeh%20Afsari&hits=3 [Accessed 3 Aug. 2017].
- Baral, L.: 2017. *How to save data to Google Spreadsheet from Unity 3D (No SDK - Plugins)*. [video] Available at: <https://www.youtube.com/watch?v=z9b5aRfrz7M> [Accessed 4 Oct. 2017].
- Danker, F. and Jones, O.: 2014. *Combining Augmented Reality and Building Information Modelling - An industry perspective on applications and future directions*. In: eCAADe. [online] England: eCAADe, pp.525 - 536. Available at: http://papers.cumincad.org/cgi-bin/works/Show?_id=ecaade2014_111&sort=DEFAULT&search=Fabian%20Danker&hits=9 [Accessed 1 Sep. 2017].
- Dunston, P. and Wang, X.: 2011. *A hierarchical taxonomy of AEC operations for mixed reality applications*. Information Technology in Construction, [online] 16, pp.433-444. Available at: <http://www.itcon.org/paper/2011/25> [Accessed 3 Sep. 2017].
- Dynamobim.org.: 2017. *Dynamo BIM*. [online] Available at: <http://dynamobim.org/> [Accessed 26 Oct. 2017].
- Flux.io.: 2015. *What is Flux?*. [video] Available at: https://www.youtube.com/watch?time_continue=45&v=P6B5H1zUWW4 [Accessed 27 Oct. 2017].
- GAMMA.: 2017. *Augmented Reality for Construction Sites and Facility Management*. [online] Available at: <http://gamma-app.de/?lang=en> [Accessed 29 Oct. 2017].

- GU, N., Singh, V. and Wang, X.: 2010. *Applying augmented reality for data interaction and collaboration in BIM*. In: CAADRIA. [online] CAADRIA, pp.511-520. Available at: https://cumincad.architexturez.net/system/files/pdf/caadria2010_048.content.pdf [Accessed 26 Aug. 2017].
- Hallberg, M.: 2017. *Apple ARKit Augmented Reality App*. [online] Instructables.com. Available at: <http://www.instructables.com/id/Apple-ArKit-Augmented-Reality-App/> [Accessed 6 Aug. 2017].
- Hearn, G. and Foth, M.: 2005. *Action Research in the Design of New Media and ICT Systems*. [ebook] Nova Science. Available at: <https://eprints.qut.edu.au/1910/1/1910a.pdf> [Accessed 21 Oct. 2017].
- Holzer, D.: 2016. *The BIM manager's handbook*. United Kingdom: Wiley.
- Jadeja, Y. and Modi, K.: 2012. *Cloud Computing - Concepts, Architecture and Challenges*. In: ICCEET. [online] ICCEET, pp.877 -880. Available at: https://www.researchgate.net/publication/254035330_Cloud_computing_-_concepts_architecture_and_challenges [Accessed 2 Sep. 2017].
- Shapetrace.: 2017. *Prevent construction errors*. [online] Available at: <https://www.shapetrace.co/> [Accessed 28 Oct. 2017].
- Unity Community.: 2015. *Distance based score system*. [online] Available at: <https://answers.unity.com/questions/923146/distance-based-score-system.html> [Accessed 10 Oct. 2017].
- Wainwright, O.: 2015. *Is Frank Gehry really the right person to revitalise the Los Angeles river?*. [online] the Guardian. Available at: <https://www.theguardian.com/cities/2015/oct/23/frank-gehry-revitalise-los-angeles-la-river> [Accessed 6 Oct. 2017].
- Wang, X. and Chen, R.: 2009. *An experimental study on collaborative effectiveness of augmented reality potentials in urban design*. CoDesign, 5(4), pp.229-244.
- Wang, X., Love, P., Kim, M., Park, C., Sing, C. and Hou, L.: 2013. *A conceptual framework for integrating building information modeling with augmented reality*. Automation in Construction, [online] 34, pp.37-44. Available at: <http://www.sciencedirect.com/science/article/pii/S0926580512001793> [Accessed 3 Sep. 2017].
- Wang, X., Truijens, M., Hou, L., Wang, Y. and Zhou, Y.: 2014. *Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry*. Automation in Construction, 40, pp.96-105.